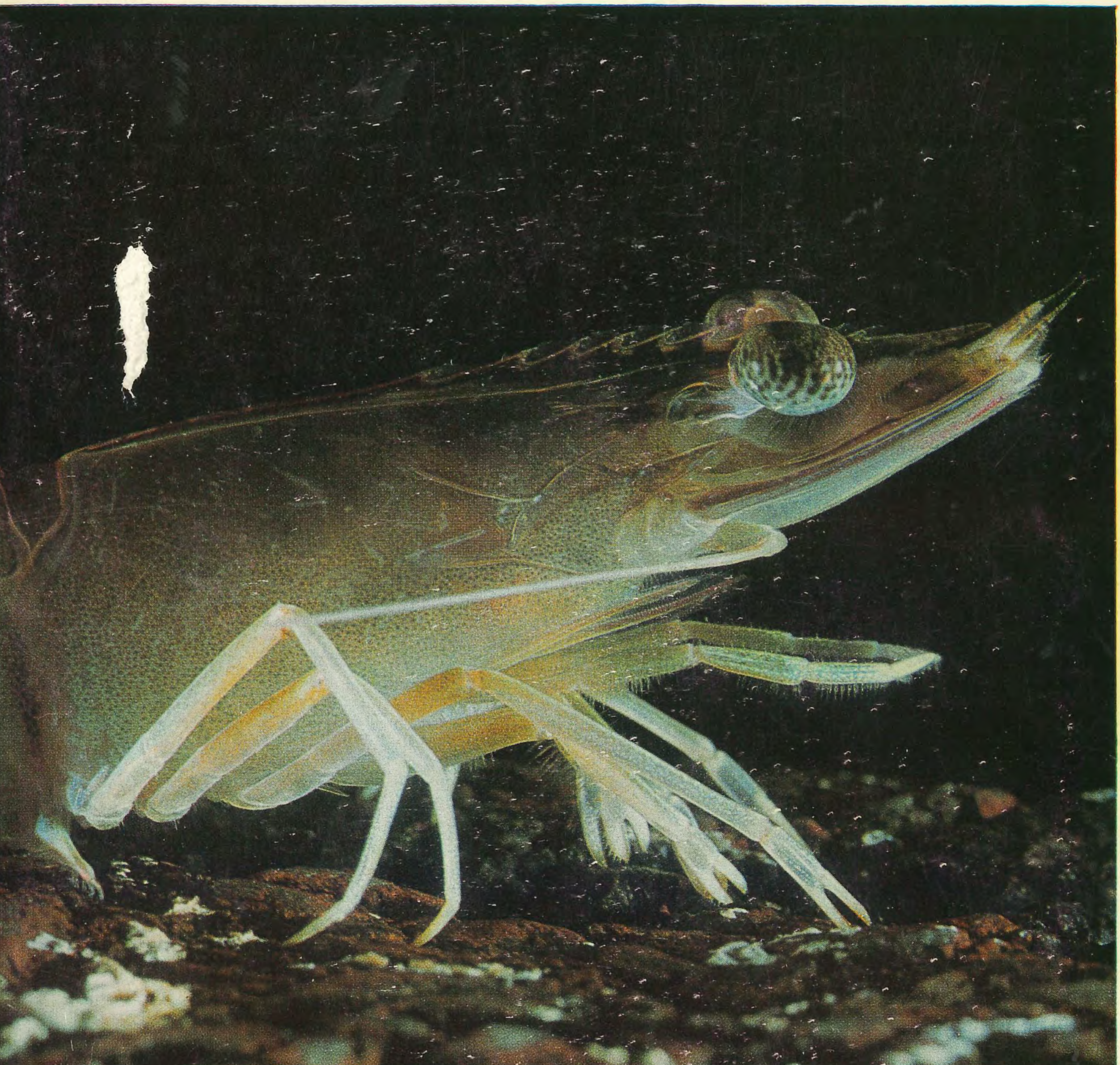
73113

National prawn seminar

Maroochydore, Queensland 1973



Australian Fisheries Council

73/13

AUSTRALIAN FISHERIES COUNCIL
NORTHERN FISHERIES RESEARCH COMMITTEE

First Australian
National Prawn Seminar

Maroochydore, Queensland, 22-27 November, 1973

Edited by P. C. Young

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE, CANBERRA, 1975

ISBN 0 642 00755 1

Printed in Australia by G. W. Green, Printers—Melbourne

FOREWORD

Considerable publicity has been given to the Australian prawn fishing industry of recent years as the annual production figures continue to grow. Most of the increases were from the exploitation of new grounds and the development of better boats and fishing gear.

At present the prawn resources of Australia are utilised in the north from Exmouth Gulf in Western Australia to Botany Bay in New South Wales and in the south a prawn fishery has commenced in St Vincent's Gulf in South Australia.

Recognising the enormous interest in prawns in Australia, the Northern Fisheries Committee of the Australian Fisheries Council proposed that a National Seminar on prawns be held. The Standing Committee on Fisheries (Australian Fisheries Council) gave its approval and funds were granted from the Fishing Industry Research Trust Account, the meeting to be held in November 1973.

A steering committee was appointed with representatives from CSIRO, the Queensland Department of Primary Industries, and the Australian Department of Primary Industry, and the technical convener was chosen from this committee to organise the scientific aspects of the meeting.

It was decided to hold the Seminar at Maroochydore, Queensland over four working days and contributions were solicited from workers in each of the five major fields of prawn research in Australia: Descriptive Biology, Population Dynamics, Culture, the Commercial Fishery, and Management. A chairman was appointed to each of these fields and a session was devoted to each.

To broaden the scope of the Seminar and to put the Australian research in perspective with that overseas, a guest speaker from the U.S.A., Dr R. A. Neal, was invited to address the Seminar and to describe the current advances in the Gulf of Mexico prawn fishery in each of the above five major fields of endeavour.

Two background papers were prepared and circulated to participants, together with advance copies of the papers presented by participants.

These proceedings are a presentation of the papers submitted to the seminar and the discussions that ensued.

P. C. YOUNG

NOTE

Imperial units used in the original text of these papers have, as far as possible, been converted to their metric equivalent.

Where conversion to metric units would involve extensive alterations to text matter or to tables and figures, the original imperial units have been retained.

Since the seminar was held there have been changes in titles of some State fisheries organisations. Fisheries Branch of the Queensland Department of Primary Industries has become Queensland Fisheries Service, Department for Aboriginal and Islanders' Advancement and Fisheries; Fisheries Branch, NSW Chief Secretary's Department has become NSW State Fisheries, Department of Lands and Forests; Victorian Fisheries and Wildlife has become Ministry for Conservation; and the Western Australian Department of Fisheries and Fauna has become the Western Australian Department of Fisheries and Wildlife. The Fisheries Division, Department of Northern Territory is now Fisheries Division, Department of Northern Australia.

Some of the participants have also taken new positions or have been given new titles since the seminar.

Where possible these changes have been incorporated in the report.

CONTENTS

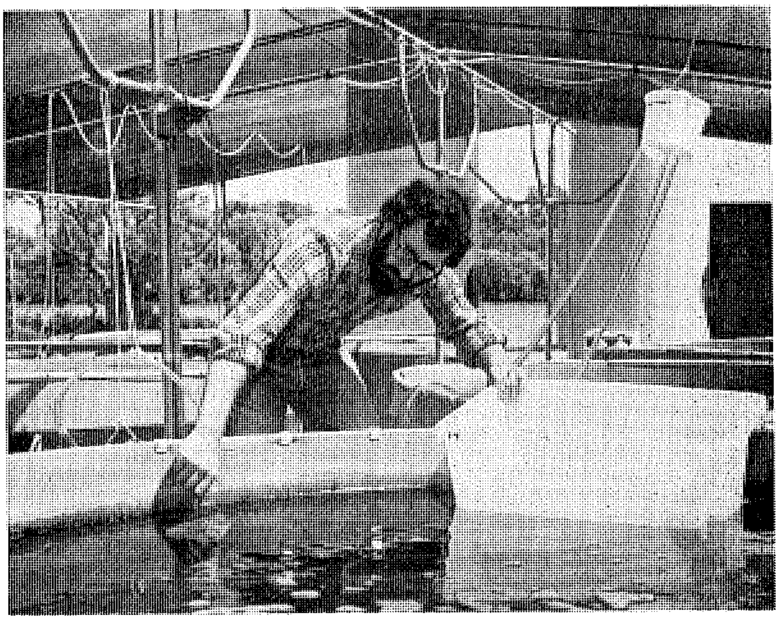
Session 1. DESCRIPTIVE BIOLOGY

Session 2. POPULATION DYNAMICS

Session 3. THE CULTURE OF PENAEID PRAWNS

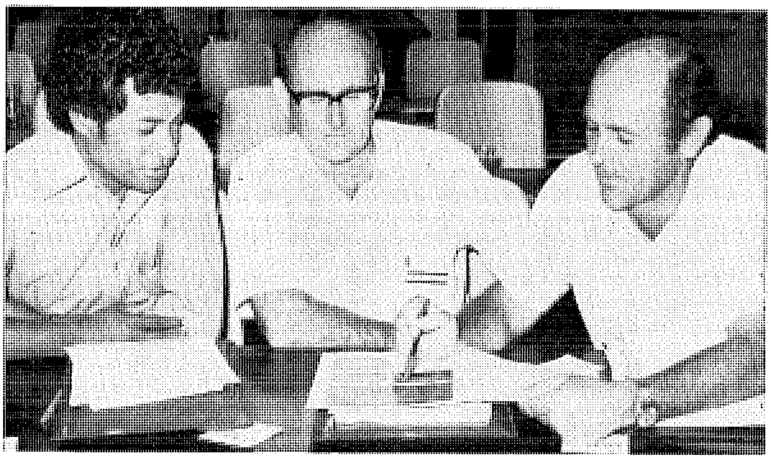
Session 4. THE COMMERCIAL FISHERY

Session 5. MANAGEMENT



Prawn biologist Ian Smith gathering prawn samples in a plastic tank at the N.S.W. Fisheries Fish Culture Research Station at Port Stephens. (Photo by J. Fitzpatrick, Australian Information Service, Sydney.)

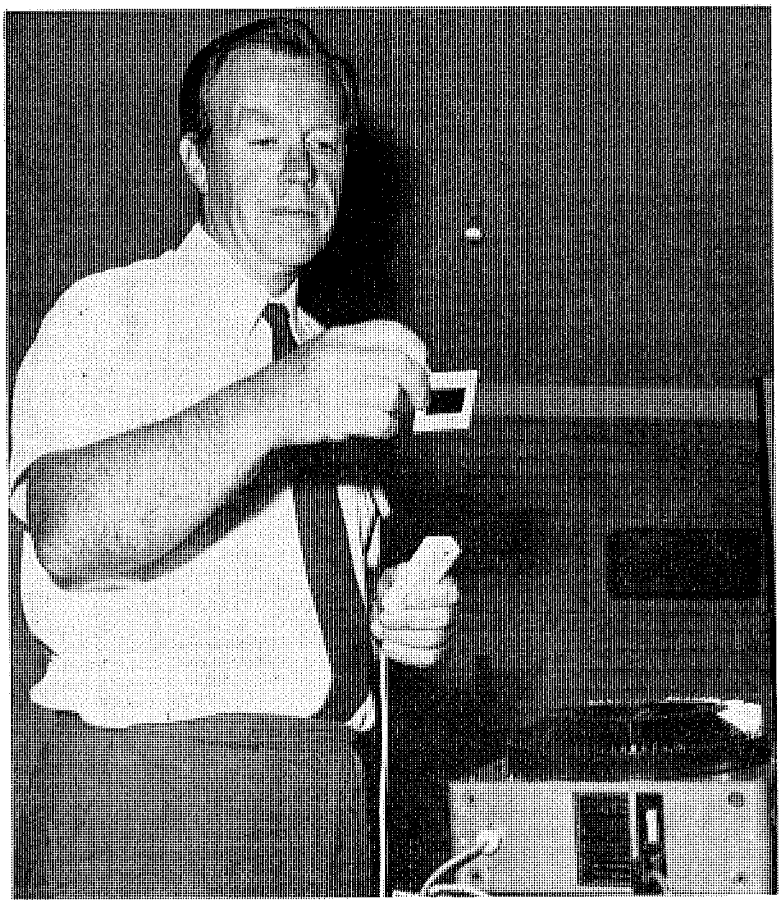
Husband and wife team Nick and Judy Ruello admire a large model of a prawn made from fibreglass by the Fisheries Branch of the Queensland Department of Primary Industries, displayed in the seminar meeting room at Maroochydore. Mr Ruello is a biologist with the N.S.W. State Fisheries and his wife is an experimental officer with CSIRO Division of Food Research in Sydney. Both delivered papers at the Seminar.



Mr T. B. Gorman (right), N.S.W. State Fisheries, describes some of the prawns caught during deep water trawling cruises by the research vessel *Kapala* to Messrs A. Vala (left) and C. McIntosh, Papua New Guinea Department of Agriculture, Stock & Fisheries.

Mr J. W. Penn (left), Western Australian Department of Fisheries and Fauna, discusses a point or two with Dr C. Lucas, CSIRO Division of Fisheries and Oceanography.

On the beach of Maroochydore, Queensland, Dr P. C. Young (left) of CSIRO Division of Fisheries and Oceanography, convener of the National Prawn Seminar, and Dr R. A. Neal, of Galveston, U.S.A., guest speaker at the seminar. (Photo by R. Nicol, Australian Information Service, Brisbane.)



Dr D. A. Hancock, Western Australian Department of Fisheries and Wildlife, checks colour slides before a session at the National Prawn Seminar.

Mr I. Smith (left), N.S.W. State Fisheries, exchanges notes with Mr A. G. Shanahan of Aqua Farms, Southport, Queensland (centre) and Mr M. Harris of Amatil, Queensland. They are all closely associated with the farming of prawns. (Seminar photographs by R. Nicol, Australian Information Service, Brisbane.)

INTRODUCTORY PAPER

THE GULF OF MEXICO RESEARCH AND FISHERY ON PENAEID PRAWNS

BY R. A. NEAL

Investigation Chief,
Aquaculture Research and Technology,
Gulf Coastal Fisheries Center,
National Marine Fisheries Service,
Galveston, Texas

THE GULF OF MEXICO RESEARCH AND FISHERY ON PENAEID PRAWNS[1]

BY RICHARD A. NEAL[2]

ABSTRACT

A review of recent biological research on the Gulf of Mexico penaeid prawn stocks is presented. The status of population dynamics research on these stocks is discussed as well as management procedures being used by various States in the United States.

The general history of this fishery is reviewed with emphasis on recent trends, changes in fishing methods and regulations, and the biological and economic consequences.

INTRODUCTION

Since the topic of this talk is very broad, I am not going to discuss all aspects of the fishery. Instead I will emphasise recent research developments in relation to the major subject areas of this Seminar: Descriptive Biology, Population Dynamics, Commercial Fishery and Management.

DESCRIPTIVE BIOLOGY

During the last 20 years annual shrimp landings from the United States fishery in the Gulf of Mexico have ranged from 60 million kg to 108 million kg heads-on. About 98% of the catch consists of the brown shrimp, *Penaeus aztecus*, the white shrimp, *Penaeus setiferus*, and the pink shrimp, *Penaeus duorarum*. The remaining 2% of the landings are seabob shrimp, *Xiphopenaeus kroyeri*, royal red shrimp *Hymenopenaeus robustus*, Brasilian shrimp, *Penaeus brasiliensis*, and rock shrimp, *Sicyonia brevirostris*. Descriptive information on the fishery, the distribution of catches and the seasonal changes in landings is presented by Osborn, Maghan and Drummond (1969).

Although our knowledge of the basic biology of the three major species in the Gulf of Mexico is incomplete, recent research has added to our understanding of these species. Research work on diseases of shrimp has blossomed in recent years because of interest in shrimp culture. Because of the lack of basic research in this field, much of the recent work has been descriptive histology and histopathology. The most harmful pathogen observed in the larval stages is a fungus of the genus *Lagenidium* which has caused mortalities of 100% in shrimp hatcheries. In the juvenile and adult stages microsporidians, *Nosema*, *Pleistophora* and *Thelohania*, and bacteria, *Vibrio alginoliticus* and *V. parahaemoliticus* are common disease organisms. The role of a protozoan parasite, *Zoothamnium* sp. is illustrative of the importance of stress in shrimp diseases. *Zoothamnium* frequently occurs attached to the gills with little if any adverse effect. However, when shrimp infected with *Zoothamnium* are subjected to environmental stresses such as low oxygen or unusually low salinity the parasite has a harmful effect. Synergistic effects of disease organisms and environmental stresses seem to be extremely important with shrimp. With captive shrimp deaths attributed to disease are frequently associated with poor environmental conditions. Overstreet (1973) has presented a good discussion of shrimp diseases in the Gulf of Mexico region.

In the field of behavior we have a long-standing puzzle concerning how postlarvae get into the estuaries and how juveniles get back out to sea. Hughes who worked first in South Africa and later in the United States on this problem has provided some partial explanations for the migrations (Hughes, 1967; 1969a; 1969b). In summary he observed that postlarvae were active in the water column after acclimation to a given salinity. If the salinity decreased, the postlarvae settled to the bottom until the salinity increased again. Juveniles exhibited changing rheotactic responses in a rhythm corresponding to tidal cycles. This biological rhythm was maintained after the shrimp were removed from the natural environment. Juveniles also swam into the current or maintained their position on the bottom except when salinity was reduced, at which time they swam with the current.

Recent shrimp experiments conducted at the

---

[1] Contribution No. 388, National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston Laboratory, Galveston, Texas 77550.

[2] National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston Laboratory, Galveston, Texas 77550.

Galveston Laboratory utilising improved tagging methods have been surprising in that a substantial number of shrimp were recovered after long periods at large. We have concluded from these experiments that shrimp live longer than previously thought (some for more than 3 years) and that mortality rates in the offshore environment are lower than we had estimated.

Some interesting observations have been made relating to the differences in environmental requirements between the estaurine and oceanic stages in the life cycle of shrimp. From laboratory experiments we have evidence that juveniles benefit from a high organic content in the water. Nevertheless, there are apparent drastic changes in the environmental requirements of shrimp corresponding to their immigration from the estuaries. We are just beginning to understand the requirements of sub-adults and adults, which is probably the reason these stages grow poorly in captivity and fail to develop normal ovaries. Two factors which seem to be very important in this respect are light intensity and dissolved organics.

Because of recent interest in pollution in the United States, a vast amount of data are being accumulated on the tolerance of shrimp to pesticides, herbicides and other pollutants. While most of this information has not been published, it should be appearing in the literature soon.

POPULATION DYNAMICS

Although biologists at the Galveston Laboratory have worked with the population dynamics of Gulf of Mexico stocks for a number of years, we don't have any simple solutions to the unusually difficult problems encountered with penaeids. There are no simple formulas for learning how to manage penaeid populations correctly. We can learn much, however, by examining those approaches which have been used and by asking ourselves which are most valuable.

Numerous studies of spawner-recruit relations have been conducted in search for answers to the question 'How heavily can we fish a stock of shrimp without reducing its reproductive potential?' Although the results of these studies are not clear-cut, some general assumptions have emerged. The assumptions, which are illustrated by the spawner-recruit curve in Fig. 1, are as follows:

(a) Because of the high fecundity of shrimp, a relatively small population of spawners is required to maintain stock levels.

(b) The fishery is operating at levels of spawner abundance somewhere on the flat part of the curve so that environmental fluctuations rather than changes in spawner abundance are the primary cause of stock fluctuations.

(c) Overfishing is unlikely because fishing becomes unprofitable at levels of abundance which are still on the flat part of the curve.

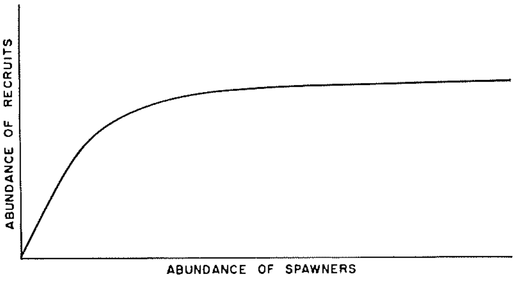


Figure 1. A hypothetical spawner-recruit relationship for penaeid shrimp.

I want next to discuss spawner-recruit relations for two separate fisheries in the Gulf of Mexico.

The first is the situation with brown and pink shrimp. These species are fairly typical 'grooved' penaeids which Kutkuhn (1966) placed near the 'deep-water, marine' end of the environmental spectrum for penaeid shrimp. In most cases there are spawning reserves of these animals in deep water that are not fished. Trawling usually is discontinued when catches drop below about 70 kg of tails per day. We have worked with all kinds of indices of abundance for these species using good data collected over a 15-year period, but have found no correlations between numbers of spawners and numbers of recruits to the fishery produced by these spawners. One of two things is happening; either the spawner-recruit relationship is very flat over the range of stock sizes encountered, or environmentally induced variation is masking underlying spawner-recruit relationships.

Personnel in our Population Dynamics Investigation at the Galveston Laboratory have looked for the same kind of relationships in their prediction work with brown shrimp, except they have examined shorter portions of the life cycle. For example our biologists have been interested in correlations such as those between abundance of postlarvae and juveniles, postlarvae and adults, and larvae and adults. Sampling has been conducted to measure abundance at all stages in the life history of the shrimp and landing statistics from both offshore and estuarine fisheries have been used. Relationships can be summarised as follows:

(a) No correlations were found between abundance of adults and abundance of larvae or postlarvae which were offspring of these adults.
(b) No correlations were found between abundance of larvae and abundance of later stages.
(c) Positive correlations were found between abundance of postlarvae and abundance of both juveniles and adults (Baxter, 1962; Berry and Baxter, MS.; Baxter and Renfro, 1966; and Berry and Baxter, 1969).
(d) Positive correlations were found between abundance of juveniles and adults (Berry and Baxter, 1969).

It is apparent from this work that the variability in the system is greatest between the adult and postlarvae stages. Failure to discover spawner-recruit relationships is probably due to environmentally induced variability during this portion of the life cycle.

Other evidence that the reproductive capacity of brown shrimp has not been reduced by fishing is the stability of the catch over the last 15 years.

The second shrimp fishery I want to discuss is the white shrimp fishery. The white shrimp is much closer to the estuarine end of Kutkuhn's environmental spectrum (Kutkuhn, 1966) and is seldom found in water deeper than 20 m. Some adults apparently move back into the estuaries. The stocks of white shrimp are fished very heavily and are all readily accessible to the fishermen. There are no 'spawning reserves' in deep water as there are with brown shrimp.

In searching for relationships between the abundance of spawners and the abundance of recruits we have found, as we did with browns, an absence of any clear-cut relationship.

The major difference between browns and whites can be seen by examining landings of white shrimp for the period that records exist. In contrast to landings of brown shrimp, white shrimp landings have declined over a period of years. White shrimp landings are portrayed in Figs. 2 and 3. Caution must be used in the interpretation of these figures since statistics are incomplete prior to 1955 and since only white shrimp were harvested until the late 1940s. The shaded portions of the landings curves (Figs. 2 and 3) represent white shrimp landings. For both the Georgia-Florida area and the Louisiana area a marked decline in white shrimp landings has occurred. For Louisiana I have also presented a measure of effort (number of trawl licences sold) which indicates effort has increased and, therefore, catch-per-unit-of-effort has declined more rapidly than landings. Although we don't have

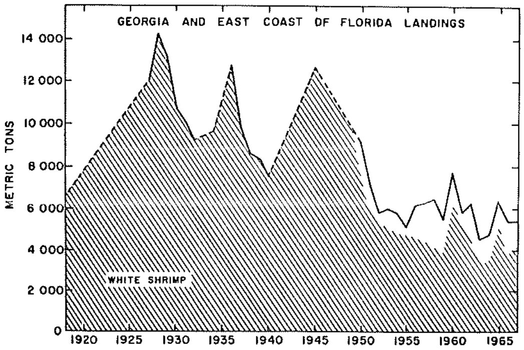


Figure 2. Landings of all shrimp and landings of white shrimp (shaded), Georgia and east coast of Florida.

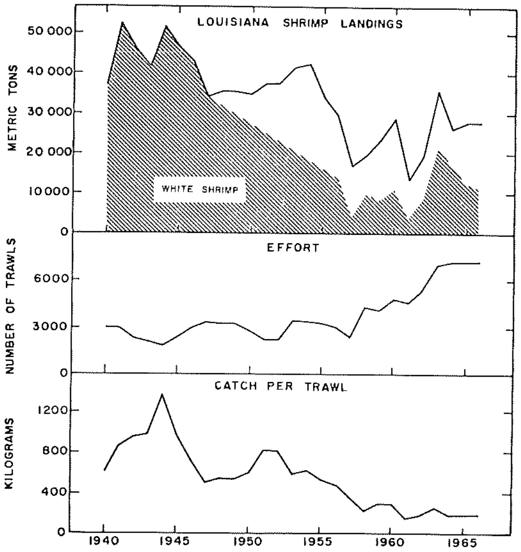


Figure 3. Landings of all shrimp and of white shrimp, number of trawl licences sold and catch per trawl, Louisiana.

firm evidence, there may be situations where the reproductive capacity of penaeid shrimp stocks has been reduced.

Beverton and Holt models have frequently been used to determine the optimum time to begin fishing a shrimp population. Results have been applied to situations where a closed season exists to protect small shrimp in the estuaries and a decision must be made concerning when to begin harvesting as the year-class increases in average size. Growth and mortality rates have been estimated using mark-recapture experiments. The central problem has been separating fishing mortality from natural mortality. The model is sensitive to small changes in these parameters, i.e. small differences in the proportion of the total mortality assigned to fishing or to natural causes make relatively large differences in the optimum size at first harvest.

The reasons we have had trouble separating natural from fishing mortality are as follows:

(a) Fishing effort is constantly shifting so that it is nearly impossible to estimate effort being applied to a given stock over a long period of time.

(b) During the period when growth and mortality rates are critical, shrimp are very small and difficult to mark.

(c) Population size in numbers is so great it is difficult to mark sufficient numbers of shrimp.

(d) We have never obtained a satisfactory estimate of the mortality caused by marking.

Although this approach has been used frequently in the United States, the results have not been very satisfying. It is, nevertheless, useful because it provides at least ballpark estimates where none are otherwise available. Berry (1967) has developed a model for the pink shrimp population of the Florida Tortugas grounds. This study probably represents the most successful use of Beverton and Holt's model with penaeids. Several aspects of this fishery, such as the discrete nature of the population, relatively constant effort and localised landings made this study a model of considerable value for comparative purposes.

Although shrimp prices have been used with the Beverton and Holt model, models for shrimp fisheries have never been developed to truly economic models including harvesting costs.

Are there alternative approaches to the size at harvest problem? There are no well-tested techniques that I can recommend; however, there are some other possible approaches utilising landing statistics.

The first approach is that of comparing the value of the harvest in different years in which the average size at harvest has been different. In Texas (Neal, 1967) the value of 1,000 shrimp harvested has varied from $18 to $22 with no change in regulations. This comparison is of special interest for years with the same initial crop size.

A second aproach is that of comparing the value of harvests from different fisheries in which management or fishing pressure differs.

A third possible approach is that of manipulation of regulations for purposes of evaluation. If conducted over a long period on a scientific basis this approach offers some interesting opportunities.

Each of these approaches requires a solid statistical base for a period of years. A problem which frequently arises in the interpretation of catch and effort statistics for the fisheries in the Gulf of Mexico is that fishing methods change. Changes in the gear type or size of nets and vessels require an adjustment to standardise the units of effort. Three separate groups of vessels in the Gulf of Mexico shrimp fishery have been examined to determine the relative fishing power of vessels with different characteristics. Characteristics considered were those which have changed over the last 15 years such as vessel weight, horsepower, vessel length, and total width of the nets used.

Although the results have not been published, the results of the three studies were similar. In all three cases the best vessel characteristic was vessel length. The relationship between relative fishing power and vessel length was represented by the equation:

Fishing Power $= a + b$ (Vessel Length) where a ranged from $-$ 0.424 to 0.630 and b ranged from 0.022 to 0.036 when vessel length was expressed in feet.

COMMERCIAL FISHERY

The Gulf of Mexico fishery is a particularly complex one involving a large number of vessels with rapid changes in effort from one species to another or one location to another. Total United States landings (Fig. 4) increased until the early 1950s and have been relatively constant since that time. Numbers of vessels have increased since 1962 (Fig. 5) as have numbers of fishermen. Both statistics are apparently related to the price of shrimp. The results of increasing fishing pressure on these

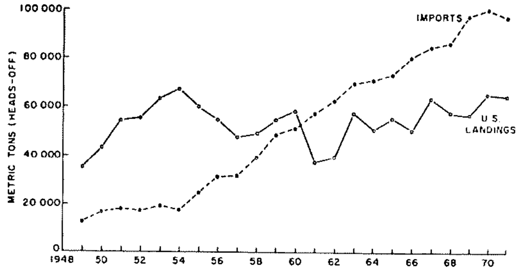


Figure 4. Total United States landings of shrimp from the Gulf of Mexico and total United States imports of shrimp.

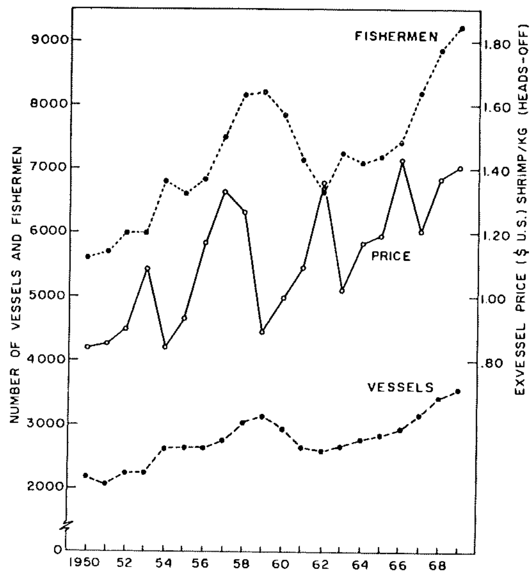


Figure 5. Number of vessels (over 5 tonnes) and numbers of fishermen working on these vessels in the Gulf of Mexico shrimp fishery, along with average ex-vessel price of shrimp.

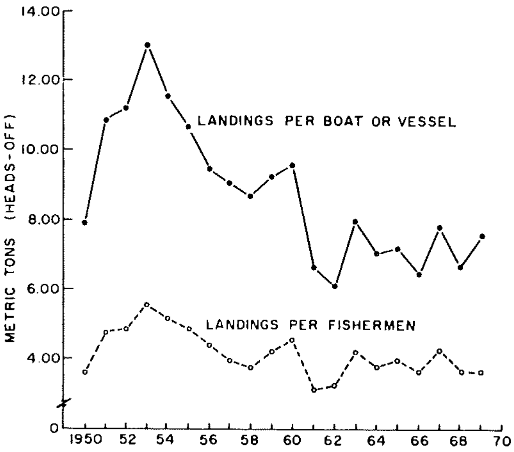


Figure 6. Landings per boat or vessel and landings per fisherman for the Gulf of Mexico shrimp fishery.

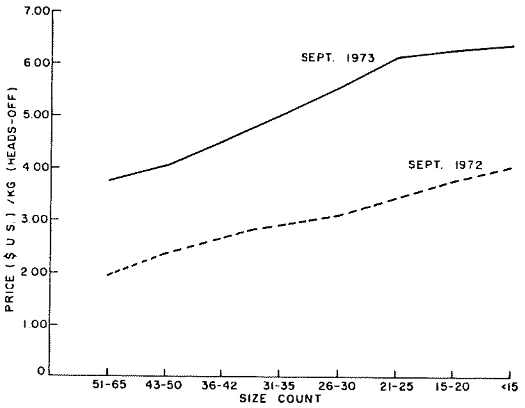


Figure 7. Dockside prices for brown shrimp, heads-off, on the Texas coast, September 1972 and September 1973.

populations are illustrated in Fig. 6. Landings per vessel have definitely declined, and landings per fisherman are lower than they have been during at least two periods in the past.

The usual method of holding shrimp on the boats is with ice. Trips of up to 12-14 days are common. Boats with freezers have been used occasionally, but mechanical problems with the freezers and a lack of qualified maintenance people have caused most of the boat owners to shift back to the use of ice. A sodium bisulphate dip is used by some fishermen to prevent black spot, but more frequently fishermen simply mix the chemical with the shrimp as they are being iced on the boat.

Problems with the quality of the product reaching the consumer have resulted in the initiation of a voluntary inspection program. The inspection is conducted by the federal Government at the request of and at the expense of the individual processor. The response to the program has been very good and at present 45 large shrimp processing plants take part in the voluntary inspection plan. The advantage to the processor is that he can advertise his products as government inspected, and the Government publishes lists of firms taking part in the inspection.

A major increase has occurred in the *per capita* consumption of shrimp in the United States (Table 1) in spite of the price increases. At least part of the increase in demand has been generated by active market promotion programs. These programs have been funded largely by industry contributions. Our economists have projected a demand picture for the United States market through the year 2000. Based upon projected *per capita* consumption of 1.15 kg by 1980 and 1.17 kg by 2000, and expected increases in the U.S. population, consumption will be 269,438 tonnes (heads-off) by 1980 and 359,251 tonnes (heads-off) by 2000. World consumption is expected to reach 747,718 tonnes (heads-off) by the year 1980.

Prices during the last year (Fig. 7) reflect the increasing demand combined with a fixed supply from the Gulf of Mexico. Of major interest is the fact that the price for 51-65 count shrimp increased 98% during the 12-month period, while the price for 15-count shrimp increased 58%.

Table 1.
Consumption of Shrimp in the United States (Heads-off weights)

Year	*Total consumption (Tonnes)*	*Per capita consumption (Kilograms)*
1947	45,128	0.31
1948	45,945	0.31
1949	48,124	0.32
1950	49,531	0.33
1951	58,975	0.38
1952	63,469	0.40
1953	64,241	0.40
1954	66,874	0.41
1955	71,187	0.43
1956	68,736	0.41
1957	62,970	0.37
1958	69,099	0.39
1959	84,489	0.48
1960	88,939	0.49
1961	87,304	0.48
1962	88,212	0.66
1963	98,927	0.52
1964	102,513	0.54
1965	111,366	0.57
1966	111,003	0.57
1967	121,218	0.61
1968	129,617	0.65
1969	127,892	0.64
1970	146,233	0.72
1971	141,103	0.69

MANAGEMENT

A particularly awkward situation exists with respect to management of the Gulf of Mexico shrimp fishery. It is complicated from the political standpoint as well as the biological standpoint. Most of the management oriented research has been conducted by the federal Government, yet the federal Government has no management authority. The States each regulate their own fisheries even though vessels move freely from State to State. A substantial portion of the fishing is done in international waters where no regulations are applied. Vessels from five Gulf coast States, Mexico and Cuba, take part in the fishery.

The regulations applied by the various States differ considerably. Generally there is at least partial protection of the small shrimp during the estuarine portion of their life cycle. Some States also have short closed seasons to protect the shimp immediately after they leave the estuaries. Most States regulate the mesh size used in their waters as well as the net size used in estaurine waters. There is essentially no regulation offshore in waters outside the jurisdiction of the various States. The width of the fishery jurisdiction of the States varies from 3 to 10 miles depending upon the State.

With increasing international fishing pressure on the stocks and rapidly increasing prices, the United States must demonstrate that the shrimp stocks are being managed wisely if it hopes to protect its fishing interests. The present system of conflicting State laws does not help the United States position. As a possible solution to this predicament a State-Federal Management Program has been implemented. Under this program federal money is being used to implement management programs under the direction of State Governments. Close co-operation between the State and federal authorities is being encouraged to insure that State management policies support federal interests.

A controversial issue with respect to management of the shrimp fishery is that of limited entry. The United States prawn fishery is a classic example of overcapitalisation or economic overfishing. The harvesting costs are higher than necessary because unnecessarily large numbers of boats and men are involved in harvesting. As a result real income per fisherman is declining even though the total catch is static. The concept of limited entry is very unpopular with State regulatory agencies.

LITERATURE CITED

BAXTER, K. N. (1962). 'Abundance of postlarval shrimp—one index of future shrimping success.' *Proc. Gulf Caribb. Fish. Inst.*, 15, pp. 79-87.

BAXTER, K. N. AND RENFRO, W. C. (1966). 'Seasonal occurrence and size distribution of postlarval brown and white shrimp near Galveston, Texas, with notes on species identification.' *U.S., N.M.F.S., Fish. Bull.*, 66 (1), pp. 149-158.

BERRY, R. J. (1967). Dynamics of the Tortugas pink shrimp population. (Ph.D. Thesis, University of Rhode Island.) University Microfilms, Inc. Ann Arbor, Michigan. 160 pp.

BERRY, R. J. AND BAXTER, K. N. (1969). 'Predicting brown shrimp abundance in the northwestern Gulf of Mexico.' *FAO Fish. Rep.*, 3 (57), pp. 775-798.

BERRY, R. J. AND BAXTER, K. N. (MS.). Forecasting shrimp abundance and fishing success. Paper presented at the 94th Annual Meeting of the American Fisheries Society, September 1964.

HUGHES, D. A. (1967). 'On the mechanisms underlying tide-associated movements of *Penaeus duorarum* Burkenroad.' *Proc. World Scientific Conf. Biology and Culture of Shrimps and Prawns. FAO Fish. Rep.*, 3 (57), pp. 867-874.

HUGHES, D. A. (1969a). 'Responses to salinity change as a tidal transport mechanism of pink shrimp, *Penaeus duorarum.' Biol. Bull.*, 136, pp. 43-53.

HUGHES, D. A. (1969b). 'Evidence for the endogenous control of swimming in pink shrimp, *Penaeus duorarum.' Biol. Bull.*, 136, pp. 398-404.

KUTKUHN, J. H. (1966). 'The role of estuaries in the development and perpetuation of commercial shrimp resources.' *Amer. Fish. Soc. Spec. Publ.*, 3, pp. 16-36.

NEAL, R. A. (1967). 'An application of the virtual population technique to penaeid shrimp, *Proc. 21st Ann. Conf. Southeastern Assoc. Game Fish Commissioners*, pp. 264-272.

OSBORN, K. W., MAGHAM, B. W. AND DRUMMOND, S. B. (1969). *Gulf of Mexico shrimp atlas.* U.S. Bur. Commer. Fish., Circ. 312, 20 pp.

OVERSTREET, R. M. (1973). 'Parasites of some penaeid shrimps with emphasis on reared hosts.' *Aquaculture*, 2 (2), pp. 105-140.

SESSION 1

DESCRIPTIVE BIOLOGY

CHAIRMAN: PROFESSOR J. M. THOMPSON

AUTHORS
M. A. POTTER W. E. BARBER
P. C. YOUNG C. P. LEE
J. P. R. HINDLEY I. KIRKEGAAD
I. S. R. MUNRO

MOVEMENTS OF THE EASTERN KING PRAWN, *PENAEUS PLEBEJUS*, IN SOUTHERN QUEENSLAND WATERS

BY M. A. POTTER
Biologist, Queensland Department of Primary Industries,
Fisheries Research Station, Deception Bay.

ABSTRACT

A total of 29,659 tagged king prawns were released in five tagging experiments between 19 September 1971 and 31 March 1972.

Subsequent recaptures indicated a northerly movement by juvenile prawns. Adult tagged prawns released in deep water showed no coastal migrational tendency, but did tend to move towards deeper water. The existence of strong currents off the coast is noted and some possible effects on prawn movements discussed.

INTRODUCTION

The prawn fishing industry of southern Queensland is a multi-million dollar industry in terms of annual catch. Capital invested in prawn trawlers and shore facilities also would amount to millions of dollars.

Prawning fleets operate from the ocean ports of Tin Can Bay, Mooloolaba, Southport and Tweed Heads-Coolangatta, and the Moreton Bay ports of Scarborough and Cabbage Tree Creek. The ocean trawling fleets fish for the king prawn, *Penaeus plebejus*, all year round, fishing in the vicinity of estuarine bars in the spring and early summer months and moving into deeper water as the year progresses. Most vessels from these ports make several trips of four or five days' duration to the established deep water trawling ground off Cape Moreton during the winter months (see Fig. 1).

Trawlers operating from the Moreton Bay ports fish for king prawns in Moreton Bay during the spring and summer months. Almost all fishing for king prawns takes place at night but some vessels work during the day, trawling for the greasy-back prawn, *Metapenaeus bennettae*. In the autumn and winter larger vessels fish the deep water trawling grounds for large king prawns north and south of Cape Moreton.

The relationship between the juvenile prawn stocks in the estuarine fishing areas and the adult stocks has not been clearly defined. A series of prawn tagging experiments conducted in 1971-72 has helped to demonstrate some movement routes of the juveniles from the estuarine environment to offshore areas and the subsequent movements of adult king prawns.

Five experiments have been considered in this paper. Two were large scale experiments in Moreton Bay which were designed to give information on growth rates and mortality rates of juvenile king prawns in addition to the information on migrations. In two other experiments tagged prawns were released just outside bars and in the fifth experiment tagged prawns were released in deep water (110-119 m) on the ocean trawling grounds (see Fig. 1).

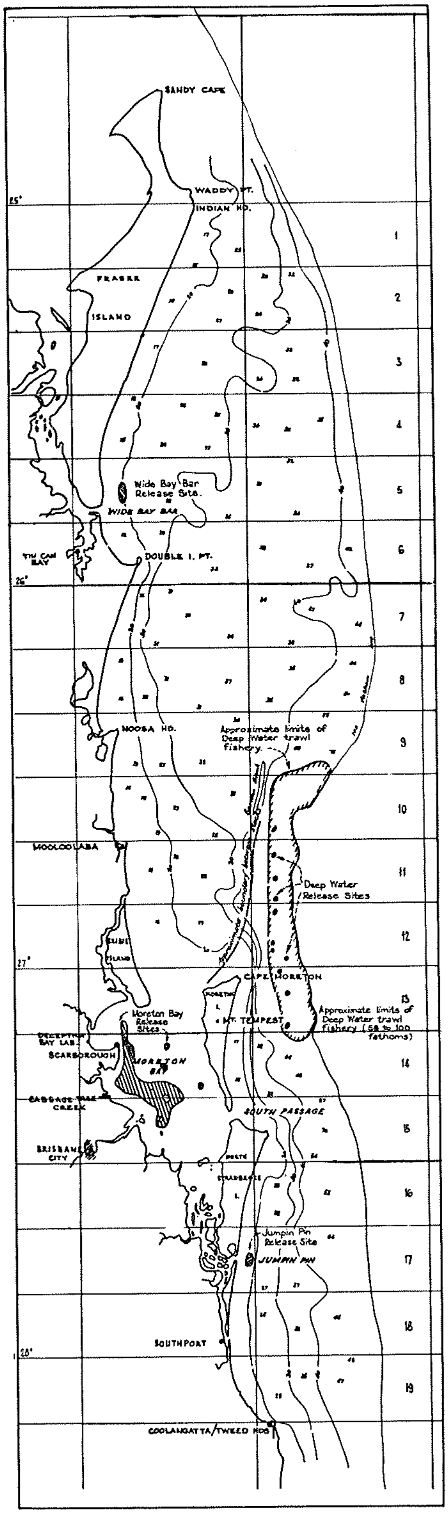
METHOD

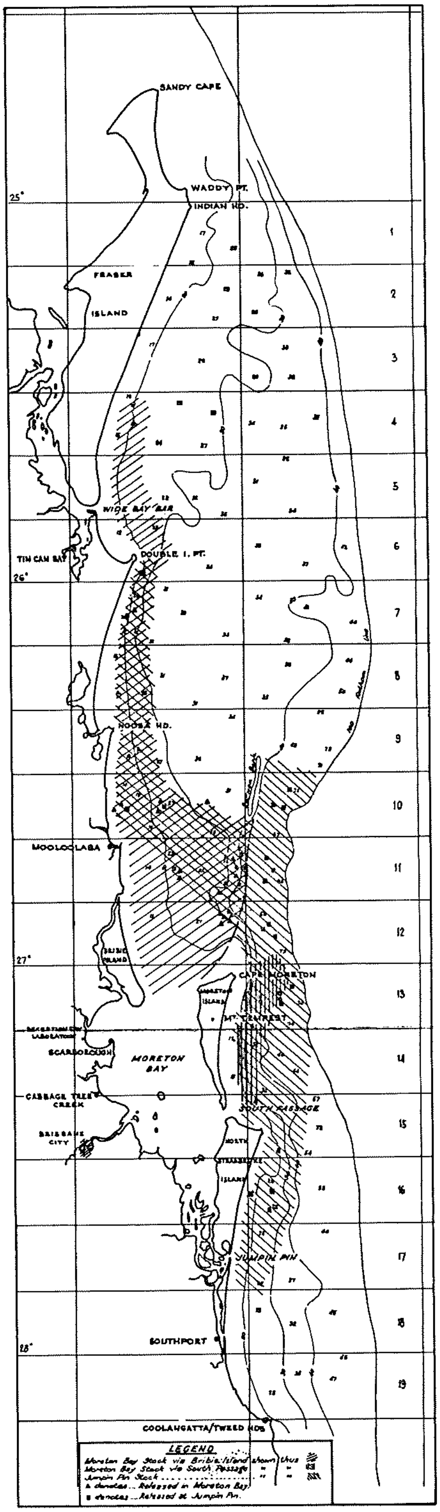
King prawns were captured for tagging by a chartered vessel towing standard 41 mm mesh Yankee Doodle prawn trawls with ticklers and drop chains. The duration of each trawl was chosen so as to obtain the maximum number of undamaged king prawns for each shot. This was dependent on the amount of trash in the area and the condition of the prawns themselves. Generally the trawl durations were of the order of thirty minutes.

King prawns were removed from the sorting tray as quickly as possible after spilling the cod ends and placed in a swimming tank with circulating sea water. Healthy prawns were selected from this tank for tagging. After tagging the prawns were placed in another swimming tank until ready for release. Before release the swim tank was checked for dead or obviously sick prawns. These were removed. Tagged prawns were released on the bottom from a canister designed for that purpose.

The tag used in these experiments consisted of a type 'o' stainless steel entomological pin and a numbered plastic disc attached to the pin. The pin was inserted through the middle of the first abdominal segment of the prawn

Figure 1. Charts of the Southern Queensland coast showing tagged prawn release and recovery sites.


SANDY CAPE
WADDY PT.
INDIAN HD.
25°
FRASER
ISLAND
Wide Bay Bar Release Site.
WIDE BAY BAR
TIN CAN BAY
DOUBLE I. PT.
26°
NOOSA HD.
Approximate limits of Deep Water trawl fishery.
MOOLOOLABA
Deep Water Release Sites
BRIBIE ISLAND
27°
CAPE MORETON
MORETON I.
MT. TEMPEST
Approximate limits of Deep Water trawl fishery (58 to 100 fathoms)
Moreton Bay Release Sites
DECEPTION BAY LAB.
SCARBOROUGH
MORETON BAY
CABBAGE TREE CREEK
SOUTH PASSAGE
BRISBANE CITY
NORTH STRADBROKE I.
Jumpin Pin Release Site
JUMPIN PIN
SOUTHPORT
28°
COOLANGATTA/TWEED HDS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


SANDY CAPE
WADDY PT.
INDIAN HD.
25°
FRASER
ISLAND
WIDE BAY BAR
TIN CAN BAY
DOUBLE I. PT.
26°
NOOSA HD.
MOOLOOLABA
BRIBIE ISLAND
27°
CAPE MORETON
MORETON ISLAND
MT. TEMPEST
DECEPTION BAY LABORATORY
SCARBOROUGH
MORETON BAY
CABBAGE TREE CREEK
SOUTH PASSAGE
BRISBANE CITY
NORTH STRADBROKE ISLAND
JUMPIN PIN
SOUTHPORT
28°
COOLANGATTA/TWEED HDS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
LEGEND
Moreton Bay Stock via Bribie Island shown thus
Moreton Bay Stock via South Passage " "
Jumpin Pin Stock " "
▲ denotes ... Released in Moreton Bay
■ denotes ... Released at Jumpin Pin.

and bent so that it would not pull back through the prawn.

The tag has evidently been quite successful. Several tagged prawns have been returned more than a year after release and to date the longest time spent in the field between release and recapture has been twenty months.

Tagged prawns were released in four different areas: (1) At the Wide Bay Bar in 29-37 m; (2) In Moreton Bay in 4-22 m; (3) At the Jumpinpin Bar in 18-26 m; (4) In the deep water in 110-119 m from east of Noosa to east of Tempest. King prawns were tagged in the first three areas in September and October 1971. Tagging in the deep water experiment was conducted in March 1972.

RECOVERIES OF TAGGED PRAWNS

Tagged prawns were mostly recovered from the fishermen by five contractors. These contractors were local men employed in the ports of Tin Can Bay, Mooloolaba, Cabbage Tree Creek, Southport and Coolangatta-Tweed Heads for the purpose of liaising with fishermen and collecting their logbook sheets and tagged prawns. The port of Scarborough was visited regularly by technical assistants from the Fisheries Research Station at Deception Bay to collect logsheets and tagged prawns. Visits were also made to Fish Board depots to collect any tags handed in by fishermen and to fishing companies established in Tweed Heads to collect any tags recovered during the processing of prawns.

A large Tweed Heads company unloaded a high percentage of the Mooloolaba ocean king prawn catch at its facility in the port of Mooloolaba. From there it road-freighted the landed prawns direct to its factory in Tweed Heads where they were processed. A number of tagged king prawns were recovered during processing and it was often not possible to trace the exact location of recaptured tagged prawns handled in this way, though in many instances the general fishing area could be established. However, these returns have not been considered in this paper.

The location of recoveries outside of Moreton Bay was recorded as a function of the grid and the depth in which the tagged prawn was recaptured. The grid system used is the same as that being used to record fishing effort in the prawn logbooks for Southern Queensland. Each grid is ten minutes of latitude. Grid number 1 is 25° South to 25° 10′ S numbering to Grid 19 which is 28° South to 28° 10′ S as per Fig. No. 1. This system has been in use for over three years and fishermen using the system can locate themselves in a grid with satisfactory accuracy.

Table 1. Summary of 1971-72 king prawn tagging experiments.

Exp. no.	*Release area*	*Release date*	*Number released*	*Recovery area*	*Number recovered*	*Period of recovery*
1	Moreton Bay	19-26/9/71	7,671	Moreton Bay	884	19/9/71-24/12/71
				North of Moreton Bay	23	2/11/71-20/7/72
				East of Moreton Bay	1	12/10/71
2	Wide Bay Bar	14/10/71	1,589	Wide Bay Bar	168	14/10/71-10/12/71
3	Jumpinpin Bar	16-17/10/71	5,461	Jumpinpin	570	16/10/71-5/3/72
				North of Jumpinpin	31	23/11/71-19/10/72
4	Moreton Bay	20-30/10/71	11,984	Moreton Bay	1,715	20/10/71-19/1/72
				North of Moreton Bay	29	15/12/71-19/6/72
5	Deep Water Grounds	30-31/3/72	2,954	Deep water grounds	233	30/3/72-17/7/73
				North of deep water grounds	1	24/8/72
				South of deep water grounds	1	26/4/72
	Total		**29,659**		**3,656**	

RESULTS

All king prawns tagged were released near or at the point of capture on commercial prawning grounds. Most recaptured tagged prawns were also recaptured by commercial vessels on the same prawning grounds as they were released. Some, however, moved over quite large distances within a fishery or from one fishery to another. The number of these tagged prawns is not high but is sufficient to indicate general movement trends off the southern Queensland coast. The 1971-72 experiments and recaptures are summarised in Table 1.

The juvenile king prawns tagged in experiments (1), (3) and (4) all demonstrated a tendency to move in a northerly direction along the coastline and into deeper water as they grew older. No tagged prawns released at the Wide Bay Bar in experiment (2) were recaptured outside the fishing area. There is very little fishing effort exerted north of the Wide Bay Bar and that particular result is not inconsistent with the results of the other experiments.

Tagged king prawns recaptured in the deep water tagging experiment did not show the same tendency to travel north. However, many were recaptured at a greater depth than they were released, showing the same tendency of the juvenile prawns to move into deeper waters.

DISTRIBUTION OF RECOVERED TAGGED PRAWNS

The movements of tagged king prawns released in Moreton Bay are summarised in Table 2. One tagged prawn not shown on the table was recaptured just outside South Passage in 55 m. This was due east of its point of release. Many more tagged prawns may have left Moreton Bay by this exit, but fishing effort outside South Passage is spasmodic and only occurs during a relatively short season.

The remainder of the tagged king prawns recaptured outside Moreton Bay in experiments (1) and (4) were recaptured north to north-east of Moreton Bay where fishing effort is greater and the season is more extended. These tagged prawns were recaptured in depths ranging from 13-82 m.

Only the one however was recaptured in the deep water trawling ground and that tagged prawn was recaptured in grid 13 south of Cape Moreton. No other confirmed recaptures from Experiments (1) and (4) occurred in deeper water than 79 m. There are two possible

Table 2. [a] **Migrations of king prawns released in Moreton Bay (Experiments (1) and (4) combined).** *(Confirmed recapture locations only)*

	Distance moved (km) north to north-east				
	34-48	49-64	65-80	98-112	146-160
Number	11	14	1	2	1
Mean—days out	81.3	87.9	123	138.0	38
Range—days out	51-235	46-232	123	106-171	38

[a] An additional 23 tagged prawns were recovered from processed prawns originally landed at Mooloolaba.

Table 3. [a] **Migrations of tagged king prawns released at Jumpinpin** *(Confirmed recapture locations only)*

	Distance moved (km)						
	0-16 S.	0-16 N.	50-64 N.	65-80 N.	81-96 N.	97-112 N.	162-177 N.
Number	5	3	5	3	4	5	1
Mean—days out	51.0	26.7	192.0	184.3	250.0	177.4	124
Range—days out	3-137	14-33	136-253	160-231	136-367	37-261	124

[a] An additional 13 tagged prawns were recovered from processed prawns originally landed at Mooloolaba during the period 21/2/72 to 28/8/72.

routes that this tagged prawn may have taken to reach this location in grid 13. It either moved out through the northern entrance to Moreton Bay, east around Cape Moreton and then south, or it moved out through South Passage then along Moreton Island moving into deeper water as it progressed north.

The movements of king prawns tagged and released at the Jumpinpin Bar are summarised in Table 3. Five prawns moved slightly south. Thirty-one prawns were recaptured in grid 13 or further north although the recapture locations are only confirmed for eighteen of the thirty-one prawns and only these have been considered. These eighteen tagged prawns were recaptured in depths ranging from 20-146 m; twelve of them being recaptured on the deep water trawling grounds. A number of tagged prawns were also recaptured east of the Jumpinpin Bar in deeper water than they were released.

The results of experiment (5) differed radically from the previous experiments in that tagged king prawns were recaptured in quantity south, as well as north, of their release points. These movements are summarised in Table 4. These adult tagged king prawns showed no obvious movement trend when compared with the juvenile tagged king prawns of experiments (1), (3) and (4). Only two confirmed recaptures were made outside the deep water trawling ground. The first was recaptured approximately due east of Double Island Point, about 48 km north of the deep water trawling ground, and about 64 km north of its release point. The second was recaptured 48-64 km south of the deep water trawling ground in 55 m, some 48-64 km south of its release point. This recapture seemed to be contrary to the general trend of recaptures at the time and was doubly checked to verify the recapture location.

Some inshore ocean recaptures (< 55 m) from Moreton Bay and Jumpinpin releases have travelled considerable distances in relatively short periods. The furthest distance a tagged prawn was recaptured from its release point at Jumpinpin was 176 plus kilometres. It covered this distance in 124 days. The furthest distance a prawn released in Moreton Bay covered was 160 kilometres. It covered this distance in only 38 days. This is more than double the average speed of the next best migration speed recorded in these experiments. However, it is similar to the average migration speeds of several king prawns tagged in New South Wales waters which have been recaptured on the deep water trawling grounds near Cape Moreton (Ruello). No recaptures of tagged king prawns have been recorded north of the Wide Bay Bar fishing areas as the fishing effort is light north of that area.

DISCUSSION

The results of these tagging experiments have to be interpreted bearing in mind that fishing effort is not uniform over the area under discussion, i.e. from Fraser Island to the Queensland/New South Wales border. Large areas receive no fishing effort at all and other areas are only fished for a short period of the year. There are a number of reasons why large areas receive little or no fishing effort. These include such factors as distance from shelter, unsuitable trawling bottom and lack of suitable navigational marks which skippers can use to locate themselves.

Lack of tag recaptures from an unfished area or an area that is fished for a brief season only cannot therefore be interpreted as indicating no migration to or through such areas. While being aware of this qualification, the king prawn tagging experiments have nevertheless shown some interesting results.

At the time of the commencement of the tagging experiments being discussed two king prawns tagged in central New South Wales

Table 4. Movements of tagged king prawns released in the deep water grounds.
(Confirmed recapture locations only)

	Distance moved (km) north or south								
	49-64 S.	33-48 S.	17-32 S.	1.6-16 S.	0	1.6-16 N.	17-32 N.	33-48 N.	49-64 N.
Number	1	1	16	27	43	24	4	5	1
Mean—days out	26	48	36.9	52.7	49.7	105.2	114.3	121.2	146
Range—days out	26	48	0-109	0-151	0-402	6-473	81-149	80-159	

waters had been recaptured by prawn trawlers working in deep water off Moreton Island. Further recaptures have occurred since this time. It is not surprising then, that more than a dozen king prawns tagged at Jumpinpin have been recovered by trawlers working the deep water grounds north and south of Cape Moreton. This result would seem to indicate that juvenile prawns from the Jumpinpin area contributed strongly to the adult king prawn stock of the deep water grounds in that season. The number of recoveries of tagged prawns released in New South Wales waters also suggests that juveniles from New South Wales estuaries may make a significant contribution to these prawn stocks.

Tagging and staining experiments have shown migration patterns in other species of penaeids. Lindner and Anderson (1956) found that white shrimp, *Penaeus setiferus*, make migrations over considerable distances on the Atlantic coast of the United States. Costello and Allen (1966) found that juvenile pink shrimp, *Penaeus duorarum*, from a number of nursery grounds on the Florida Gulf Coast travel up to 240 km to the Tortugas and Sanibel shrimping grounds.

A more surprising result in these experiments was the single recovery of a tagged prawn released in Moreton Bay on the deep water grounds. Considering the large number of tagged prawns released in Moreton Bay, it was originally expected that there would be more than one recapture in the deep water. From the location of this recapture, it is possible that this particular prawn left Moreton Bay by way of South Passage and moved into deeper water as it progressed north, in a similar manner to those prawns which moved north from Jumpinpin. If this is so, then not one tagged prawn which left Moreton Bay via the Bribie-Moreton Island entrance was recovered on the deep water trawling grounds. This indicates that the contribution to the adult deep water stock of prawns from Moreton Bay (in the areas where tags were released) was small. What contribution there was most probably came from nursery areas which contributed to juvenile stocks leaving Moreton Bay via South Passage.

The adult deep water prawns did not display the same tendency as the juveniles to move in a northerly direction. These tagged prawns moved both north and south of their release points. Slightly more moved south than moved north.

Lindner and Anderson (1956) also found that tagged adult *Penaeus setiferus* off the Louisiana coast 'appeared to drift about like cattle on an open range'. Klima (1963) found that stained brown shrimp, *Penaeus aztecus*, distributed themselves between the 30 and 55 m contours over approximately the same general area in which they were released.

Interestingly, the mean number of days of freedom of a tagged king prawn which moved north was approximately double that of a tagged prawn which was recaptured in the same grid or further south. Two factors may have been responsible for this apparent phenomenon. Firstly, there was, and is, a predominantly southerly current on the deep water grounds. This current, the East Australian Current, possibly assisted the southerly movement of some of the tagged prawns, particularly any which may have been in a weakened condition as a result of tagging. The situation is confused when it is taken into consideration that there was a northerly shift in the concentration of effort during the deep water season from April 1972 to August 1972. The bias introduced by this shift in the concentration of effort may be sufficient to account for the apparent difference in the average number of days of freedom.

The East Australian Current is an offshore southerly current which varies from 0 to 7 km/hr near the 180 m countour according to the time of year and the latitude. Closer inshore the current decreases in strength and there are changes in current direction from south to north on some parts of the coast, principally in the winter. The northerly current, when it does occur, is not very strong—up to approximately 1 km/hr (Hamon).

In these experiments tagged king prawns which had moved the greatest distances in the shortest times were recaptured close inshore, though in deeper water than they were released. By remaining close inshore, king prawns moving north may avoid the stronger southerly currents which exist further offshore, and so be able to cover greater distances in a shorter time. At times, weak northerly currents may assist this northward movement inshore. The only southerly movements of any distance by tagged king prawns have been recorded from the deep water grounds where there is a consistent southerly current.

CONCLUSIONS

1. Juvenile king prawns from Jumpinpin made a considerable contribution to the stock

of adult king prawns on the deep water trawling ground north and south of Cape Moreton. There is also some evidence to suggest that king prawns from the southern part of Moreton Bay which left Moreton Bay by the South Passage may have made a contribution to the adult stocks of the deep water fishery.

2. The juvenile king prawns that were trawled for in the spring and summer in Moreton Bay did not appear to make a significant contribution to the adult prawn stocks of the deep water fishery, though they contributed to other fisheries closer inshore.

3. The adult king prawns tagged in the deep water fishery showed no migrational tendency, but spread both north and south on the fishing grounds.

LITERATURE CITED

Costello, T. J. and Allen, D. M. (1966). 'Migrations and geographic distribution of pink shrimp, *Penaeus duorarum*, of the Tortugas and Sanibel Grounds, Florida.' *Fishery Bull.*, Fish Wildl. Serv., U.S., 65(2), pp. 449-459.

Hamon, B. V. (unpublished data). CSIRO, Div. Fish. and Oceanogr., Cronulla, N.S.W.

Klima, E. F. (1963). 'Mark-recapture experiments with brown and white shrimp in the northern Gulf of Mexico.' *Proc. Gulf Caribb. Fish. Inst.*, 16th s., pp. 52-64.

Lindner, M. J. and Anderson, W. W. (1956). 'Growth, migrations, spawning and size distribution of shrimp *Penaeus setiferus. Fishery Bull.*, Fish Wildl. Serv., U.S., 106(56), pp. 553-645.

Ruello, N. V. (Manuscript). Geographical distribution, growth and spawning migration of the eastern king prawn, *Penaeus plebejus* (Hess).

DISCUSSION

Lucas. I thought it might be appropriate here for me to mention some of the prawn tagging experiments and the observation of those results on migrations. These mainly concern the releases in Moreton Bay and the releases at Jumpinpin. Approximately similar numbers of prawns were released in Moreton Bay and at Jumpinpin in 1970 in the same months as the releases that Mike Potter describes in 1971. The conclusions that he has come to, that the Jumpinpin area contributes mostly to the deep water fishery and that Moreton Bay does not, is a little bit different from the results of the previous year, where it appeared that the deep water fishery was fed from the Moreton Bay area, as 16 recaptures were in the deep water area from the Moreton Bay releases while only 2 recaptures in the deep water fishery were from the Jumpinpin releases. This could be explained by three different ways:

1. Difference in the migratory behaviour from one year to the next.
2. We are only dealing in small numbers of recaptures and differences could just be a statistical variation.
3. The deep water fishery operates in the winter months mainly while the juvenile fishery at Jumpinpin and in Moreton Bay operates in the summer months and we have a six-month time difference in the fisheries. Considering the expected tag mortality operating on the prawns then the probability of recapturing any in the deep water six months later is extremely low so we are dealing in small numbers and it is very difficult to be specific about recruitment to the deep water fishery from any area.

I don't really see how we can overcome the problem by recapture experiments because of the tag mortality effect.

The other point I might just mention concerning the deep water fishery, is that from releases south of the area off Coolangatta, there were four recaptures in the deep water fishery; there were two recaptures in the deep water fishery from releases off Double Island Point. So the situation is certainly not clear cut as far as any definite direction of movement in that fishery.

Potter. There was a difference in these particular two seasons and the results are as Dr Lucas has mentioned. However, I thought it might be appropriate to explore at this time some of the possible reasons as to why this has occurred. There was a large difference in rainfall in the two years we are talking about, 1970 and 1971. The catch rate in kg per hour in king prawns in Moreton Bay shows some variations between 1970 and 1971 (Fig. 2) when the set of tag experiments that I have been talking about were carried out. I believe that the amount of rain which fell in the Brisbane area in that time is related to this. For instance, in the 1970 season, there was 195 mm in October as against half that amount the following year. The same applies in November, half the amount in 1971; in December 1970 there was 403 mm and in 1971 111 mm, and in January 426 and 197 mm respectively. The totals show in 1970 we had 1300 mm over five months of the Bay season all in the Brisbane area, and in 1971 we had 592 mm. The average up to this year and including this year is

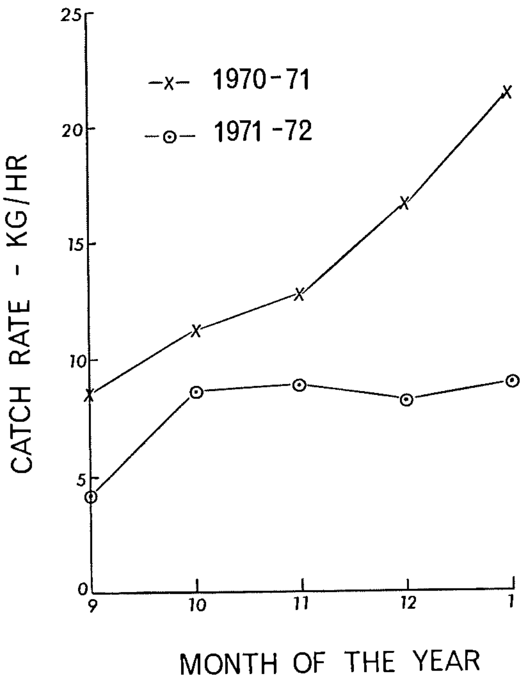


Figure 2. Catch rate of king prawns in Moreton Bay in the 1970/71 and 1971/72 seasons.

490 mm over those five months. This information is from the Bureau of Meteorology (Table 5).

These average figures are closer to what we had in 1971 but the point is that variability in environment, and in this particular case the rainfall, had changed the migration patterns considerably, and this may hold for further years.

Another important point I have mentioned in my paper is that there is a very strong southerly current off the coast here, the East Australian current. I believe that the currents also have quite an effect on prawn migrations and prawn movements.

Table 5.
Monthly rainfall totals (Brisbane) in mm for the 1970/71 and 1971/72 Moreton Bay trawling seasons.

	1970/71	*1971/72*	*Average*
September	48	48	48
October	195	93	68
November	225	143	92
December	403	111	127
January	426	197	156
Totals	1 297	592	491

In summation, since we do have different results so far from year to year, perhaps the tagging that Dr Lucas is doing this year may throw more light on the subject.

PRELIMINARY OBSERVATIONS ON THE ENVIRONMENT AND BIOLOGY OF JUVENILE KING PRAWNS *(PENAEUS PLEBEJUS)* IN MORETON BAY, QUEENSLAND

BY P. C. YOUNG
Senior Research Scientist, CSIRO,
Division of Fisheries and Oceanography,
P.O. Box 21, Cronulla, N.S.W. 2230

ABSTRACT

A range of discrete habitats within Moreton Bay, Queensland, was investigated to determine the relative importance of each as a nursery area for a number of species of penaeid prawns. The distribution and abundance of various size classes were measured by fortnightly samples from each.

The juvenile king prawns use shallower parts of Moreton Bay (in which there is shelter and abundant food) as a nursery area. Areas of Moreton Bay were classified according to the sea-grass communities on them, and in each area regular sampling for juvenile prawns was done with a small beam trawl.

At the same time characteristics of the water such as turbidity, salinity and temperature were measured. The biomass of the sea-grasses was measured and core samples of the bottom sediments were taken.

Results so far show that the small prawns settle in littoral areas, and numbers are much greater in sea-grassed areas than on bare sand or mud. King prawns come into the nursery areas throughout the year, but most recruitment occurs during three periods—February, June and October-November. It is possible that the June recruitment comes from a different source from the February and October-November recruitment.

Immediately after settling the juvenile prawns begin a slow migration into the deeper waters of Moreton Bay.

INTRODUCTION

At present in Australia, the estuarine environment is changing rapidly as a result of pollution, dredging, canal development, etc. Not the least of the estuaries involved in dramatic man-made changes is the large body of water in south-east Queensland known as Moreton Bay. This is a large wedge-shaped depression deepening towards the north-west, approximately 96 km long and ranging in width from 0.8 km in the south to a maximum of 30 km near its northern limit (Fig. 1). It extends from the mouth of the Nerang River at latitude of 27° 56′ S. to a free opening between Bribie and Moreton Islands at a latitude of 27° 2′ S. Except for this northern opening, which is 14.5 km wide, and the three narrow openings at South Passage, Jumpinpin and the Southport Bar, all of which are less than a kilometre wide, its 1400 km^2 of water and low islands are enclosed by the mainland and the large, high, offshore islands of Moreton, North Stradbroke and South Stradbroke.

The tidal influx within the Bay occurs along a north-south axis at right angles to the east-west river inflow. This occurs along the deep eastern side whilst the rivers flow onto a shallow western and southern fringe. Shear forces produced by the tidal currents produce lateral mixing of fresh water eastwards and the water exchange on each tidal cycle is only 5-6% (Newell, 1971).

Moreton Bay supports an annual prawn fishery of approximately 2 million kg. Of this, 33% are juvenile eastern king prawns (*Penaeus plebejus* Hess). The rest are juvenile and adult tiger prawns (*P. esculentus* Haswell) and 'bay' prawns. This last category consists of a mixture of endeavour prawns (*Metapenaeus endeavouri* Schmitt), school prawns (*Metapenaeus macleayi* Haswell), greasyback prawns (*Metapenaeus mastersii* Haswell), hardback prawns (*Trachypenaeus anchoralis* Bate, *Trachypenaeus fulvus* Dall), New Guinea prawns (*Metapenaeopsis novaeguineae* Haswell), cherry prawns (*Atypopenaeus formosus* Dall), and 'clickers' (*Alpheus stephensoni* Banner, *Alpheus distinguendus* de Man).

The importance of the estuarine ecosystem to the juvenile stages of penaeid prawns has been well attested. However, of the species caught commercially from Moreton Bay, only

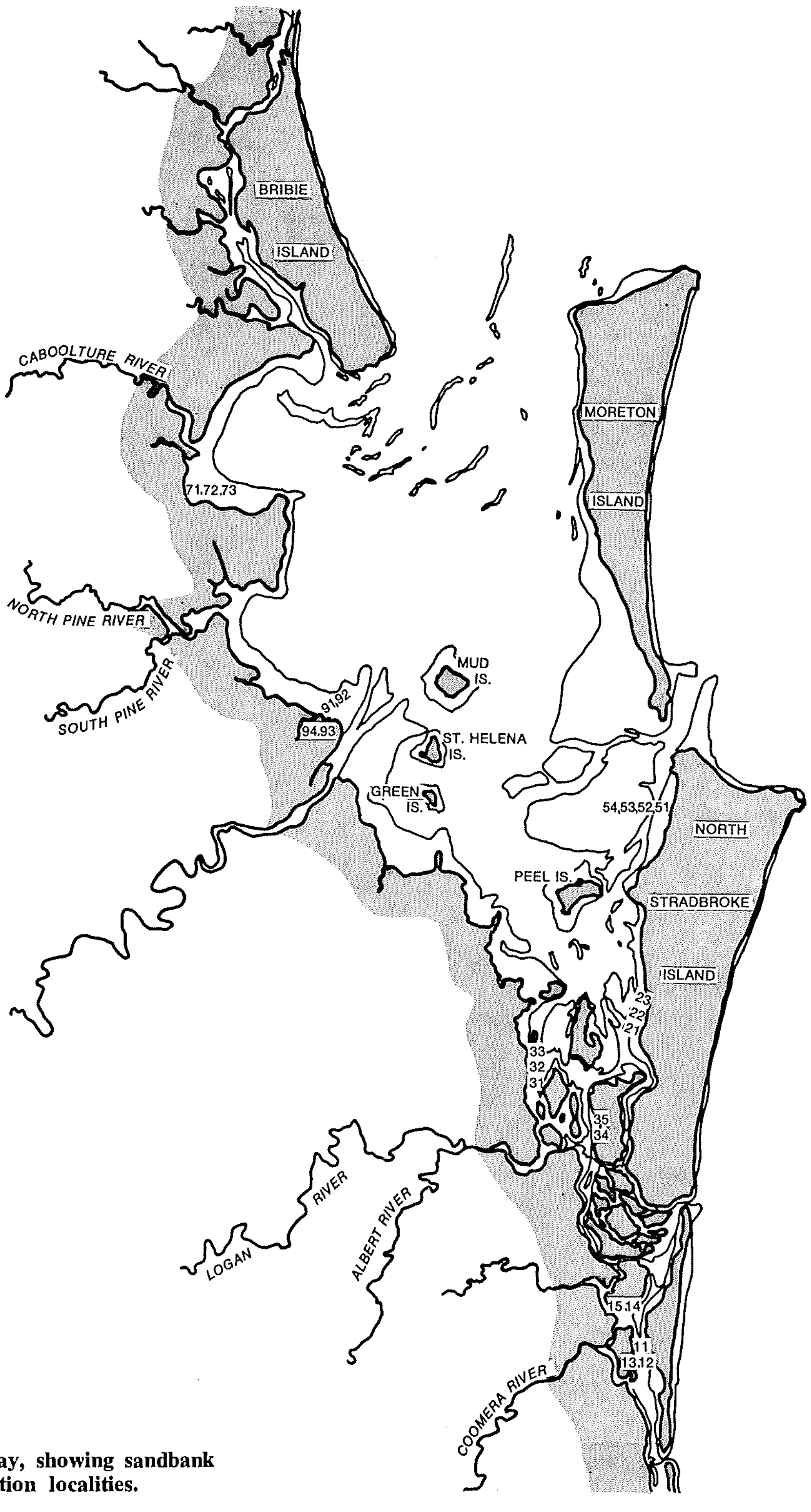


Figure 1. Moreton Bay, showing sandbank development and Station localities.

king prawns and greasyback prawns have been investigated (Dakin, 1938, 1940, 1946a, 1946b; Morris and Bennett, 1952; Dall, 1958). These workers did not emphasise the relationships between the environment and juvenile prawns.

The role of salinity as a limiting factor in estuarine nursery areas has been investigated in the U.S.A. (Gunter, 1950; Hildebrand and Gunter, 1953; Gunter and Hildebrand, 1954; Williams, 1955 (a) and (b); Gunter, Gordon, Christmas and Killebrew, 1964). However, the role of such factors as cover, temperature, turbidity, substrate, has been treated with less thoroughness. Williams (1955a, 1958) and Hughes (1966) discussed the influence of cover and substrate on estuarine distribution and others have considered this subject briefly. Temperature has been treated chiefly with relationship to low temperature tolerance.

Because of its shape, bathymetry, island and sand bank development, Moreton Bay is a suitable site for investigating models of the inter-dependence of the distribution and abundance of juvenile prawns with environmental factors.

In this paper a preliminary account is given of some aspects of the environment and biology of juvenile king prawns in some study areas in Moreton Bay, Queensland.

METHODS

Following a preliminary survey, a comprehensive study of Moreton Bay was undertaken in which all the intertidal areas were visited by shallow draft boats and the composition of their sea grass communities determined by eye. Their extent was further corroborated by aerial observation.

It was originally intended to select comparable habitats from the various parts of Moreton Bay and simultaneously sample these for prawns to determine geographical differences. Due to the differences of substrate and flora with geography, it was not always possible to do so. However, sampling sites were set up in which the predominating floral communities were included from a range of geographic areas and the adjacent littoral and sublittoral substrates, bare of vegetation, were sampled simultaneously. Some areas were conspicuous by the absence of plant life. In these locations, stations were set up over the bare substrate.

Initially, the mangrove communities were not sampled, however, at a later stage some stations were set up to include stands of *Avecinnia marina* (Forst. f). These results are not presented here.

At each sampling site, permanent markers were set up 50 m apart. In littoral areas they consisted of 4.26 m poles, with reflective surfaces, embedded in the ground. In sublittoral areas, the markers consisted of large buoys painted with reflective substances and attached by chain to a large concrete block.

Sampling was done with a roller beam trawl constructed of galvanised piping with skids and rollers, and nets were constructed as shown and attached to the frame (Fig. 2). The frame was towed 15 m behind a small boat to eliminate turbidity due to the propulsion unit of the boat. Its efficiency and stability on the bottom over sand, mud and eelgrass meadows was confirmed by scuba divers. The towing speed of 25-30 m a minute was seen to be the maximum effective towing speed for the net tended to rise off the bottom if pulled faster.

The net was towed between the markers, lifted on boards, and the catch preserved in 100% methyl alcohol. The penaeid prawns were then sorted from the rest of the catch at the laboratory. Here they were identified, counted, and measured into 1 mm carapace length size classes, using a binocular microscope fitted with an ocular micrometer.

Simultaneously, a measure was taken of the depth of the water, the time, the salinity, the temperature of the water, and its turbidity.

To eliminate variability due to lunar influence or tidal period, the stations were sampled on the new and the full moon. Samples were collected from the full tide to two hours after. It was not possible to sample all stations in the one night and samples were taken into the current on the three or four days surroundnig each new or full moon. Two boats were used and the locations were selected so that stations close together were sampled on the same night. The order in which groups of stations were sampled was randomised around the new and the full moon. In Moreton Bay this meant samples were taken once a fortnight at approximately the same time of night each fortnight. The sampling was continued for a period of just over one year.

At each of the sampling sites, the plant communities were not considered to remain constant, so concurrently with the prawn sampling program, the biomass of seagrasses by species was estimated over the study areas. Here a 0.25 square quadrat was thrown. The plants within the quadrat were removed entirely (including roots) and taken to the laboratory. Here the plant material was removed from the soil, sorted into species, dried and weighed. Ten or twenty samples were removed from quadrats thrown at random. Samples were taken according to the diversity of the community.

At the beginning of the program, two samples were taken of the substrate at each site. This was done by driving a corer 3.4 cm in diameter, 36 cm into the substrate. The corer with sediment *in situ* was deep frozen with CO_2 and removed to the laboratory where it was held in a deep-freeze and subsequently processed.

The horizons were separated by eye and an analysis was made of each. The following components were measured—organic carbon, pH, clay, silt, fine sand, coarse sand, carbonate. The methods used for the mechanical analysis were those of Piper (1943), and the organic carbon was calculated by the Walkley and Black method (1934).

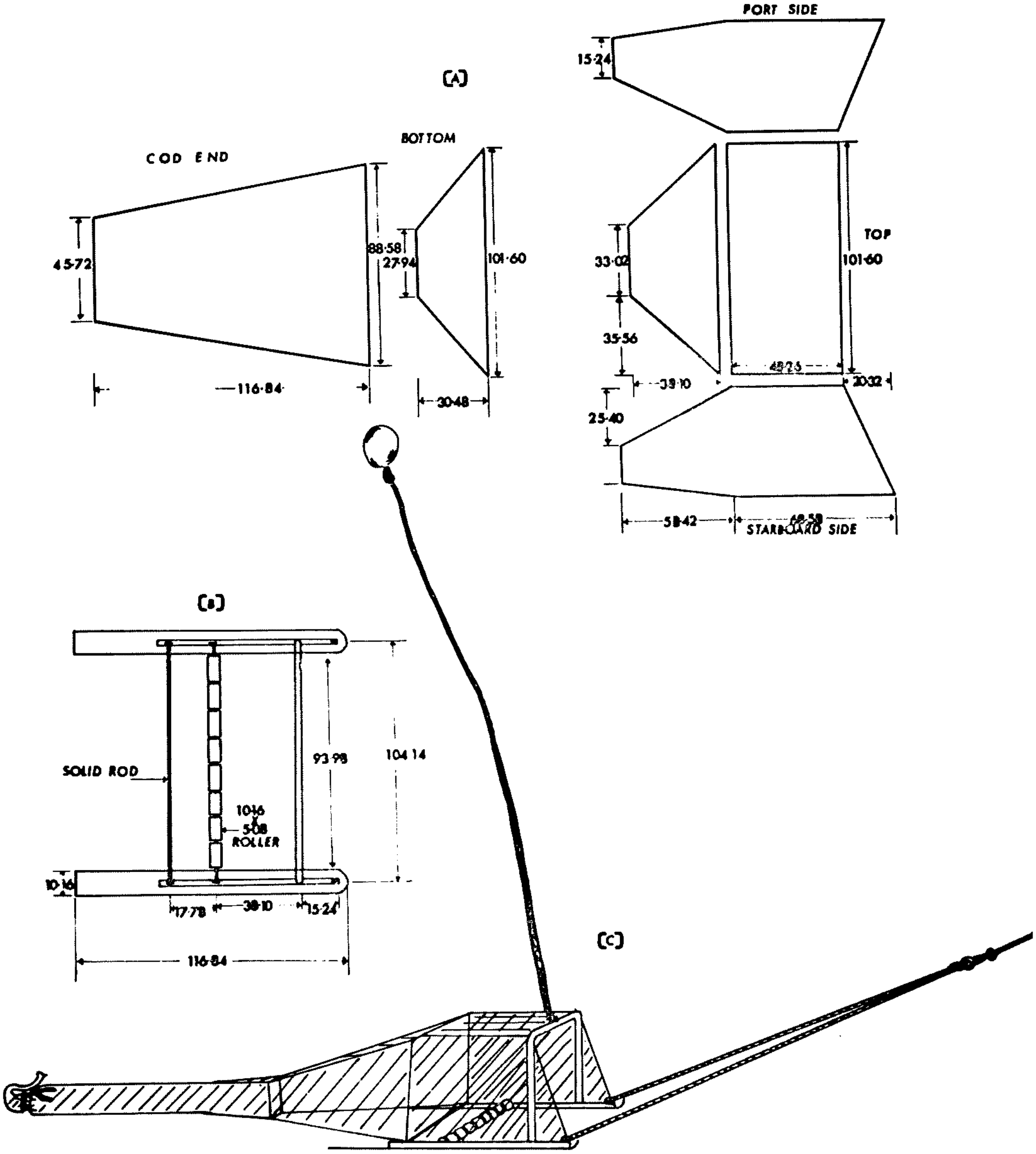


Figure 2. Roller Beam trawl (a) Net pattern, (b) Frame, (c) Rigged Net.

RESULTS

1. Composition of habitat in study areas

The mean sea grass cover of the stations from April to September is given in Table 1 with the percentage by weight of coarse and fine sand in the sediments. The station localities are shown in Fig. 1.

AREA 1: *Southport Broadwater*

This area is a narrow deltaic complex to the south of Moreton Bay bounded on the east by South Stradbroke Island and to the west by the mainland mass, punctuated by the entry of numerous rivers. The area consists of numerous mangrove covered islands and extensive oyster beds and mudflats, often covered with seagrasses.

Station 11: Aldershot Banks. This area is muddy, intertidal and devoid of vegetation.

Station 12: Adjacent to Station 11: 16 cm deeper than Station 11 and covered by patches of *Zostera capricorni* (Aschers) and *Halophila ovalis* (R.Br.).

Station 13: Adjacent to Stations 11 and 12. This area is 95 cm deeper than Station 11, covered by *Halophila spinulosa* (R.Br.) and *H. ovalis*. It is shallow, but not exposed at low tide.

Station 14: Located intertidally between the entrance of the north mouth of the Coomera River and an adjacent unnamed mangrove island. It is devoid of vegetation and adjacent to a stand of *A. marina.*

Station 15: In the centre of the channel between Station 14 and the mainland some 51 cm deeper. This area is exposed only at extreme low tides and is located near the co-tidal line between water coming into the Southport Broadwater from the Jumpinpin Bar and the Southport Bar. Dense patches of *Z. capricorni* occur across this station.

AREA 2: *Pelican Banks*

These banks, mostly covered with sea grasses, are situated between the north end of Macleay Island and the middle of North Stradbroke Island. The Banks appear to have been derived mostly from sand off North Stradbroke Island. The tidal currents reaching here come from the South Passage entry between Moreton Island and North Stradbroke Island.

Station 21: Situated on a patch of bare intertidal sand, fairly small in extent.

Station 22: Adjacent to Station 21 and of the same depth. Its seagrass flora consists entirely of *Z. capricorni.*

Table 1. Mean seagrass cover in gm dry weight for 0.25 sq. m and per cent of coarse and fine sand *April to September 1972*

	Zostera capricorni	*Halophila ovalis*	*Halophila spinulosa*	*Halodule uninervis*	*Syringodium isoetifolium*	*Cymodocea serrulata*	*Soil composition*		Relative depths by area
							Coarse sand	Fine sand	
11	—	—	—	—	—	—	59.6	23.2	0
12	5.16	0.03	—	—	—	—	72.2	10.1	16
13	—	—	0.13	2.06	—	—	81.6	2.7	95
14	—	—	—	—	—	—	47.8	33.3	0
15	15.16	—	—	—	—	—	64.8	30.9	51
21	—	—	—	—	—	—	92.3	6.9	0
22	11.83	—	—	—	—	—	84.1	11.1	0
23	14.23	0.03	—	—	—	—	85.6	6.4	42
31	—	—	—	—	—	—	42.9	31.3	0
32	10.26	—	—	—	—	—	36.5	26.0	30
33	—	—	—	—	—	—	72.2	11.7	100
34	—	—	—	—	—	—	41.2	27.5	0
35	—	—	—	—	—	—	14.9	14.3	236
41	—	—	—	—	—	—	81.9	7.8	0
51	4.06	—	—	0.20	—	—	79.3	18.4	0
52	0.93	2.8	—	1.60	1.46	—	74.3	22.3	85
53	—	—	—	0.20	29.43	—	76.9	18.2	118
54	—	—	—	—	—	21.06	82.2	9.9	199
71	—	—	—	—	—	—	51.0	33.0	0
72	5.76	—	—	—	—	—	86.0	8.8	31
73	—	—	—	—	—	—	64.4	14.2	52
91	—	—	—	—	—	—	60.4	29.6	0
92	—	—	—	—	—	—	73.2	13.8	116
93	—	—	—	—	—	—	1.6	45.9	0
94	—	—	—	—	—	—	53.7	21.9	136

Station 23: Situated a few hundred yards to the north of Station 22 and 42 cm deeper. The sea grasses here also consist mostly of *Z. capricorni* but with a smattering of *H. ovalis*. This is also a littoral area.

AREA 3: *Point Talburpin and Browns Bay*

These two areas are on the west side of the southern part of Moreton Bay and near the deltaic entrance to the Logan River.

Station 31: On a littoral area of bare substrate adjacent to stands of *A. marina*, north of Point Talburpin.

Station 32: Situated adjacent to, and 30 cm deeper than Station 31 in the middle of a dense monospecific stand of *Z. capricorni*. This location is littoral.

Station 33: Adjacent to, but 100 cm deeper than Station 31, over a bare sublittoral substrate.

Station 34: In the littoral zone and on an extensive mudflat on the west side of Russell Island.

Station 35: Situated sublittorally, in a deep channel, between mudflats and adjacent to Station 33. This station is 236 cm deeper than the previous station.

AREA 4: *Peel Island*

This area is on the north shore of Peel Island, south of the tidal delta of South Passage. This island is fringed by live coral and the currents reaching it come from the South Passage.

Station 41: Situated littorally over a substrate of crushed coral and mussels (*Tricomya hirsuta* L.).

AREA 5: *Wanga Wallen Bank*

This Bank is due south of South Passage and adjacent to the northern part of South Stradbroke Island. It runs for about six miles from the north of South Stradbroke Island to a point adjacent to Peel Island and is up to 1 km wide. The substrate is sandy and covered by sea grass communities which occur in distinct zones.

Station 51: On a littoral area adjacent to a coastal strip of *A. marina*. The substrate is sandy and covered with a bed of mixed *Z. capricorni* and *Halodule uninervis* (Forsk). This substrate is worked by burrowing crustaceans giving a lumpy appearance to the ground.

Station 52: Situated littorally adjacent to Station 51 and 85 cm deeper. The sea grasses here are a mixed community of *Z. capricorni*, *H. uninervis*, *H. ovalis*, and *Syringodium isoetifolium* (Aschers) in similar proportions by dry weight.

Station 53: Situated sublittorally, 118 cm deeper than Station 51 and adjacent to it. The predominating sea grass is *S. isoetifolium* with a little *H. uninervis*.

Station 54: In the sublittoral zone, 199 cm deeper than Station 51 and adjacent to it. This is situated on an extensive meadow of *Cymodocea serrulata* (R.Br.).

Stations 51 to 54 were set up in a line from the shore to the outer edge of the Bank, a distance of about 0.8 km.

AREA 7: *Deception Bay*

Deception Bay is the northern-most bay of the series of bays forming the western edge of Moreton Bay. The whole bay is under 5 m in depth and was fringed with mangrove forests and extensive sea grass communities. The currents reach Deception Bay mostly around the south edge of Bribie Island through the Skirmish Banks.

Station 71: Situated littorally and adjacent to a stand of *A. marina*, the substrate is bare sandy mud.

Station 72: Situated adjacent to Station 71, 31 cm deeper and on a bed of *Z. capricorni*.

Station 73: Adjacent to Station 71, littoral, over bare mud and 52 cm deeper than Station 71.

AREA 9: *Bramble Bay*

This is the bay south of Deception Bay. The stations were set up around and in the mouth of the Serpentine Creek. This area is influenced by the Brisbane River to which it is adjacent.

Station 91: Situated littorally over bare sandy mud, adjacent to a stand of *A. marina*.

Station 92: Situated sublittorally, over bare sandy mud and adjacent to Station 91 but 116 cm deeper.

Station 93: Situated littorally in the Serpentine Creek over a bare mud bank.

Station 94: Situated in the middle of Serpentine Creek, sublittoral over bare mud and 136 cm deeper than Station 93.

2. **Prawn Catches**

I. *Preliminary investigation*

Before the catch of the trawl gear could be used as an index of abundance of juvenile prawns, it was necessary to examine factors that might influence its catchability. Those examined were: size of the net meshes, the tidal stage, the time of night or day, and the alignment of the towing direction with the water current.

Although the net would not catch the total population over the area swept, near equal representation of all age/size classes was preferred, otherwise consideration may not be made for the bias present in the samples.

To investigate the effect of mesh size on net selectivity, an experiment was carried out near Station 52, a locality known to give suitable numbers at all size categories of post-larval and juvenile prawns.

Here an area was marked out over a mixed sea grass community of *Z. capricorni*, *H. ovalis*, *H. uninervis* and *S. isoetifolium*.

Two boats and trawl frames were used. One boat towed a trawl frame on which was mounted a net of 2 mm mesh minnow netting, the other boat towed a trawl frame with a net of 2 mm mesh minnow netting in which the codend was replaced by 1 mm mesh mono-filament nylon netting.

Both boats trawled simultaneously into the current between the marker poles. For the first five trawls both nets were covered by a 1 mm mesh terylene cover and for the next five the cover was removed. The results are shown in Table 2.

From this preliminary experiment, it was seen that the presence of a cover on the 2 mm mesh net with a 2 mm codend masked some escapement of prawns from size 1.1-2 mm c.l. (carapace length) (Table 2). After allowance for masking it was calculated that almost 100% of prawns size 1.1-2 mm c.l. escaped and 66% of prawns size 2.1-3 mm c.l. escaped through the meshes of this net. This was reduced to 50% and 15%, respectively, in the net in which the codend was replaced by 1 mm mesh netting. Prawns greater than 4 mm did not escape from either net.

To investigate the effect of tide stage, time of day or night and alignment of towing direction upon the catch, an experiment was designed in which four trawls were made at Station 13 every two hours, each in an

Table 2.

	Size of prawns									
Trawl no.	1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10	> 10
Contents of 1 mm net with cover										
S 1	19	51	11	8	6	5	1	1	0	1
S 2	29	102	11	13	14	6	0	3	6	1
S 3	22	104	8	16	19	4	6	0	4	3 (a)
S 4	23	163	22	31	16	7	2	2	0	4
S 5	16	130	6	9	9	4	1	1	0	2
Contents of cover of 1 mm net with cover										
S 1	31	13	0	0	0	0	0	0	0	0
S 2	15	5	0	0	0	0	0	0	0	0
S 3	35	37	0	0	0	0	0	0	0	0 (b)
S 4	18	24	0	0	0	0	0	0	0	0
S 5	8	14	1	0	0	0	0	0	0	0
Contents of 1 mm net without cover										
S 6	7	64	7	17	6	2	0	0	2	4
S 7	36	106	4	1	4	0	0	1	0	3
S 8	40	88	9	8	8	2	0	0	1	5 (c)
S 9	53	142	22	18	23	6	1	2	0	3
S10	19	114	13	16	18	6	1	4	3	2

't' TESTS (a) versus (c)

	Size of prawns								
	1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10
't'	0.22	0.64	0.09	0.41	0.47	0.95	0.94	0	0.36

(No masking)

Per cent escapement $\left[\frac{(b)}{(a) + (b)} \times 100\right]$

50	15	0	0	0	0	0	0	0

Table 2. ***(continued)***

Trawl no.	Size of prawns 1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10	> 10
	Contents of 2 mm net with cover									
J 1	16	70	16	14	20	6	1	3	0	3
J 2	12	53	14	18	9	5	2	1	1	0
J 3	8	59	14	6	6	2	1	0	0	2 (a)
J 4	1	11	3	3	3	2	1	0	0	1
J 5	7	53	13	13	13	6	0	1	0	1
	Contents of cover of 2 mm net with cover									
J 1	18	22	0	0	0	0	0	0	0	0
J 2	25	62	0	0	0	0	0	0	0	0
J 3	114	151	0	0	0	0	0	0	0	0 (b)
J 4	228	165	0	0	0	0	0	0	0	0
J 5	70	83	0	0	0	0	0	0	0	0
	Contents of 2 mm net without cover									
J 6	1	40	8	15	8	5	2	3	0	1
J 7	0	45	16	16	12	8	0	2	1	2
J 8	0	13	7	3	9	3	2	0	0	3 (c)
J 9	0	24	6	2	6	4	1	0	1	4
J10	0	23	6	4	6	1	1	0	0	2

'*t*' TESTS (a) versus (c)

	Size of prawns 1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10
'*t*'	2.16*	0.40	0.72	0.43	0.40	0	0.26	0	0.80

(Masking on 1.1-2 at 0.05 level of significance)

$$\left[\frac{((a) + (b)) - c}{(a) + (b)} \times 100\right]$$

Per cent escapement for sizes 1.1-2

$$\left[\frac{(b)}{(a) + (b)} \times 100\right]$$

for other sizes

	1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10
	100	66	0	0	0	0	0	0	0

alternate direction from its predecessor. The net consisted of a 2 mm mesh woven minnow netting with a codend of 1 mm mesh monofilament nylon. The water depth, salinity and temperature were measured at the end of each set of four trawls and the experiment was terminated after 96 hours.

The prawns caught during the study were 79.2% king prawns. Graphs are presented in Fig. 3 of the number of this species obtained in replicate samples into and against the current. The lines are drawn to fit sample means against the time of day at which the samples were taken.

The graphs show that (i) as many prawns of 1.1-2 mm c.l. were caught during the day as at night, (ii) more of 3.0-3.9 mm were caught at night, and (iii) almost all bigger than this were caught at night (Fig. 3).

More king prawns of 1.1-2 mm and 2.1-3 mm c.l. were caught towing into the current than with it. This was not so for prawns of 3.1-4 mm c.l. In Table 3 the number of times that more prawns were caught towing into the current are given for king prawns. A sign test demonstrates that in a significant number of trawls more prawns equal to or smaller than 3 mm c.l. were caught towing into the current, but there was not a significant difference with prawns greater than 3 mm c.l.

II. *General survey*

In this survey a 2 mm mesh net with a 1 mm mesh codend was used. Because of the escapement and catch differences mentioned above, prawns below 3 mm c.l. are not considered in this analysis.

The relative abundance of king prawns of size 3.1-4 mm c.l. from Area 7 (Deception Bay, Stations 71, 72, 73) and Area 1 (Southport Broadwater, Stations 11, 12, 13, 14, 15) showed three recruitment peaks during the year (Fig. 4) around February, June and October/November. However, the relative number of prawns present during each of these periods of recruitment was different between the two areas. Thus most prawns arrived in June in Deception Bay, while more arrived in October/November in the Southport Broadwater.

The mean number of prawns of this size caught between April and October 1971 are shown for the other stations sampled in Fig. 5. These confirm the general pattern of recruitment seen in Areas 1 and 7. All the sublittoral stations, with the exception of Station 13, showed insignificant recruitment of 3.1-4 mm c.l. prawns over this period (i.e. Stations 31, 53, 54, 92, 94). Station 93, littoral and situated in a creek, also showed insignificant recruitment. The presence of dense masses of sea grass at Stations 53 and 54 indicate that this alone is not sufficient to allow a recruitment of small prawns.

To compare habitats, the recruitment period over June is taken here as a 'typical' recruitment of a population of prawns and the size of this population can be compared with time at each of the stations.

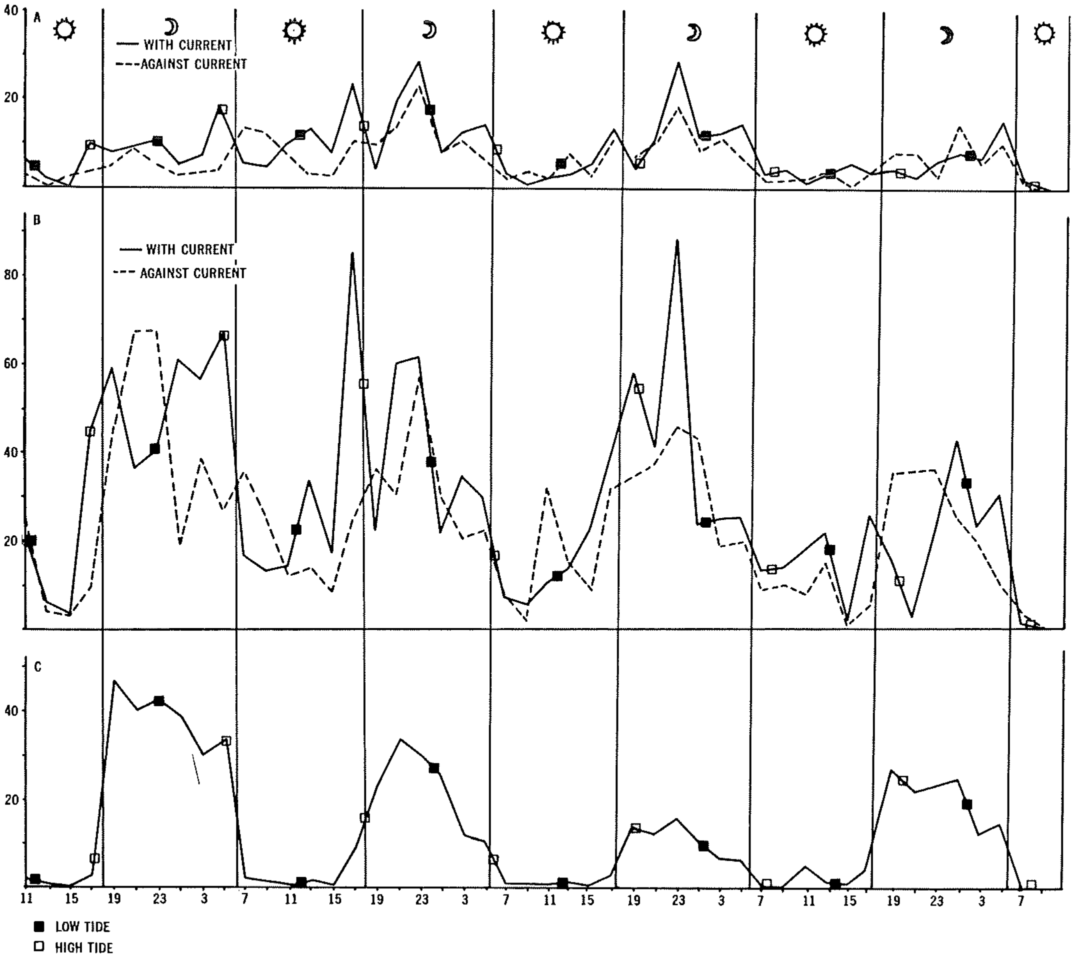


Figure 3. Mean number of king prawns caught at two-hourly intervals over 96 hours. (a) Prawns 1.1-2 mm c.l. towing into and with the current. (b) Prawns 2.1-3 mm c.l. towing into and with the current. (c) Pooled samples over 3 mm c.l.

Table 3. Catches of penaeid prawns at station 1 during 96 hours successive trawling

Size range of prawns	*Number of times that more were caught towing into the current*	*Number of times that the same numbers were caught*	*Number of times that more were caught towing with the current*
	P. Plebejus		
1.1 - 2	52	9	35 *
2.1 - 3	54	5	37 *
3.1 - 4	38	27	31 N.S.
< 3	59	4	33 ***
> 3	37	24	35 N.S.

* = significant at 0.05 probability by sign test.
*** = significant at .005 probability by sign test.
Zeroes eliminated from scores.

Total number of prawns caught

P. plebejus

Below 3 mm carapace length		3 mm carapace length or above	
With current	Into current	With current	Into current
2 858	3 595	1 134	1 223

Somers (1973) has shown that the growth curve of king prawns of this size is variable according to temperature, however a general equation of the form

$$L_t = 2.467\ e^{\cdot 0914t}$$

where t is in weeks does describe the average growth rate of prawns of this size at this time of year in these habitats.

Table 4. Growth rate of Juvenile *P. Plebejus*

Weeks from entry to nursery areas (assumed size at entry 2.467 mm c.l.)	*Size (mm carapace length)*
2	3.0
4	3.6
6	4.3
8	5.1
10	6.2
12	7.4
14	8.9
16	10.6

From this growth curve, it may be seen (Table 4) that the population of prawns of size 3.1-4.0 mm arriving on the nursery areas in the third week of April will be a population of size 4.1-5.0 mm by the first week of May. This may be extrapolated to succeeding weeks for prawns up to size 7.0 mm while prawns of size 8.1-9 mm will be of size 10.1-11 mm by the following fortnight.

To obtain an estimate of the reduction in numbers from a known recruitment onto the nursery areas indices were calculated for the same population from sizes 3.1-4, 4.1-5, 5.1-6, 6.1-7 and 7.1-8 by making allowances for the movement, with time of the size of the population over the weeks of April until October 1972.

The indices were calculated by finding the least squares quadratic of the form

$$Y = N_0 + N_1x + N_2x^2$$

for the various sizes at each station over the period of time that the recruitment peak was distinguishable in each size class. From this curve the time of commencement and finish of the recruitment period was extrapolated and the area under the curve found by integration to obtain an index of abundance.

The logarithms of these indices are plotted versus time on Fig. 6 for stations in which significant recruitment of prawns of size 3.1-4.0 mm occurred. (Stations 11, 12, 13, 14, 15, 21, 22, 23, 31, 32, 33, 34, 41, 51, 52, 71, 72, 73, 91).

DISCUSSION

Maxwell (1970) divided the sedimentary framework of Moreton Bay into three facies: A clean sand in which less than 1% mud is present, best developed in the eastern and extreme northern and southern parts of the Bay where it forms a fairly narrow fringe 0.8 to 3.2 km wide along the edge of the Barrier Islands, expanding considerably at the South Passage tidal delta to more than 13 km where it extends almost to the western shore near Cleveland. It also crosses the north of the Bay as the northern ridge system.

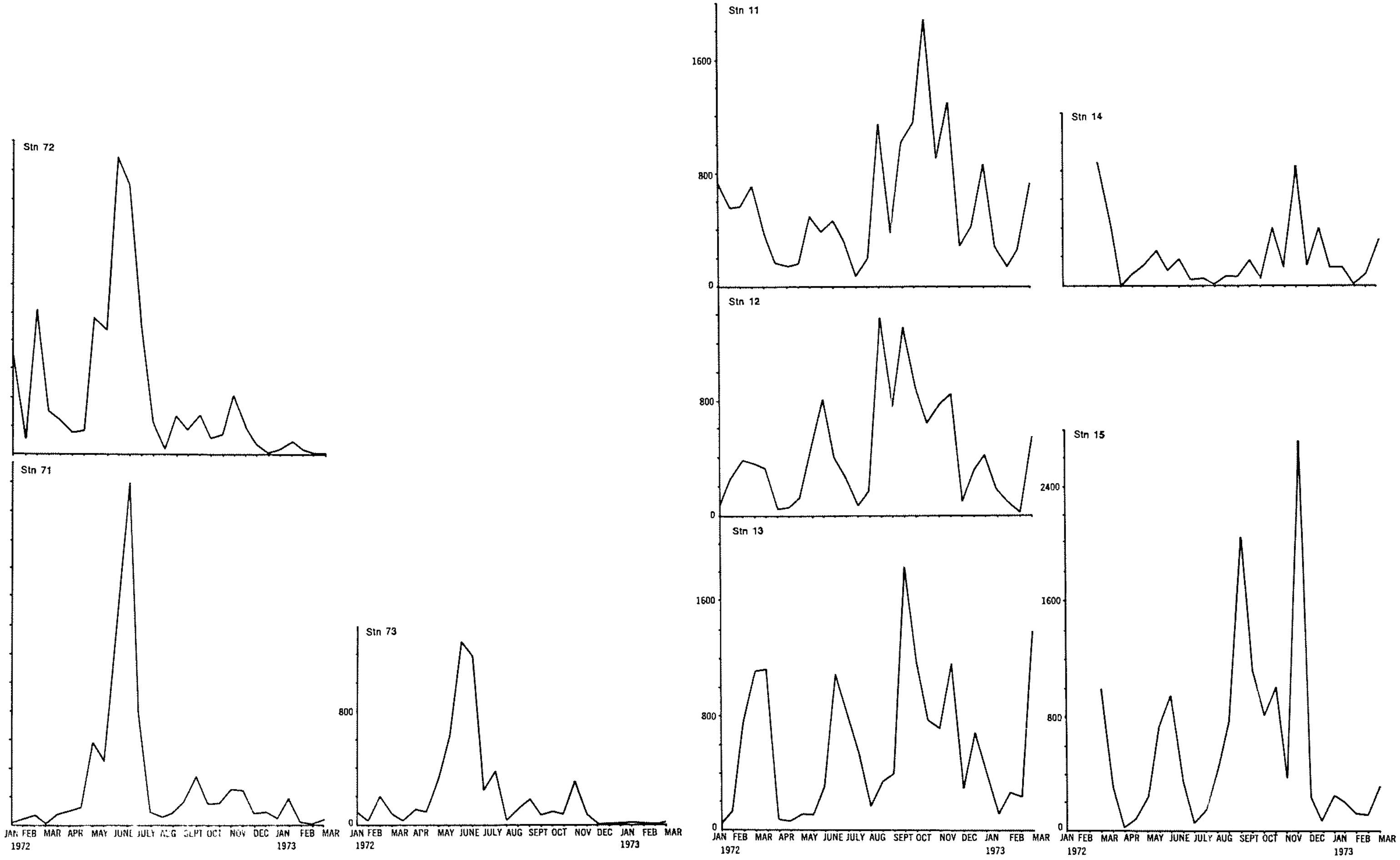


Figure 4. Number of king prawns of size 3.1-4 mm c.l. caught per 500 sq m from January 1972 to March 1973 from Areas 1 to 7.

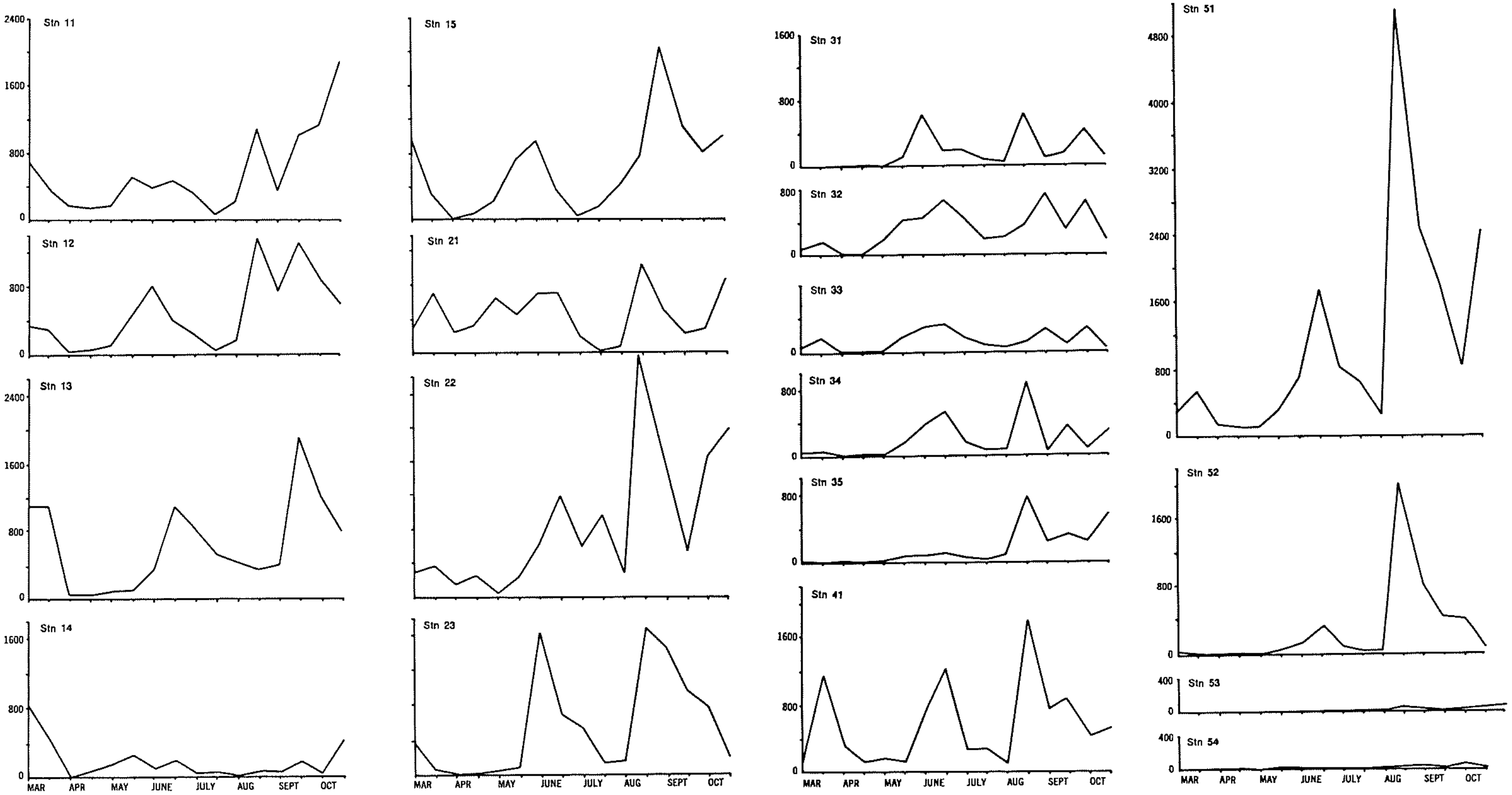


Figure 5. Number of king prawns caught of size 3.1-4 mm c.l. per 500 sq m from March 1972 to October 1972. ***(continued on page 30)***

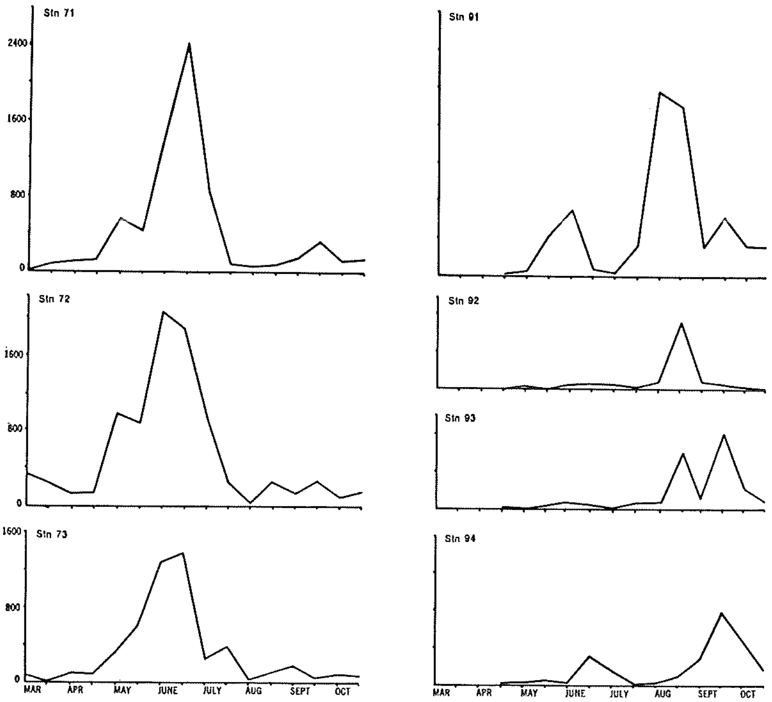


Figure 5 ***(continued)***

The second facies is muddy sand, between 1 to 50% mud, occupying the western part of the Bay except where the South Passage tidal delta has encroached. The third facies is mud and sandy mud, containing more than 50% mud and occurs in the deep northern section beyond the 9 m line and in the protected channels near the south-western shore and in the lower regions of all the inflowing streams.

At present the main source of these sediments is the Barrier Islands where ancient dune deposits feed the eastern part of the Bay with sand. The main contribution from the western land mass is mud, restricted largely to the western and southern parts of the Bay. Relict coral reefs and coral communities contribute to a restricted carbonate facies in an L-shaped bank from Mud Island south to Coochiemudlo Island then east to Peel Island and Macleay Island.

Previous authors have described postlarvae and juveniles of penaeid prawns as inhabiting the saltcord grass, *Spartina alternifolia* (Allen and Inglis, 1958), shell and mud flat (Caillouet, Dugas and Fontenot, 1968), sand flats (Hughes, 1966), and turtle grass, *Thallasia testudinum* (Strawn, 1954).

The intertidal vegetation of Moreton Bay consists mostly of mangroves and sea grass beds. The mangrove forests predominate around the deltaic complexes of the Southport Broadwater and the mouths of the Logan, Albert, Coomera and Pimpama Rivers in the south. They also fringe the western side of Moreton Bay where they form extensive forests around the mouths of Tingalpa Creek, the Brisbane River, Serpentine Creek, the Pine Rivers, Hay's Inlet, Burpengary Creek and the Caboolture River. They are also found in a fringe alongside North Stradbroke Island but not adjacent to Moreton Island.

The predominating tree is *A. marina* which may occur in monospecific stands or in a mixed forest with the shrubs *Aegiceras corniculatum* (L.), *Ceriops tagal* (Perr.) and *Rhizophora stylosa* (Griff). These species sometimes occur in distinct zones but also are found in mixed communities.

Sea grasses are distributed throughout Moreton Bay. Tidal currents and wave exposure are limiting in all areas, and light penetration through turbid water limits sea grass growth in the muddy western and southern areas.

Z. capricorni is the most widely dispersed sea grass and also the most abundant. It may grow as a monospecific meadow on mud flats or with other species in the littoral or sublittoral areas. *S. isoetifolium* and *C. Serrulata*

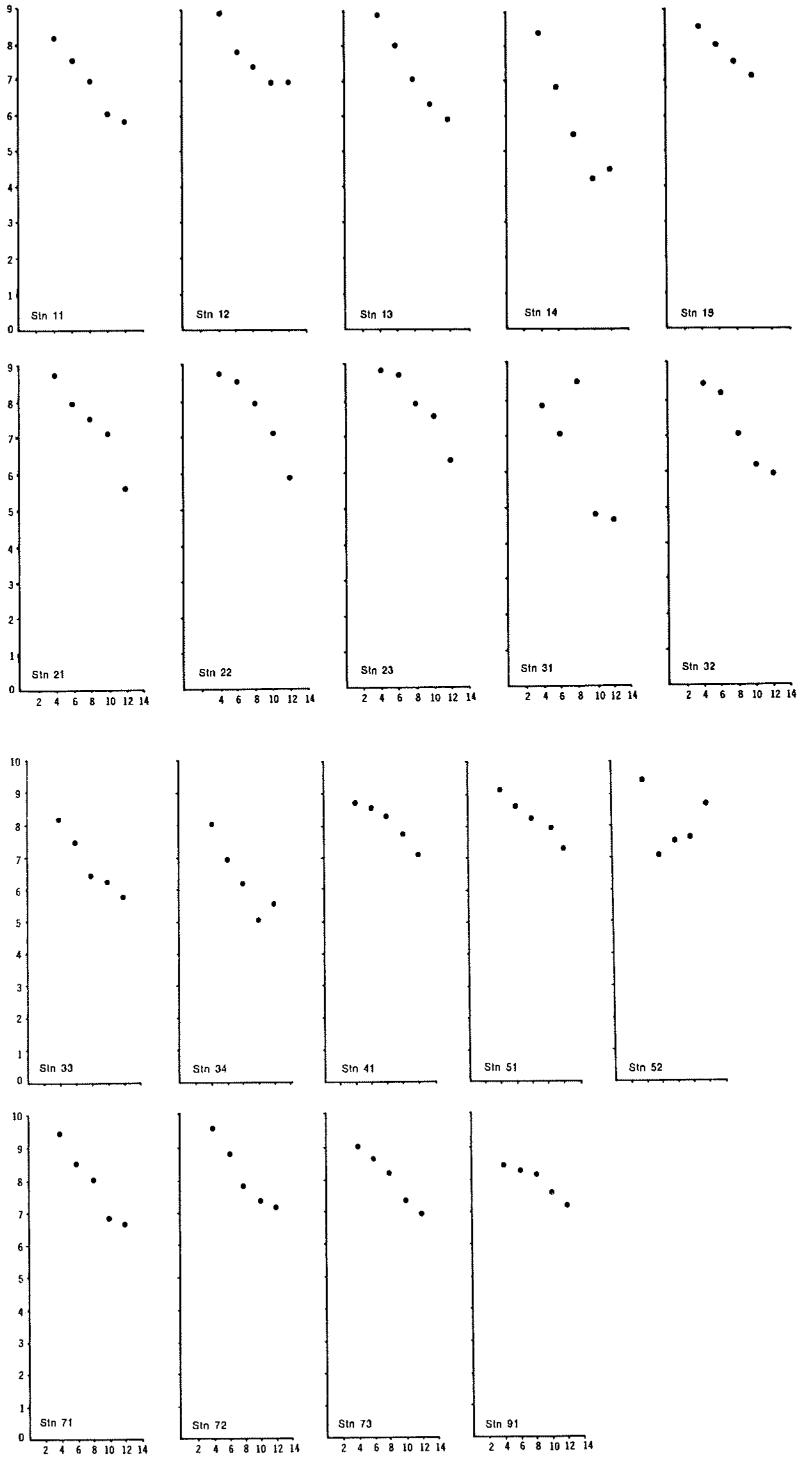


Figure 6. The natural log of the index of abundance for juvenile prawns from areas of significant recruitment versus the time in weeks that the population remains on the nursery area.

grow only in sublittoral areas where light is available. These grow in mainly monospecific meadows but *S. isoetifolium* may be associated with *Z. capricorni*, *H. uninervis*, and *H. ovalis*. These last three species also grow in littoral areas, the dominant species normally being *Z. capricorni*. Algae are found together with the sea grasses. *Udotea argentea* Zanard and *Caulerpa* spp. are the most constant species but are only present in small quantities. Other species show marked seasonal changes in abundance. Thus epiphytic blooms of *Hydroclathus clathratus*, *Polysiphonia* sp. and *Ectocarpus* sp. occur in winter.

Hughes (1966) noted differences in 'preferred' habitat in five species of penaeid prawn. Hoese (1960) also noted differences in abundance, unrelated to salinity but related to presence or absence of sea grasses (*Thalassia testudinum*). Both these studies were made without allowance for seasonal diversity.

Because of the geographic differences in abundance in this study it is not possible, with the data presented here, to pool recruitment to the various habitats throughout Moreton Bay in an analysis of the role of habitat. They may be eliminated however by comparing recruitment in those littoral areas in which two adjacent stations are present, one over sea grass and the other over a bare substrate, and both of approximately the same depth. The indices of abundance calculated in this study for prawns of size 3.1-4 mm c.l. are shown for paired samples from areas 1, 2, 3 and 7 in Table 5, and a 't' test confirmed that more prawns were recruited to the littoral sea grass beds.

Table 5. Indices of abundance for prawns of size 3.1-4 mm c.l. from paired stations

Sea grass	*Meadow*	*Bare*	*substrate*
Station	*Index of abundance*	*Station*	*Index of abundance*
12	7 746	11	3 539
22	6 674	21	6 367
32	4 829	31	2 578
72	14 869	71	12 629

't' = 2.827*

From the results it may be seen (Fig. 6) that in areas with substantial recruitment the rate of decrease in numbers of prawns is approximately exponential, i.e.

$$N_t = N_0 \, e^{-t(m+x)}$$

m = a coefficient of mortality

x = a coefficient of emigration.

If prawns emigrate from shallow to deeper water at a constant rate with time then the x part of $(m + x)$ will decrease in deeper water due to the increased number of prawns passing deeper stations during their emigration, giving a lower value for $(m + x)$. This was seen to occur in the present observations, where deeper stations in an area had lower values than shallower stations (Table 6).

Table 6. Depth and mortality plus emigration rate in adjacent stations

Station number	*$(m + x)$*	*Relative depth*
11	.309	0
12	.236	16
13	.372	95
14	.516	0
15	.233	51
21	.354	0
22	.362	0
23	.306	42
31	.537	0
32	.352	30
33	.300	100
71	.361	0
72	.316	31
73	.271	52

The data from Stations 51, 52, 53 confirmed this conclusion. These are in line across the Wanga Wallen Bank and each station is proportionally deeper than the next. From a (t x l) matrix of size classes on these three stations it may be seen (Table 7) that more prawns of smaller size categories are in the shallower stations, and that prawns of larger sizes predominate in the deepest station (53).

Previous authors (e.g. Copeland, 1964; Roessler and Rehrer, 1971) have shown that in related penaeid species seasonal periodicity occurs in postlarval recruitment. Baxter and Renfro (1966) found seasonal peaks in spring and late summer for *Penaeus aztecus* and *P. setiferus*, but Christmas, Gunter and Musgrave (1966) gave no indication of a bimodal seasonal occurrence.

The results given here show a trimodal seasonal abundances with peaks in distribution in February, June, and October/November. Deception Bay is the only area in which the June rise is the only one of significance, all other areas show the greatest rise in recruitment in October/November.

Potter (1973) has shown that prawns from the northern part of Moreton Bay move northwards to form a separate fishery from those in the south and East of Moreton Bay, and that the latter move east and northwards

Table 7. Prawns caught per 500 m

	Size category										
	0.1	1.1-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10	> 10
						Station 51					
Apr.	0	0	6	11	12	7	2	1	1	0	1
May	0	0	25	11	4	4	0	0	1	2	9
May	0	8	80	29	5	2	2	2	2	1	1
June	0	9	188	71	28	15	3	3	0	3	8
June	0	0	57	175	34	17	12	5	1	1	6
July	0	1	29	80	65	22	13	10	8	1	6
July	0	16	110	64	92	47	15	14	8	3	2
Aug.	0	26	238	27	18	35	30	14	9	8	16
Aug.	0	32	349	496	130	23	23	27	23	9	7
Sep.	0	95	264	244	209	89	18	4	3	8	9
Sep.	0	12	362	180	141	78	46	26	8	1	4
Oct.	0	34	109	85	88	21	11	5	3	0	0
Tot.	0	680	5 512	4 633	2 585	1 210	594	371	238	145	243
						Station 52					
Apr.	0	0	0	0	0	0	0	0	0	2	2
May	0	0	3	0	0	0	0	0	0	0	3
May	0	5	31	5	1	0	0	0	0	0	1
June	0	3	17	15	5	1	3	0	0	0	4
June	0	0	20	36	19	14	6	5	2	3	5
July	0	0	6	9	23	43	28	23	13	11	17
July	0	29	34	4	5	20	12	17	9	7	14
Aug.	0	6	110	4	5	9	26	30	21	12	23
Aug.	0	35	156	202	20	20	15	26	22	11	18
Sep.	0	11	103	80	300	378	118	35	18	20	30
Sep.	0	1	24	44	42	127	120	32	6	3	11
Oct.	0	12	58	41	154	262	175	70	20	7	2
Tot.	0	308	1 585	1 303	1 717	2 615	1 502	693	325	229	381
						Station 53					
Apr.	0	0	0	0	0	0	0	0	0	0	3
May	0	0	0	0	0	0	0	0	0	0	2
May	0	0	1	0	0	0	0	0	0	0	1
June	0	0	1	0	0	0	0	0	0	0	2
June	0	0	0	0	0	0	0	0	0	0	4
July	0	0	2	0	0	1	0	1	0	0	6
July	0	0	1	0	0	0	0	0	0	0	2
Aug.	0	0	15	1	0	0	0	3	2	0	7
Aug.	0	1	5	7	2	2	2	7	8	5	16
Sep.	0	1	9	2	6	14	6	4	6	5	39
Sep.	0	1	0	0	2	8	15	10	7	4	23
Oct.	0	4	30	4	10	25	29	38	44	21	15
Tot.	0	26	183	44	70	155	168	195	215	112	376

to mix with the stocks that are moving northwards from New South Wales. It may be hypothesised here that the February and October/November recruitments are from a different source than the June recruitment due to the very great differences shown between the numbers in Deception Bay and the Southport Broadwater.

This preliminary analysis is incomplete. It is anticipated that observations for all areas will be examined over a period of one year and that the possible effect of environmental parameters will be considered.

The results to hand do show, however:

(a) Recruitment of small prawns occurs mostly in the littoral areas.

(b) More recruitment occurs on sea grasses than on bare substrates.

(c) Recruitment varies throughout the year with three peaks in abundance.

(d) Emigration starts as soon as prawns settle in the littoral zone and they move from shallow to deeper water.

LITERATURE CITED

ALLEN, D. M. AND INGLIS, A. (1958). ' A push net for quantitative sampling of shrimp in shallow estuaries. *Limnol. Oceanogr.*, 3(2), pp. 239-41.

BAXTER, K. N. AND RENFRO, *W. C.* (1966). 'Seasonal occurrence and size distribution of post-larval brown and white shrimp near Galveston, Texas, with notes on species identification.' *Fishery Bull.*, Fish Wildl. Serv., U.S., 66(1), pp. 149-58.

CAILLOUET, C. W. JUN., DUGAS, R. J. AND FONTENOT, B. J. JUN. (1968). 'Effects of radius and direction of semi-circular tow near the shoreline on catch of postlarval shrimp (*Penaeus* spp.) with the Renfro beam trawl.' *Trans. Am. Fish. Soc.*, 97(2), pp. 127-30.

CHRISTMAS, J. Y., GUNTER, G. AND MUSGRAVE, P. (1966). 'Studies of annual abundance of postlarval penaeid shrimp in the estuarine waters of Mississippi, as related to subsequent commercial catches.' *Gulf Research Report*, 2, pp. 177-212.

COPELAND, B. J. (1963). 'Seasonal distribution of adult and larval shrimp in Aransas Pass (Texas) Inlet.' *Circ.*, Fish Wildl. Serv., U.S., 183, pp. 92-3.

DAKIN, W. J. (1938). 'The habits and life history of a penaeid prawn (*Penaeus plebejus* Hess).' *Proc. Zool. Soc. Lond.*, Ser. A., 108, pp. 163-83.

DAKIN, W. J. (1940). 'Further notes on the life history of the king prawn (*Penaeus plebejus* Hess).' *Rec. Aust. Mus.*, 20(5), pp. 354-9.

DAKIN, W. J. (1946). 'Life history of a species of *Metapenaeus* in Australian coastal lakes.' *Nature*, 158 (4003), p. 99.

DAKIN, W. J. (1946). 'A further step in the elucidation of the strange story of the penaeid prawns.' *Aust. J. Sci.*, 8(6), pp. 160-1.

DALL, W. (1958). 'Observations on the biology of the greentail prawn, *Metapenaeus mastersii* (Haswell) (Crustacea Decapoda: Penaeidae).' *Aust. J. mar. Freshwat. Res.*, 9(1), pp. 111-34.

GUNTER, G. (1950). 'Seasonal population changes and distributions as related to salinity of certain invertebrates of the Texas coast, including the commercial shrimp.' *Publ. Inst. mar. Sci.*, Univ. Tex. 1(2), pp. 7-51.

GUNTER, G., CHRISTMAS, J. Y. AND KILLEBREW, R. (1964). 'Some relations of salinity to population distributions of mobile estuarine organisms, with special reference to penaeid shrimp.' *Ecology*, 45, pp. 181-5.

GUNTER, G. AND HILDEBRAND, H. H. (1954). 'The relation of total rainfall of the state and catch of the marine shrimp *Penaeus setiferus* in Texas waters.' *Bull. Mar. Sci., Gulf Caribb.*, 4(2), pp. 95-103.

HILDEBRAND, H. H. AND GUNTER, G. (1953). 'Correlation of rainfall with the Texas catch of white shrimp, *Penaeus setiferus* (Linnaeus).' *Trans. Am. Fish. Soc.*, 82, pp. 151-5.

HOESE, H. D. (1960). 'Juvenile penaeid shrimp in the shallow Gulf of Mexico.' *Ecology*, 41(3), pp. 592-3.

HUGHES, D. A. (1966). 'Investigations of the "nursery areas" and habitat preferences of juvenile penaeid prawns in Mozambique.' *J. appl. Ecol.*, 3, pp. 349-54.

MAXWELL, W. G. H. (1970). 'Sedimentary framework of Moreton Bay, Queensland.' *Aust. J. mar. Freshwat. Res.*, 21, pp. 71-89.

MORRIS, M. C. AND BENNETT, I. (1951). 'The life-history of a penaeid prawn (*Metapenaeus*) breeding in a coastal lake (Tuggerah, N.S.W.).' *Proc. Linn. Soc. N.S.W.*, 76(5/6), pp. 164-82.

NEWELL, B. S. (1971). 'The hydrological environment of Moreton Bay, Queensland, 1967-68.' *CSIRO Aust.* Div. Fish. Oceanog., *Tech. Pap.* 30.

PIPER, C. F. (1942). *A pipette method for mechanical analysis.* Univ. Adelaide Press.

POTTER, M. A. (1974). Movements of the eastern king prawn (*P. plebejus*) in Southern Queensland waters. National Prawn Seminar, Maroochydore, 1973.

ROESSLER, M. A. AND REHRER, R. G. (1971). 'Relation of catches of postlarval pink shrimp in Everglades National Park, Florida, to the commercial catches on the Tortugas Grounds.' *Bull. Mar. Sci.*, 21(4), pp. 791-805.

SOMERS, I. (1974). Growth of eastern king prawns (*Penaeus plebejus*). National Prawn Seminar, Maroochydore, 1973.

STRAWN, K. (1954). 'The pushnet, a one-man net for collecting in attached vegetation.' *Copeia*, 3, pp. 195-197.

WALKLEY, A. AND BLACK, T, A. (1934). 'An examination of the Dejtjareff method for determining soil organic matter.' *Soil Sci. J.*, 37, pp. 28-38.

WILLIAMS, A. B. (1955a). 'A contribution to the life histories of commercial shrimps (Penaeidae) in North Carolina.' *Bull. Mar. Sci., Gulf Caribb.*, 5, pp. 116-46.

WILLIAMS, A. B. (1955b). 'A survey of North Carolina shrimp nursery grounds.' *J. Elisha Mitchell Scient. Soc.*, 71, pp. 200-7.

WILLIAMS, A. B. (1958). 'Substrates as a factor in shrimp distribution.' *Limnol. Oceanogr.*, 3(3), pp. 283-90.

DISCUSSION

Dredge. Do you find any correlation in the abundance of prawns in shallow water areas of Moreton Bay such as a certain size category in different areas?

Young. The catches that we get do vary, but there does not seem to be a geographical difference in the size range. In other words, they always seem to come in at a size category of 2 to 3, mostly 3s, and all the histograms that you get of numbers by size category tend to have many more prawns of smaller sizes in the intertidal areas. Once you get into the deeper areas all sorts of weird things go on due to the migration by juveniles into deeper areas.

Lucas. There is one thing that worries me a little bit about the paper and this concerns the growth rate. While we will probably be talking about growth rates tomorrow, it is relevant here in that it seems to me that the time of the year when you are catching most of these small prawns 2 to 4 mm carapace length is places other than Deception Bay. You mention October/November or possibly as early as September. Using this growth rate and doing a quick calculation, gets them from 2 mm carapace length to 20 mm carapace length, which is the size eventually of the fishery in approximately five months. Five months from September takes you through to February, but by February the season is virtually finished.

Young. This is something that Ian Somers is going to deal with. The growth rate that I give here is based from data collected on prawns at the time that this work was done, and is for that particular temperature of that time of year for that kind of prawn. It looks like the growth rate is variable with temperature but I think it would be better to wait until he talks growth and this growth is only for prawns between the sizes of 2 to 10. It doesn't extrapolate further than that.

Lucas. The point that I was getting to in relevance in this section is that do you feel then that this possibly might cause some doubt in the process of identifying a particular age class, for example a fortnight age class?

Young. I don't think you can identify a fortnight age class. The way that I identified mine was arbitrary. You tend to find that numbers of the smallest size class come in at one time if you were very lucky. In fact quite a lot of the time this did happen. If you then plotted out the next size class up you got class separation, and then the next and so on. What I did was to take the curve over the observed time period and describe it for each size class. I extrapolated the two ends and integrated to get a size class. It's a bit risky but if you can think of a better way to separate them out I would be very pleased to hear about it. What we did have was a fairly discrete recruitment pattern with not much before and not much after. Once you get to the bigger sized prawns, 7, 8 and 9s for instance, the picture is not so clear.

Barber. In fresh water there is an interaction between type of substrate and the type of collecting of the gear. Do you have any data which might say your gear collects equally in all habitats?

Young. It is very difficult to answer this one unless you can use tagging data. One of the things that might lead one to think that you might catch more prawns in *Zostera* is because you pick up a lot of the *Zostera* in a conventional net. Our particular net does not tend to pick up weed. It rolls over the top of it so all we are catching are the prawns that are in the water column or just above the bottom. I would imagine that the tendency would be not to catch as many here because they could well get caught down with the weed and not come up. This is a real problem I agree but the sort of differences we are talking about are of occasionally as much as ten-fold. Certainly two or three times as many. All our samples were collected in triplicate, and we get a pretty good correlation among our trio of triplicates. So there may be a bias according to the substrate but I think the bias would only be with sea grass or non-sea grass. We do get differences between different depths of sea grass beds, and although I haven't got any data to prove it, I do feel that the effect of substrate upon the catch is probably a fairly minor cause of variability.

Thomson. You seem to have no young king prawns in the mangroves themselves or in the creek adjacent. Do you think in fact there is any correlation between the mangroves and these prawns even indirectly through mangrove productivity or could you equally have a population on similar muddy creeks with a similar hinterland but without the mangroves.

Young. The area near South Passage is sand and has got *Z. capricorni* over it. We have not done sations there, but we have stations on very similar areas and we have had up to about 600 to 700 small prawns for 50 sq m which is a pretty large population. There is very little mangrove here and there is none at all out on the South Passage banks. For king prawns I don't think that mangroves are terribly important. I don't know about mangrove productivity—it's always been a puzzle to me why the mangrove leaves are meant to produce such a lot of nutriment in the nutrient cycle in a mangrove swamp. Where did it originally come from apart from the leaf drop? I think the sea grasses play a very large role in the estuarine ecosystem and the difference between bare sand and sea grasses as a nursery for a wide variety of fishes and the diversity you get in a sea grass area from a bare mud flat is just astronomical. However, I will just put in a point here, a lot of greasyback prawns go into the mangroves and it may well be important for that species.

THE LOCATION OF FOOD BY *PENAEUS MERGUIENSIS*

BY J. P. R. HINDLEY
James Cook University of North Queensland, Townsville, Qld.
Present address:
Research Scientist,
CSIRO, Division of Fisheries and Oceanography, Perth, W.A.

ABSTRACT

Penaeus merguiensis *spends a large proportion of its time browsing, i.e. performing non-stimulated food seeking. It is stimulated to search for food by a range of amino acids at low concentration. Rheotaxis is probably the most important mechanism in the location of food, but chemotaxis may be important in the final stages. Higher concentrations of a range of substances are necessary for the recognition of food by the mouthparts. The chemoreceptors are distributed primarily at the anterior end of the animal.*

INTRODUCTION

I have no first-hand data on the diet of *Penaeus merguiensis.* The literature contains only one analysis of stomach contents of the banana prawn, and this shows a fair range of food types in the diet (Hall, 1962). But there have been many other analyses of the stomach contents of other species (Gopalakrishnan, 1952; Panikkar, 1952; Ikematsu, 1955; Williams, 1955; Flint, 1956; Eldred, 1958; Darnell, 1958; Kesteven & Job, 1958; George, 1959; Racek, 1959; Eldred *et al.*, 1961; Hall, 1962; Burukovsky, 1969; Sastrakusumah, 1971). There is general agreement that a wide range of food types is taken, but the predominant items vary. Whether this is due primarily to different dietary preferences or to different availability of food types to different species is not clear. In addition to recognisable items, stomachs also contain quantities of unrecognisable debris, variously thought to be triturated food, fine detritus or bacterial colonies (Dall, 1968).

Banana prawns which have not actually detected the presence of food spend a large amount of time walking over the substratum, probing it with the first three pairs of legs. Many small particles are passed to the mouthparts, where many are rejected.

Where a prawn has detected food, the behaviour is similar, but more rapid. There is usually also a raising of the cephalothorax, which is a very useful indication that the animal has detected food. Strongly stimulated animals may make very rapid and erratic movements and may abandon ambulation for swimming.

This paper deals with the mechanisms by which the prawn detects food, the mechanisms by which food is then located, and the mechanism by which the mouthparts discriminate a particle of food from a particle of non-food matter. The work was performed on juvenile specimens of *Penaeus merguiensis*, but casual observation of adults of this species and juveniles and adults of several other North Queensland species suggests that the processes are broadly similar in all of them.

DETECTION OF FOOD

Any of the following senses could be used by an animal in the detection of food at a distance: (1) Sight, (2) Audio-(Vibro-), (3) Thermo-, (4) Chemo-sense. Of these, thermo- and audio-reception are unlikely because the food is mainly dead. Sight is not very likely to be important because the creeks in which juvenile banana prawns are found are extremely muddy, and the range of visibility very small. However, the eyes are well developed, and it is possible that vision would be more important in less turbid water.

Prima facie, this leaves chemo-reception as the most likely mechanism of food detection, with vision a possibility.

In order to test if vision was important, I conducted an experiment in which prawns were presented with the sight of food, either alone, or together with a food extract. The piece of food presented as a visual stimulus was behind a water-tight glass partition which prevented the odour from reaching the prawn.

The results of this experiment showed that the sight of food alone did not excite food seeking behaviour, but that the exposure to food extract did.

Having determined that chemo-reception

was important in stimulating food seeking activity in the banana prawn, I designed an experiment to investigate this aspect in more detail.

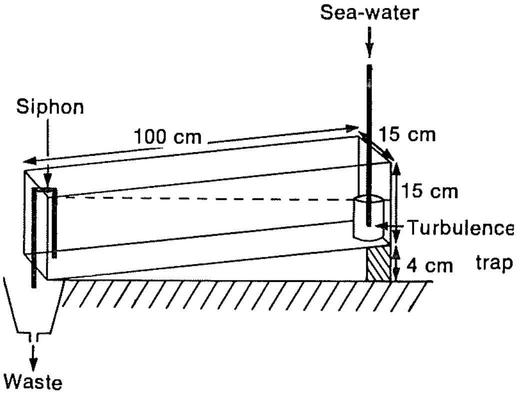


Figure 1.

The experimental tank measured 100 cm x 15 cm x 15 cm (Fig. 1). One end of the tank was raised 4 cm. Sea-water was introduced into this end of the tank through a beaker 1 cm deeper than the water. This prevented turbulence in the water flow. Flow rate of the water was 5.4 litre/minute, which produced an average current along the tank of 0.5 cm/second, but the upper layers of water flowed slightly faster than the lower layers. The bottom of the tank was covered by a layer of sand approximately 1 cm deep.

Prawns were introduced singly into the tank and left for at least one hour before experiment.

The substances with which the prawns were tested were made up in concentrations of 1M, 10^{-1}M, 10^{-2}M, 10^{-3}M, 10^{-4}M, 10^{-5}M, 10^{-6}M in sea-water. (Or, when molecular weight was indeterminable, in concentrations of 1%, 10^{-1}%, etc.)

Ten ml of sea-water was injected into the turbulence trap as a control, and the prawn was watched during the next two minutes. If no food seeking behaviour was observed, five minutes were allowed to elapse before the first solution was tested in the same manner.

The solutions were tested in order of increasing concentration with a five-minute interval between each test to allow complete flushing of the tank. After one positive result (exhibition of food seeking behaviour), higher concentrations of that substance were not generally tested on that prawn.

The food seeking behaviour in response to a stimulus is usually unmistakable and readily distinguishable from non-stimulated food searching. However, in the rare cases in which a solution produced only a slight reaction, that solution was considered non-stimulatory.

Table 1 summarises the results of a total of 43 tests. No prawn ever showed food-seeking behaviour after the introduction of sea-water, and all prawns responded to all substances tested at high concentration (10^{-1}M or 10^{-1}%).

The concentrations given are those of the solution injected into the turbulence trap, and not those detected by the prawn. The amount of dilution of the test solutions was not determined.

Although all the substances used in this experiment evoked food-seeking reactions from the prawns, the lowest effective concentrations for amino acids (10^{-5} — 10^{-6}M) was much lower than that of other substances tested (10^{-3} — 10^{-1}M). The threshold concentrations for amino acids are similar to those reported in *Homarus americanus*

Table 1. Sensitivity of distance chemoreceptors
(Number of prawns showing thresholds at different concentrations)

Compound	*Max. Conc. Used*	*Number Prawns Tested*	*10^{-3}M*	*10^{-2}M*	*10^{-1}M*	*1M*		*No Response*	*Most common Threshold Concentration*
Sucrose	1M	5	0	0	5	–		0	10^{-1} M
Ethanol	1M	5	4	0	1	–		0	10^{-3} M
Urea	1M	5	0	5	–	–		0	10^{-2} M
Soluble			10^{-3} %	10^{-2} %	10^{-1} %	1%			
Starch	1%	5	0	3	2	–		0	10^{-2} %
			10^{-6} M	10^{-5} M	10^{-4} M	10^{-3} M	10^{-2} M		
Glycine	10^{-2} M	5	1	4	–	–	–	0	10^{-5} M
Proline	10^{-2} M	5	1	2	2	–	–	0	$10^{-4}/10^{-5}$ M
Valine	10^{-2} M	4	1	0	2	1	–	0	10^{-4} M
Leucine	10^{-2} M	4	0	2	2	–	–	0	$10^{-4}/10^{-5}$ M
Lysine	10^{-2} M	5	1	3	1	–	–	0	10^{-5} M

by McLeese (1970) who found thresholds of about 10^{-5} — 10^{-6}M for several amino acids.

LOCATION OF FOOD

The experiment in which a visual cue was given to prawns showed that the sight of food did not excite food seeking behaviour. The same experiment demonstrated that, after stimulation by food odour, the prawns showed no orientation towards the visual cue, i.e. they do not locate their food by sight.

The method of location of food was first noticed by chance in holding tanks, where it was noticed that the prawns tended to congregate near the water inflow when food was added to the water.

In order to assess the various factors involved, the tilted tank already described was used again. It was set up in the same way except that a metre rule was laid alongside the tank so that the position of the prawn could be defined.

Ten ml of standard beef extract was injected into the turbulence trap. The position of the prawn was noted at the time of introduction of the extract, and at ten-second intervals for two minutes. The prawn was considered to have responded to the extract as it moved 10 cm or more in any ten-second interval. Casual observation has shown that the normal maximum speed of an unstimulated prawn is about 0.5 cm/second, but when strongly stimulated (by food or disturbance), swimming speeds of 3 cm/second can be attained.

Upstream movement of at least 10 cm in a ten-second interval was considered to be a positive response, downstream movement negative. Only the first movement of 10 cm was considered.

The beef extract was not introduced into the tank if the prawn was less than 10 cm from either end of the tank, so that the prawn was not prevented from moving a full 10 cm by the end walls of the tank.

Controls were conducted with 10 ml of sea-water introduced in place of the beef extract.

Thirty-four prawns were tested with beef extract and fifteen with sea-water as controls. The results are shown in Table 2.

These results indicate that, following stimulation by food odour, *P. merguiensis* usually moves in an upstream direction.

Incidentally, it is interesting to note that this is true rheotactic response, not a response to visual stimuli, as is the apparent rheotaxis in many fishes and some other crustaceans. There were no optical stimuli which could provide information on the current direction in this experiment.

Table 2. Rheotactic response of *P. merguiensis* stimulated by food odour

	Beef extract	*Sea-water*
Positive	23	2
Negative	1	Nil
No reaction	10	13

Chi^2 tests on these figures show that the difference between the groups of prawns tested with beef extract and sea-water with respect to positive reaction/no reaction is significant at the 0.005 level (Chi^2 = 12.07).

In the field situation, it would be expected that currents would usually be present, set up by tidal ebb and flow, by fresh water run-off or by thermal convection. In the laboratory, however, it is possible to set up tanks with no currents.

Experiments in which prawns were released into a tank in which food had previously been buried in the substratum showed little evidence of any orientated response to the source of odour until the prawns were very close, say 4 to 5 cm, to the food. At that distance, they orientated directly towards the food and rapidly dug it up from the sand.

It is impossible to set up a perfect concentration gradient in a small tank, but these results seem to indicate that chemotaxis is not an important mechanism for food location, except perhaps in the last few centimetres.

RECOGNITION OF FOOD

After food has been detected and located, it has to be passed to the mouthparts, masticated if necessary, and swallowed. Whilst browsing, prawns will pick up a large number of particles and pass them to the mouthparts using some or all of the chelate limbs. Many of these particles, presumably sand grains and other non-food items, are rejected and allowed to fall back to the substratum.

Obviously, there is some sort of recognition mechanism operating at the mouthparts. In order to investigate this, a rather crude but none-the-less effective technique was developed for presenting small doses of measured concentrations of stimulants directly onto the mouthparts.

Test solutions were made up at concentrations of 10^{-1}M, 10^{-2}M, 10^{-3}M, 10^{-4}M and 10^{-5}M in sea-water; the higher concen-

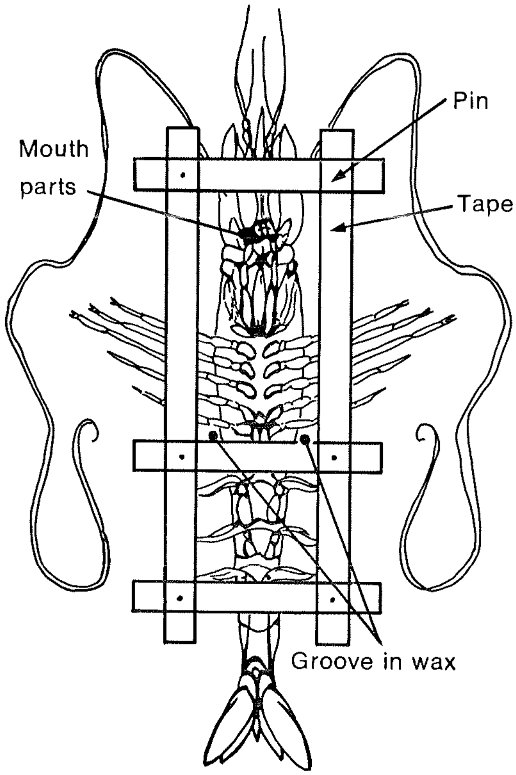


Figure 2.

trations being omitted where the chemical under test was not sufficiently soluble. If not used immediately, solutions were stored at 2°C.

The animal under test was secured dorsal side down in a groove in a dish of wax (Fig. 2). The abdomen and pereiopods, which were extended laterally, were immobilised with strips of tape. Another strip of tape covered the eyes, so that the prawn received no visual cues. Enough water was added to the dish to completely cover the animal, which was then left for at least 15 minutes before testing.

Each solution was tested by dropping three drops from a pasteur pipette over the mouthparts of the prawn at ten-second intervals. After each drop, a positive or negative response was recorded. A positive response was one in which the prawn made a vigorous movement of the mouthparts within three seconds of the introduction of the drop. Any other reaction was considered to be negative. If at least two drops out of three produced positive responses, it was considered that the prawn was sensitive to the concentration under test. Each concentration of the chemical was tested, starting with the most dilute.

Since the lowest concentration used never produced a positive reaction, no separate control was used.

Before each series of tests, and also after each chemical had been tested, the prawn was given one drop of standard beef extract over the mouthparts. If there was not a positive reaction to this drop, the entire series of tests on that animal was disregarded.

The standard extract was coloured and its flow over the prawn and its subsequent dispersal could easily be observed. The drop was quite cohesive and contacted the mouthparts with little dilution by the surrounding seawater. It was then rapidly dispersed by the respiratory current of the prawn.

Each prawn was tested with up to six chemicals and was then discarded. Each solution was tested on at least five different animals.

Results from prawns held captive in this way agreed well with pilot studies in which prawns were presented with solutions through pasteur pipettes drawn out to allow the solution to be ejected directly onto the mouthparts of unrestrained animals. This method was abandoned because it was difficult to standardise the technique.

Nineteen amino acids and three other organic compounds were tested on a total of thirty prawns. The results are summarised in Table 3.

No substance elicited a feeding response at a concentration below 10^{-3}M. Two of the twenty-two substances were stimulatory at this concentration but these only affected one prawn each. For most of the amino acids, the threshold level was either 10^{-2} or 10^{-1}M. None of the amino acids which were soluble enough to be tested at 10^{-1}M failed to produce masticatory behaviour at that concentration. However, of the three other substances tested, only glucose produced a response at 10^{-1}M, and this in only one prawn out of five.

Differences of sensitivity between prawns is generally not great, as can be seen in Table 3. However, in one case, the individual difference was very marked. Six out of seven prawns tested with tryptophan showed no response at 10^{-2}M, which was the highest concentration used, whereas one showed a positive reaction at 10^{-3}M. This test was repeated on the same prawn and the finding confirmed.

Table 3. Sensitivity of contact chemoreceptors

(Number of prawns showing thresholds at different concentrations)

Compound	*Max. Conc. Used*	*Number Prawns Tested*	*10^{-3}M*	*10^{-2}M*	*10^{-1}M*	*No Response*	*Most common Threshold Concentration*
Glycine	10^{-1} M	8	0	2	5	1	10^{-1} M
Alanine	10^{-1} M	5	0	2	3	0	10^{-1} M
Valine	10^{-1} M	5	0	1	4	0	10^{-1} M
Leucine	10^{-2} M	5	0	0	–	5	No response
Iso-leucine	10^{-1} M	5	0	2	3	0	10^{-1} M
Serine	10^{-1} M	5	0	1	4	0	10^{-1} M
Threonine	10^{-1} M	5	0	2	2	1	$10^{-2}/10^{-1}$ M
Aspartic acid	10^{-2} M	5	0	5	–	0	10^{-2} M
Asparagine	10^{-1} M	5	0	1	4	0	10^{-1} M
Glutamic acid	10^{-2} M	8	0	8	–	0	10^{-2} M
Lysine	10^{-1} M	5	0	1	4	0	10^{-1} M
Histidine	10^{-1} M	6	1	4	1	0	10^{-2} M
Argenine	10^{-1} M	5	0	0	5	0	10^{-1} M
Phenylalanine	10^{-2} M	5	0	0	–	5	No response
Tyrosine	10^{-3} M	5	0	–	–	5	No response
Tryptophan	10^{-2} M	7	1	0	–	6	No response
Methionine	10^{-1} M	6	0	1	5	0	10^{-1} M
Proline	10^{-1} M	7	0	2	5	0	10^{-1} M
Nor-leucine	10^{-2} M	7	0	0	–	7	No response
Urea	10^{-1} M	5	0	0	0	5	No response
Sucrose	10^{-1} M	5	0	0	0	5	No response
Glucose	10^{-1} M	5	0	0	1	4	No response

DISTRIBUTION OF CHEMOSENSORY ORGANS

Several workers have investigated the distribution of chemosensory organs over the surface of the body of crustaceans. Bell (1906) investigated their distribution in an unnamed crayfish. He tested eleven parts of the body (antennae, chelae, antennules, mouthparts, first, second, third and fourth walking legs, pleopods and the ventral surface of the abdomen, telson, and carapace) and found some sensitivity to meat juice at each location. However, the most definite responses were produced when the stimulus was applied to the anterior appendages.

The antennae and antennules have been implicated as the most important chemosensory organs by several authors. Copeland (1932) showed that both pairs of appendages were important in the detection of food in the prawn *Palaemonetes vulgaris*. Holmes & Homuth (1910), working on an unnamed crayfish, concluded that the outer ramus of the antennule was the most important in the detection of food, but that the inner ramus of the antennule and the antenna were also important. Hazlett (1968) found that the antennae of the hermit crab *Clibanarius vittatus* were not important in the detection of food, but that the antennules were.

The prawn under test was secured in the same way as described for the recognition of food.

All tests were carried out with standard beef extract which was introduced from a pasteur pipette. A small quantity of the extract was introduced into the part of the body being tested and the effect noted.

In order to distinguish responses due to chemical stimulation and those due to mechanical stimulation by the drop or jet of meat extract, the effect of a drop or jet of sea-water on the organ concerned was also observed.

After a test on one part of the body, the prawn was not tested again for at least five minutes. After a series of tests had been completed on an animal, a drop of the standard beef extract was introduced over the mouthparts. If the prawn did not respond with a vigorous movement of the mouthparts, all previous observations on that animal were ignored.

Sea-water dropped or squirted onto the body and appendages of the prawns never had any observable effects other than occasionally causing a momentary twitch of the part of the body concerned. By contrast, a positive response to the standard beef extract was marked either by the flexing of the walking

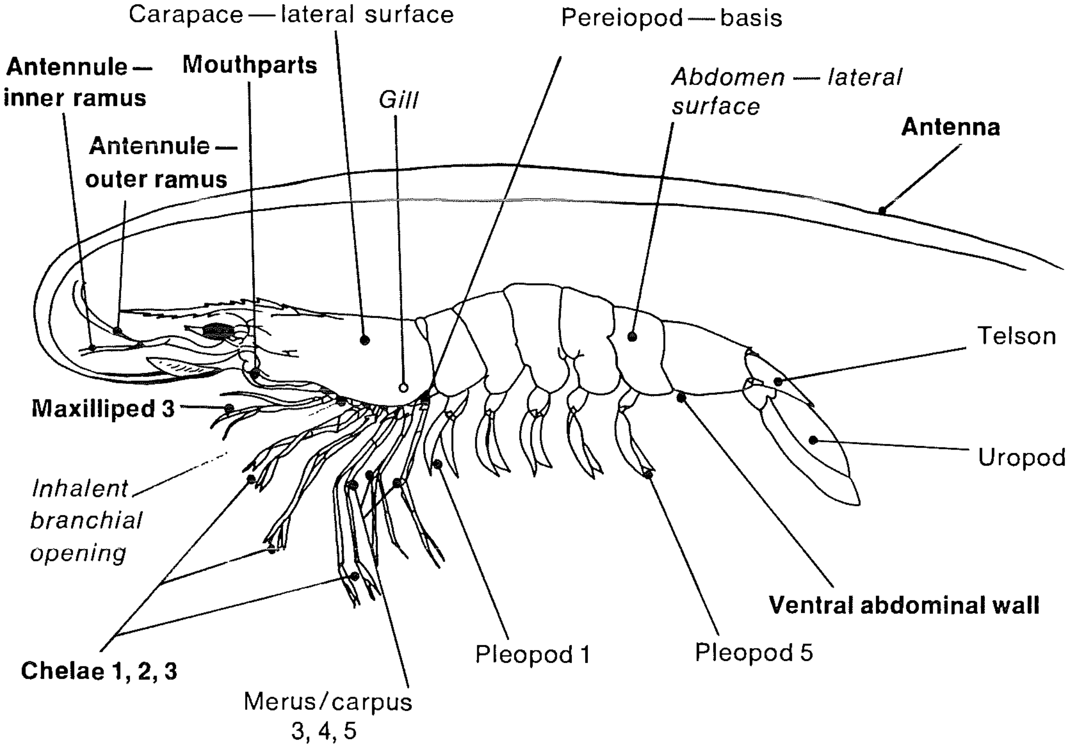


Figure 3. Distribution of chemosensory organs. Legend: words set in bold type (e.g. Antenna) indicate responsive loci; italic type (e.g. Gill) slightly responsive loci; and roman type (e.g. Uropod) unresponsive loci.

legs, the opening and closing of the chelae of the first three pairs of legs, movement of the mouthparts, or by all of these reactions.

The results are shown diagramatically in Fig. 3. The anterior part of the prawn clearly has a greater population of chemosensory organs than the posterior part, although they are not entirely lacking there.

Beef extract injected onto the gills, or into the opening of the gill chamber produced a reaction after a delay of 3-5 seconds. Elsewhere, the response was always almost instantaneous. This suggests that the gills and gill chambers themselves have no chemosensors, but that other chemosensory organs are stimulated when the extract in the respiratory current is propelled to other parts of the body.

LITERATURE CITED

BELL, J. C. (1906). 'The reactions of crayfish to chemical stimuli.' *J. comp. Neurol.*, 16, pp. 299-326.

BURUKOVSKY, R. N. (1969). 'The feeding habits of rose shrimp (*Penaeus duorarum* Burkenroad) off Mauritania.' All-Union Research Institute of Marine Fisheries and Oceanography (V.N.I.R.O.)—*Proceedings* (in Russian), 65, pp. 417-423.

COPELAND, M. (1932). 'The chemical sense of *Palaemonetes vulgaris* (Say).' *Anat. Rec.*, 24, p. 394.

DALL, W. (1968). 'Food and feeding of some Australian penaeid shrimp.' *F.A.O. Fish. Rep.*, 57(2), pp. 251-258.

DARNELL, R. M. (1958). 'Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community.' *Publs. Inst. mar. Sci., Univ. Tex.* 5, pp. 353-416.

ELDRED, BONNIE (1958). *'Meioceras lermondi* as food for *Penaeus duorarum?' Nautilus*, 71, p. 152.

ELDRED, BONNIE, INGLE, R. M., WOODBURN, K. D., HUTTON, R. F. JONES, HAZEL (1961). 'Biological observations on the commercial shrimp, *Penaeus duorarum* Burkenroad, in Florida waters.' *Prof. Pap. Ser. mar. Lab. Fla*, 3, 139pp.

FLINT, L. H. (1956). 'Notes on the algal food of shrimp and oysters.' *Proc. La. Acad. Sci.*, 19, pp. 11-14.

GEORGE, M. J. (1959). 'Notes on the bionomics of the prawn *Metapenaeus monoceros* Fabricius.' *Indian J. Fish*, 6, pp. 268-279.

GOPALAKRISHNAN, V. (1952). 'Food and feeding habits of *Penaeus indicus*.' *J. Madras Univ.*, Section B., 22, pp. 69-75.

HALL, D. N. F. (1962). 'Observations on the taxonomy and biology of some Indo-West-Pacific Penaeidae (Crustacea, Decapoda).' *Fishery Publs colon. Off.*, 17, pp. 1-229.

HAZLETT, B. A. (1968). 'Stimuli involved in the feeding behavior of the hermit crab *Clibanarius vittatus* (Decapoda, Paguridae).' *Crustaceana*, 15, pp. 305-311.

HOLMES, S. J. AND HOMUTH, E. S. (1910). 'The seat of smell in the crayfish.' *Biol. Bull. mar. biol. Lab., Woods Hole*, 18, pp. 155-160.

IKEMATSU, W. (1955). 'On the life history of *Metapenaeus joyneri* (Miers) in Ariake Sea.' *Bull. Jap. Soc. scient. Fish.*, 20, pp. 969-978.

KESTEVEN, G. AND JOB, T. B. (1958). 'Shrimp culture in Asia and the Far East: a preliminary review.' *Proc. Gulf Caribb. Fish. Inst.*, 10th Annual Session, pp. 49-68.

MCLEESE, D. W. (1970). 'Detection of dissolved substances by the American lobster (*Homarus americanus*) and olfactory attraction between lobsters.' *J. Fish. Res. Bd Can.*, 27, pp. 1371-1378.

PANIKKAR, N. K. (1952). 'Possibilities of further expansion of fish and prawn cultural practices in India.' *Curr. Sci.*, 21, pp. 29-33.

RACEK, A. A. (1959). 'Prawn investigations in eastern Australia.' *Res. Bull. St. Fish. N.S.W.*, 6, pp. 1-57.

SASTRAKUSUMAH, S. (1971). 'A study of the food of juvenile migrating pink shrimp *Penaeus duorarum*' Burkenroad. M.Sc. thesis, University of Miami, Coral Gables, 37pp.

WILLIAMS, A. B. (1955). 'A contribution to the life histories of commercial shrimps (Penaeidae) in North Carolina.' *Bull. mar. Sci. Gulf Caribb.*, 5, pp. 116-146.

DISCUSSION

Lake. I just wonder if it is necessary to assume the response described is one pleasing to the prawns. Could it not be that it is one which the prawn doesn't like? I mention this because I have read, some time ago, literature where some of the salmon in Canada were moved downstream from a fishery when washing from a mill was extreme and I think they have isolated iso-leucine as a particular ingredient that causes this negative reaction if you like.

Hindley. That's a very good point. I did try to stimulate food seeking activities by putting ammonia into the tank and they really didn't like that. Their behaviour was completely different. They went downstream instead of up. There was none of this more active probing of the substrate and they were swimming as well as walking. The type of behaviour I call food searching involves the raising of the cephalothorax slightly. I don't know the significance of it but it does seem to be a useful sign that food has been detected. There is increase in the speed of locomotion and a wider field of searching of the legs, which spread out in a band. When they're just browsing the legs spread out into a fairly narrow band. After they've been stimulated the band widens and the amount of movement of the tips of the legs are much greater. This just wasn't the same behaviour that occurred when I dropped ammonia into the tank.

Kirkegaard. You made the assumption that audio-reception is unlikely because the food is mainly dead. Did you test this at all, or consider testing it?

Hindley. I didn't. It appeared to be possible though unlikely. I have seen banana prawns take live food on occasions, but very rarely. They seem to have a great deal of trouble taking anything that is alive and active.

Kirkegaard. This is in what size range?

Hindley. A centimetre carapace length and upwards. I have kept them in tanks with other animals—polychaetes, small fish, isopods, other decapods and other organisms—and I think that it is very rare for them to actually catch something alive and active. They'll try but they don't seem to have the mechanism to grasp it very securely. The chelae themselves are not grappling hooks, they are a kind of forceps. Your point is quite valid though. It is quite possible they take live food.

Maguire. I was just wondering is there any chance as you have the extract moving progressively into the tank that instead of perhaps responding to the current the prawn is instead responding to the concentration gradient as the food moves into water?

Hindley. I don't think so. I did tests with dyes and the material injected into the top of the tank moved down more or less in a block and although I have not tested the concentration, it didn't seem that the dyes were tapering off or building up. There seemed to be a block of dye moving down the tank.

Hancock. There seems to be a conflict in terms in your conclusions between using the words chemotaxis and rheotaxis. You've said that when the prawn is stimulated by food they are stimulated when this is in the water current, but your experiments show however that when there was no food they were not stimulated by the water current. This suggests to me that this is a chemotactic response and this is the dominant thing and it is just the water which is carrying the flavour towards them. This is not really the dominant role in a truly rheotactic response. In a lot of these experiments with invertebrates it is very difficult to eliminate the role of water current to get it low enough in fact to get the food propelled towards an animal to separate chemotaxis and rheotaxis.

Hindley. I think we are talking about definitions of terms 'rheotactic' and 'chemotactic'. I guess everybody defines them differently, but my definition of rheotaxis would be: 'A movement of an animal orientated with respect to the current although this movement may have been initiated by a response to a chemical in the water.' Although the chemicals in the water stimulate this search for food, the current has directed the orientation.

Ruello. You mention in your introduction that you didn't look at the natural food, is there any reason for this?

Hindley. Well, I cut open some stomachs and found nothing but very chewed up green or brown slime, the same as everybody else who has opened up stomachs has found. All that can be recognised is the hard parts of what may be molluscs, crustacean parts, occasionally some polychaete spines. It is not really a fair guide to what it's eating to deduce its diet from hard parts. There is a lot of what people have called triturated debris or bacterial colonies; it could be almost anything. This is why I didn't draw any conclusions about the natural food.

Ruello. A quick comment. I was surprised to hear you say you didn't think that these small prawns can grasp animals. I have seen small king and school prawns and I think that they are very effective at handling polychaete worms.

Hindley. I can only say again that I don't think that they can effectively grasp active motile animals. They will go for anything but if it struggles it generally gets away. This has been my experience in tanks. Your species may have been different or my species may have been abnormal, they might not like to be kept in tanks.

Haysom. In your diagram on distribution of chemosensory organs you indicate that the antennae have responsive loci. This is an appendage that comes from the front of the animal but the tips are usually behind the animal, what part of the antennae has these loci?

Hindley. I tested all parts, from the front right through to the back, and they were all responsive. The antennae are not always behind when the prawn is walking actively. Sometimes they trail out behind, sometimes they are out in front and sometimes they flop out at the side. They may be useful as long range detectors. Certainly they were responsive to my tests.

PRELIMINARY ANALYSIS OF PHYSICAL FACTORS INFLUENCING THE INGRESS OF PLANKTONIC KING PRAWN (*PENAEUS PLEBEJUS*) POST-LARVAE INTO MORETON BAY

BY W. E. BARBER[1]
Research Scientist, CSIRO,
Division of Fisheries and Oceanography,
P.O. Box 5, Deception Bay, Qld.
and
C. P. LEE
Biologist, Fisheries Branch,
Department of Primary Industries,
P.O. Box 5, Deception Bay, Qld.

ABSTRACT

Preliminary results are presented on what physical factors influence planktonic postlarval king prawns entering Moreton Bay, Queensland. Collections made at Southport and Jumpinpin Bars indicated that the postlarvae enter on the flood tide both day and night, with fewer during daylight. During ebb tide there are few or none in the water. There is no difference between surface and bottom samples at Southport and Jumpinpin Bars on full moon. However, there appears to be a difference during new moon. Limited amount of data indicates there is a depressing effect of full moon and daylight on numbers entering the bars. Sampling on all four stages of the moon indicates that more enter on the first quarter.

Investigation into diel periodicity in vertical movement at the surface, 7 m and 14 m depths off Southport Bar showed no diel periodicity. There was also no periodicity of numbers/m^3 in relation to tide stage. Sampling inside the Bar on inflow tide showed agreement with numbers occurring outside at similar times. These data are discussed in relation to the Gulf of Mexico penaeids and based on this discussion a hypothesis is presented on the mechanism by which postlarvae reach Moreton Bay's entrances and settle out.

INTRODUCTION

The king prawn (*Penaeus plebejus* Hess) has a similar life cycle to that of the banana prawn (*Penaeus merguiensis* de Mann) of the Gulf of Carpentaria and the Gulf of Mexico penaeid prawns (Dakin, 1938; Hughes, 1969; Kirkegaard, *et all:*, 1970). Essentially, it has (1) a planktonic stage which makes its way from the offshore spawning ground to the estuary, where (2) it settles, becoming benthic and completes its juvenile existence, before (3) the species migrates offshore, where final maturation and spawning takes place.

The recruitment into a fishery such as that of Moreton Bay and adjacent offshore waters depends directly on the juvenile population occurring in mangrove areas, and associated sea grass beds and mud flats.

The recruitment to this area, however, is dependent on the planktonic stage entering the estuarine system. Therefore, the yield of the fishery may ultimately depend on the number of postlarvae entering the estuary (Bearden, 1961; Roessler and Rehrer, 1971; Williams, 1969).

In this respect we have initiated a study on the factors which may influence the ingress of postlarvae as part of a program to investigate the seasonal fluctuations of the immigration of postlarval king prawn into Moreton Bay.

GENERAL METHOD AND MATERIALS

All collections were made with 1 mm mesh monofilament plankton net, having 0.25 m^2 opening (0.5 x 0.5 m). The net was towed, with a flowmeter attached to the inside of the net frame, for a period of 5 to 10 minutes at a speed of 4.6 to 5.5 km/hr (2.5 to 3.0 knots) in the opposite direction to the tidal flow. All collections were immediately preserved in 10 per cent formalin. Flowmeter readings and weather conditions were recorded

---

[1] In 1975 was at: Victorian Fisheries and Wildlife Div., Marine Pollution Studies Group, 605 Flinders Street Extension, Melbourne, Vic. 3000.

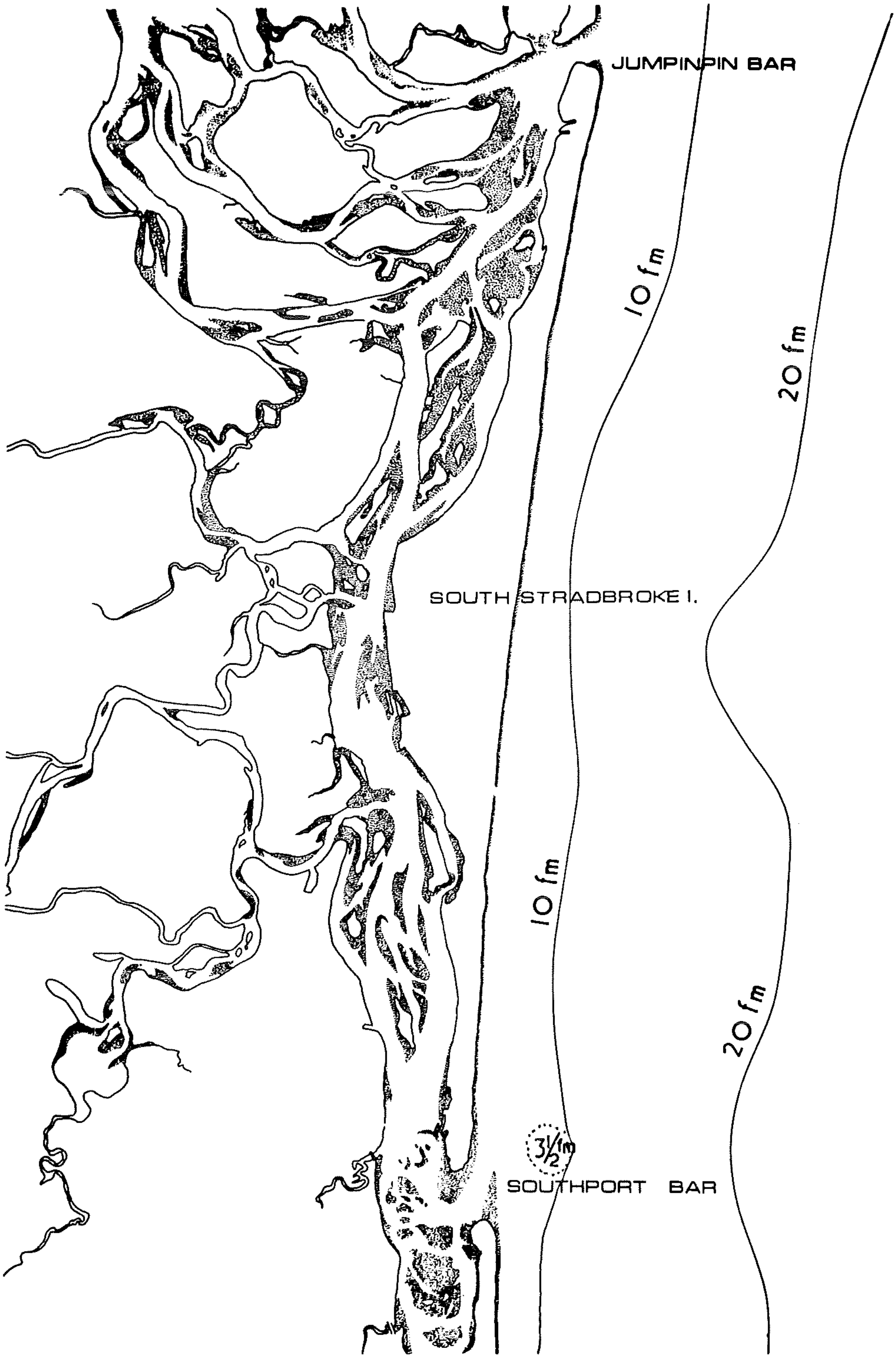


Figure 1. Study area showing the three locations sampled for king prawn postlarvae, the two entrances at Jumpinpin and Southport Bars, and the 18 m (10 fathom) line off Southport Bar.

after each period, while salinity and temperature of the water column sampled were measured with a Hamon S.T. meter after every series of tows.

RESULTS

To determine the relation of postlarval immigration to the stage of the tide, time of

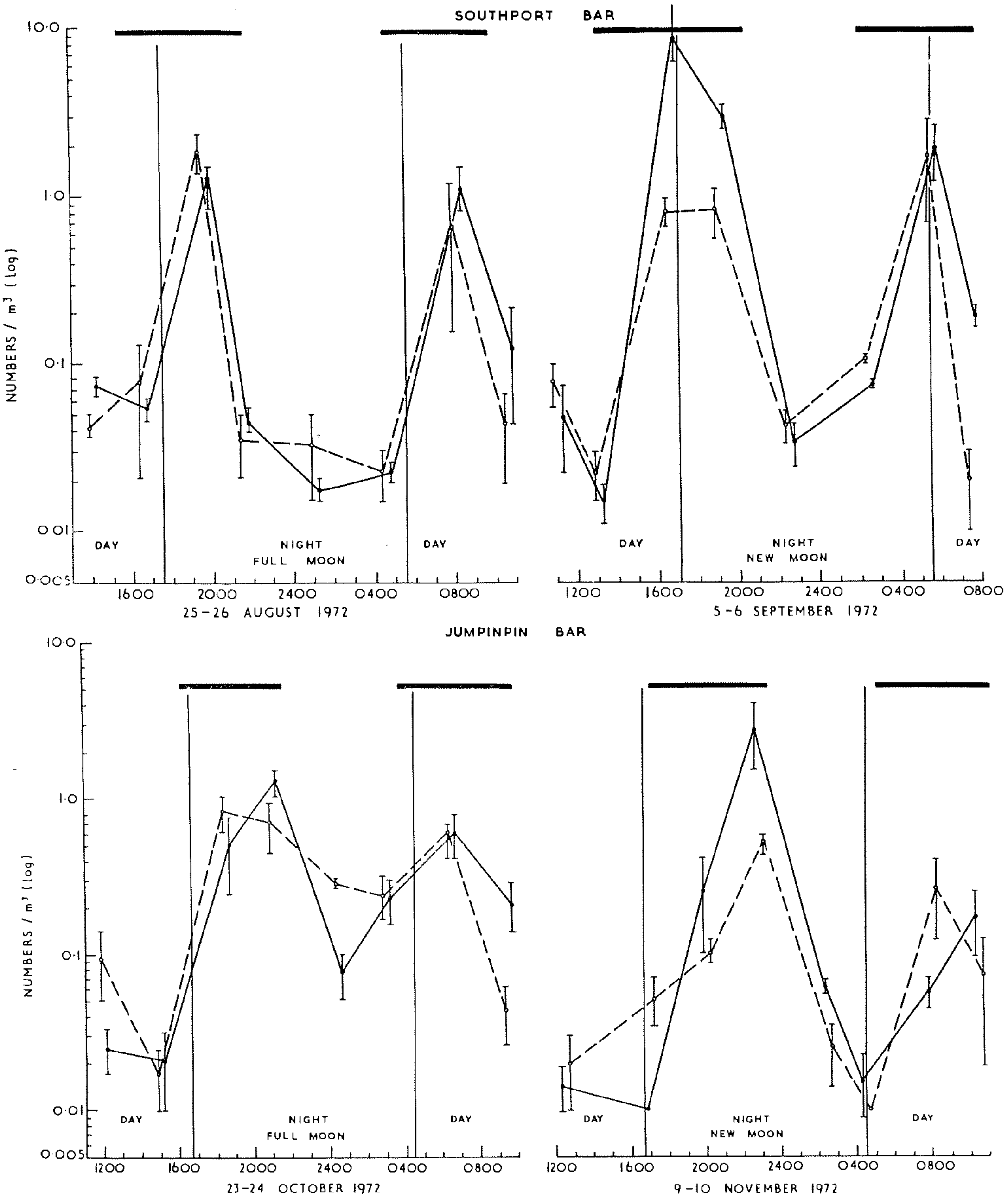


Figure 2. Mean number of postlarval king prawns/m^3 in the water at Southport and Jumpinpin Bars at various times during a number of 24-hour periods.
Solid line and closed circles are surface samples, broken line and open circles are bottom samples. Vertical lines are plus and minus one standard deviation. Prior to calculations 0.01 was added to each catch/m^3.

(Each point is average of 3 samples and vertical lines are plus or minus one standard error.)

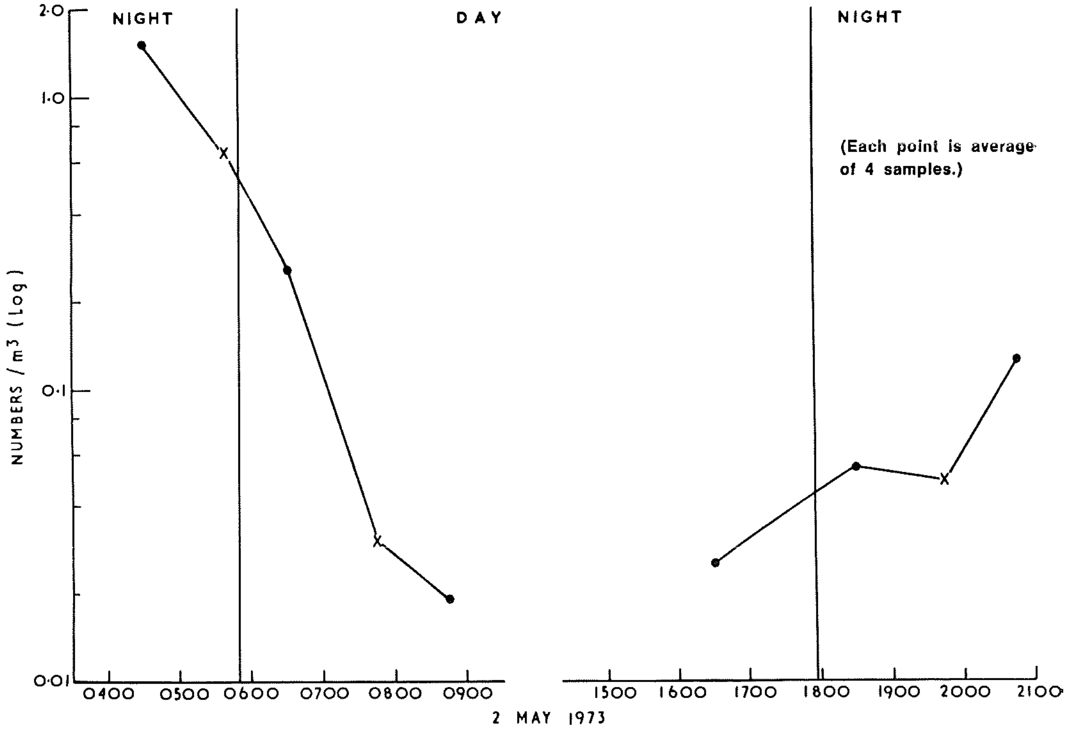


Figure 3. Mean number/m^3 of king prawn postlarvae entering on the flood tide as night progresses to day and day progresses to night. Prior to calculations 0.01 was added to each catch/m^3.

day and moon phase, six samples were collected alternatively at the surface and just above the bottom every 2.5 hours for 24 hours on full and new moon inside Southport and Jumpinpin Bars (Fig. 1). Depth of these areas was 3 m and 5 m at low tide, respectively. The net was weighed down with a 10 kg lead weight. From Fig. 2 it can be seen that the postlarvae are in the water column during the flood tide with few or none during the ebb tide. The difference in numbers between the surface and the bottom is not consistent. During full moon there is very little difference in both day and night samples at the two areas. However, on the new moon, there are more near the surface inside both bars on the first flood tide (night), but approximately equal numbers on the second day. Comparing the number of postlarvae entering on the two moon phases, there appears to be no difference at Jumpinpin, but more were present during the dark moon at Southport Bar. The number of postlarvae entering the two areas is similar during the day and night of the full moon. However, during the new moon, more are entering during the night.

To determine whether light has an effect on the number of postlarvae entering the bay, four surface samples were collected at hourly intervals for the full period of a flood tide; beginning two hours prior to dusk and two hours prior to sunrise.

Fig. 3 shows that there is a decrease in numbers as night progresses into day, and an increase as day progresses into night. This sampling regime has been attempted several other times to give more data on this, but timing of sampling with tide flow has not been successful.

To determine if there is a moon effect on numbers entering through the Bars, four samples were collected at 1 to 1½ hours after low tide for a two-day period on the four stages of the moon. Fig. 4 shows the results of the first series. The averages of the night samples were 0.69/m^3, 5.55/m^3, 1.24/m^3 and 1.84/m^3 on the new moon, first quarter, full moon and last quarter, respectively. Another sampling series has been done in respect to moon effect, but at the writing of this paper all samples have not been processed, but those that had, still indicate more entering on the first quarter.

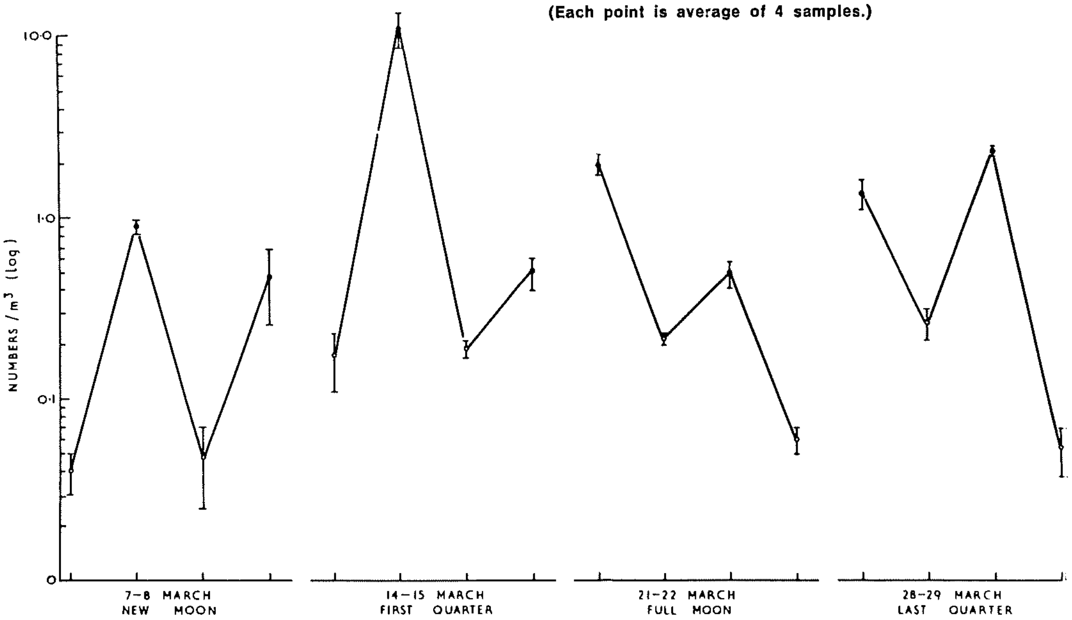


Figure 4. Mean number/m^3 of king prawn postlarvae in the water on two consecutive nights and days at four stages of the moon. Vertical lines are plus and minus one standard error. Prior to calculations 0.01 was added to each catch/m^3.

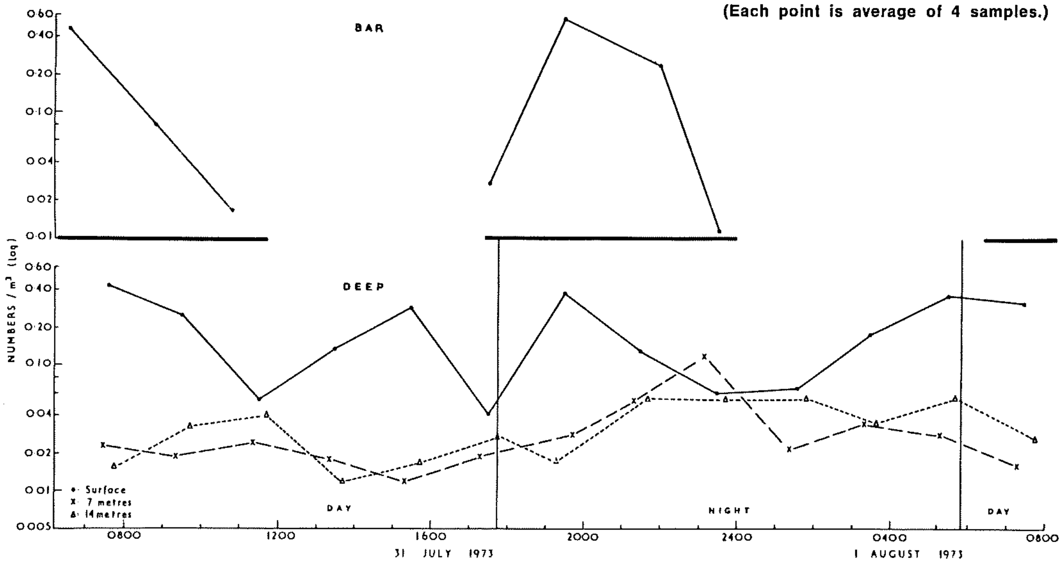
To investigate diel periodicity in depth distribution and whether the occurrence of postlarvae outside Southport Bar corresponds to that inside, sampling was done for a 24-hour period in 14.5 m to 20 m, 1.6 to 2.4 km off Southport Bar. Four consecutive 10 minute samples were taken every two hours at the surface, 7 m and 14 m depths. Concurrently four consecutive 10 minute surface samples were taken at about two-hourly intervals just inside the Bar on flood tide. Sampling was done on the dark moon and no clouds were present.

Fig. 5 indicates that the number of postlarvae occurring at these depths shows no diel or tidal periodicity. However, there seems to be a loose relation between the numbers at the surface to that at the mid and bottom-waters. As the numbers on the surface decrease, there appears to be an increase in the latter and vice versa. On the first flood tide the number of postlarvae collected inside the Bar at 0700 is nearly equal to the number collected outside the Bar, 0.46/m^3 and 0.43/m^3, respectively. Numbers declined in both areas after this, with fewer being present inside the Bar than outside (Fig. 5). On the second flood tide the first three time periods from inside the Bar coincide with those outside. Average numbers on the inside were 0.028/m^3, 0.54/m^3 and 0.27/m^3, whereas those on the outside averaged 0.04/m^3, 0.38/m^3 and 0.17/m^3. Again numbers of postlarvae decline in both locations in the latter half of the tide.

DISCUSSION

The data presented here is preliminary and few conclusions can be made in respect to the physical factors influencing king prawn postlarval immigration into an estuary. However, we will discuss the results in light of past studies on other species of penaeid prawns and then present a hypothesis concerning the mechanism of ingress of the king prawn into an estuarine system.

One conclusion that can be made from the preliminary results presented here is that the postlarvae are transported into the estuaries on the flood tide, with few being exported out on the ebb. This has been observed for other species of prawns in the Gulf of Mexico (Roessler and Rehrer, 1971; Williams, 1969; St. Amant, *et al.*, 1966; Jones, *et al.*, 1970; Tabb, *et al.*, 1962). The mechanism by which this occurs is not known, but Hughes (1969, 1972) suggests from his laboratory work that two behavioural factors are involved; an endogenous response to current and a response to salinity. In a chamber that generated



(Each point is average of 4 samples.)

Figure 5. Mean number/m³ of king prawn postlarvae at various depths in 18 m of water off Southport Bar and surface samples inside Southport Bar. Solid line and closed circles-surface samples outside and inside Southport Bar; broken line and X-7 m depth outside Southport Bar; broken line and triangle-18 m depth outside Southport Bar. Prior to calculations 0.01 was added to each catch/m³.

a uni-directional current (i.e. rate at which the postlarvae could maintain their position) of 5 cm/sec (0.1 knot) he found that at the time which flood tide would occur in the field, postlarval pink shrimp (*Penaeus duorarum*) swam with the current but at the time of ebb tide they orientated against the current, concluding this was endogenous in nature. In respect to salinity, he found that the postlarvae could distinguish a salinity discontinuity layer of 1 $^0/_{00}$ and swimming activity would decrease and become confined to near the substrate when a decrease of 2 to 3 $^0/_{00}$ occurred. The current mechanism Hughes (1972) suggests is inoperable in the present case because of current speeds, upwards of 100 cm/sec (about 2 knots) near the areas of the bar.

This re-orientation he suggests would still lead to the majority of the postlarvae oscillating back and forth with the tide. However, his suggestion of salinity change (Hughes, 1969) for triggering settling out can aid in explaining the lack of king prawn postlarvae on ebb tide, since salinity changes of 2 to 4 $^0/_{00}$ were observed during collections.

The effect of light on the ingress of postlarval prawns into an estuarine system is confusing and the present data on the king prawn does not clarify the situation. For the pink shrimp, Roessler and Rehrer (1971) and Williams and Deubler (1968) determined that more postlarvae entered during night than day. Copeland and Truitt (1966) found this also, but in contrast to Roessler and Rehrer's determination of higher numbers being near the bottom, they found higher numbers near the surface at night with no difference in vertical distribution during day flood. Idyll and Jones (1965) found a similar situation to our limited observations of a depressing effect as sun rises and increase in numbers as sun sets during flood tide. Tabb, *et al.* (1962) found that eleven times as many postlarvae entered during the night than day. Duronslet, *et al.* (1972) found that higher numbers of brown shrimp (*Penaeus aztecus*) occurred in the upper two metres at night, in two different areas of a tidal pass, but well distributed during the day. They made similar observations for the white shrimp (*Penaeus setiferus*).

In contrast to these observations, Caillouet, *et al.*, (1970) and Eldred, *et al.* (1965) found no differences between night and day flood-tides for the pink shrimp. King (1971) also found no differences between numbers entering during day and night of three species, postlarvae pink and brown (combined, *Penaeus duorarum* and *Penaeus aztecus*) and white (*Penaeus setiferus*). The apparent confusion in respect to the effect of light on immigration of postlarvae may be contributed to two factors. First is the different species involved. But this may be eliminated because most of the papers deal with observations on the pink shrimp. Another factor is the area in which the postlarvae are collected. In the present case, king prawn postlarvae are collected just inside an inlet which has an unstable sand bank system separating it from the open sea. These sand banks create extensive breakers, and, as the water flows through the tidal pass to the adjacent areas, turbulence occurs which prevents any organism from becoming vertically stratified. Most of the papers mentioned previously which found a light effect have studied areas in which nearly laminar flow probably predominated over extreme turbulence which would allow the postlarvae to become stratified.

As hinted by preliminary results for the king prawn, lunar phase has also been indicated as influencing the numbers of postlarval pink shrimp.

In one area Roessler and Rehrer (1971) found higher numbers of pink shrimp postlarvae entering on the full and third quarters of the moon than on the new and first quarters; however, they did not find this in another area. Williams and Deubler (1968) similarly suggested that more entered on the full and third quarter. Idyll and Jones (1965) however, determined that more postlarvae entered on the new moon than the full.

Diel periodicity in vertical movement within the water column is well known in planktonic organisms and has been shown to occur in several species of prawn in the Gulf of Mexico. In studying penaeids as a group (four genera involved, *Penaeus, Trachypenaeus, Sicyonia* and *Solencera*) in 35 m of water, Temple and Fischer (1965) found that postlarvae occurred most frequently at or above mid-depth with more being caught at night than day. In contrast, Jones, *et al.* (1970), sampling at a fixed station in 27 m of water, found that during the day most pink shrimp postlarvae were near the bottom, fewer being at mid-depth and very few or none at the surface. At night, although numbers of postlarvae near the bottom and mid-depth remained nearly the same, there was an increase in numbers on the surface, though the difference was not significant. Although preliminary sampling indicated that king prawn postlarvae agreed with the classical concept of plankton occurrence, i.e., few or none at the surface during the day with high numbers during night, a full 24 hours sampling showed that high numbers were caught irregularly at the surface, irrespective of time of day. It is interesting to note that Jones, *et al.*, comment on finding large numbers of postlarvae in some daylight surface samples.

Our sampling for diel migration was done at a fixed location in an area where there is a southerly current of about one knot (Wyrtki, 1959), coupled with the observations of comparable high numbers during both day and night (Fig. 5) suggests that king prawn postlarvae may be patchily distributed, well known to occur in planktonic organisms (Wiebe, 1970, 1971; Wiebe and Holland, 1968). We have made laboratory observations on postlarvae and find that they respond to varying light intensities (unpublished data). Under very low light intensities the postlarvae are very active with few being on the bottom of the tank. However, under high light intensity the majority are on the bottom of the tank with a few still actively swimming. If a percentage of the population does remain at the surface, in conjunction with patchy distribution, a patch of high density could result in comparable numbers caught during daylight to numbers caught at night when a patch of relatively less dense numbers is sampled. Patchiness and a percentage of postlarvae remaining at the surface would also account for some authors reporting no difference in numbers caught between day and night sampling at entrances to estuaries.

HYPOTHESIS

Based on the previous discussion, we would like to propose a hypothesis, in the form of a scenario, on the mechanism by which the king prawn postlarvae make their way to an estuarine system and settle. After spawning occurs offshore, the larvae are carried in a general southerly direction. The postlarvae have a clumped distribution and the clumps have varying concentrations of postlarvae. Most of the postlarvae of these clumps inhabit the upper 7 m of the water column and are transported inshore by influences of the coastal circulation (Woodhead, 1968) and processes acting over vast areas of the Pacific Ocean (Wickett, 1967) on the East Australian Current. These density independent factors lead to extensive year to year fluctuations in numbers of postlarvae that are transported close to estuarine entrances. Those postlarvae which are transported close to passages of estuarine systems come under the influence of tidal flow at flood tide and are transported into the estuary; those that are not are carried further south and/or out to sea. Upon entering the estuary, the postlarvae settle out when the current reaches less than 5 cm/sec (0.1 knot) because of salinity changes and stimuli from sea grasses, mud flats and sand banks.

LITERATURE CITED

BEARDEN, C. M. (1961). 'Notes on postlarvae of commercial shrimp (*Penaeus*) in South Carolina.' *Contr. Bears Bluff Labs.*, 33, pp. 1-8.

CAILLOUET, C. W. JUN., PERRET, W. S. AND DUGAS, R. J. (1970). 'Diel fluctuations in catch of postlarval brown shrimp, *Penaeus aztecus* Ives, with the Renfro beam trawl.' *Bull. Mar. Sci.*, 20(3), pp. 721-729.

COPELAND, B. J. AND TRUITT, M. V. (1966). 'Fauna of the Aransas Pass Inlet, Texas.' *Texas J. Sci.*, 18, pp. 65-74.

DAKIN, W. J. (1938). 'The habits and life history of penaeid prawn (*Penaeus plebejus*).' *Proc. Zool. Soc. London*, Ser. A., 108: 163-183.

DURONSLET, M. J., LYON, J. M. AND MARUELO, F. (1972). 'Vertical distribution of postlarval brown shrimp, *Penaeus aztecus*, and white shrimp, *Penaeus setiferus*, during immigration through a tidal pass.' *Trans. Am. Fish. Soc.*, 101, pp. 748-752.

ELDRED, B., WILLIAMS, J., MARTIN, G. T. AND JOYCE, E. A. JUN. (1965). 'Seasonal distribution of penaeid larvae and postlarvae of the Tampa Bay area, Florida.' *Tech. Ser.*, Fla. St. Bd Conserv., 44, pp. 1-47.

HUGHES, D. A. (1969). 'Responses of salinity change as a tidal transport mechanism of pink shrimp, *Penaeus duorarum*.' *Biol. Bull.*, 136, pp. 43-53.

HUGHES, D. A. (1972). 'On the endogenous control of tide-associated displacements of pink shrimp, *Penaeus duorarum* Burkenroad.' *Biol. Bull.*, 142, pp. 271-280.

IDYLL, C. P. AND JONES, A. C. (1965). 'Abundance and distribution of pink shrimp larvae and postlarvae in South-west Florida waters. *Circ.*, Fish. Wildl. Serv., U.S., 230, pp. 25-27.

JONES, A. C., DIMITRIOU, D. E., EWALD, J. J. AND TWEEDY, J. H. (1970). 'Distribution of early developmental stages of pink shrimp, *Penaeus duorarum*, in Florida waters.' *Bull. Mar. Sci.*, 20(3), pp. 634-661.

KING, B. D. III (1971). 'Study of migratory patterns of fish and shellfish through a natural pass.' *Tech. Ser.*, Texas Parks and Wildl. Dept., 9, pp. 1-54.

KIRKEGAARD, I., TUMA, D. J. AND WALKER, R. H. (1970). 'Synopsis of biological data on the banana prawn *Penaeus merguiensis* de Mann, 1888.' CSIRO, Aust. Div. Fish. Oceanogr., *Fish. Synopsis*, 8.

ROESSLER, M. A. AND REHRER, R. G. (1971). 'Relation of catches of postlarval pink shrimp in Everglades National Park, Florida, to the commercial catches on the Tortugas grounds.' *Bull. Mar. Sci.*, 21(4), pp. 790-805.

ST. AMANT, L. S., BROOM, J. G. AND FORD, T. B. (1966). 'Studies on the brown shrimp, *Penaeus aztecus*, in Bartaria Bay, Louisiana, 1962-1965.' *Proc. Gulf Caribb. Fish. Inst.*, 18th Ann. Sess., 1965: pp. 1-17.

TABB, D. C., DUBROW, D. L. AND JONES, A. E. (1962). 'Studies on the biology of the pink shrimp, *Penaeus duorarum* Burkenroad, in Everglades National Park, Florida.' *Tech. Ser.* Fla. St. Bd. Conserv., 37, pp. 1-31.

TEMPLE, R. F. AND FISCHER, C. C. (1965). 'Vertical distribution of the planktonic stages of penaeid shrimp.' *Publ. Inst. Mar. Sci.*, 10, pp. 59-67.

WICKETT, W. P. (1967). 'Ekman transport and zooplankton concentration in the North Pacific Ocean.' *J. Fish. Res. Bd. Canada*, 24, pp. 581-594.

WIEBE, P. H. (1970). 'Small scale spatial distribution in oceanic zooplankton.' *Limnol. Oceanogr.*, 15(2), pp. 205-217.

WIEBE, P. H. (1971). 'A computer model study of zooplankton patchiness and its effects on sampling error.' *Limnol. Oceanogr.*, 16(1), pp. 29-38.

WIEBE, P. H. AND HOLLAND, W. R. (1968). 'Plankton patchiness: effects on repeated net tows.' *Limnol. Oceanogr.*, 13(2), pp. 315-321.

WILLIAMS, A. B. (1969). 'A ten-year study of meroplankton in North Carolina estuaries: cycles of occurrence among penaeidean shrimps.' *Chesapeake Sci.*, 10, pp. 36-47.

WILLIAMS, A. B. AND DEUBLER, E. E. (1968). 'A ten-year study of meroplankton in North Carolina estuaries: assessment of environmental factors and sampling success among bothid flounders and penaeid shrimps.' *Chesapeake Sci.*, 9(1), pp. 27-41.

WOODHEAD, P. J. M. (1968). 'Sea surface drift between Central Queensland and New Zealand.' *Aust. J. Sci.*, 31(5), pp. 195-196.

WYRTKI, K. (1959). 'The surface circulation in the Coral and Tasman Seas.' *CSIRO Aust.* Div. Fish. & Oceanogr., *Tech. Pap.* 8.

DISCUSSION

Ruello. Where did this speed of .10 knot (5 cm/sec) come from?

Barber. It comes from Dave Hughes' work on the pink shrimp. He found that they can maintain themselves in a current up to that point and since I believe in the ecological equivalent concept I used that observation assuming that it is probably true for the king prawn.

Thomson. Do you think there is any mechanism similar to what you find inside the estuary that postlarvae prawns may use to approach the mouth of the estuary, i.e., are they tending to sink to the bottom or maintain position by the estuary mouth; do you think that they are purely carried by the water column?

Barber. I think they are essentially carried willy-nilly by the physical operation of the current and it's just by chance that they make it into the estuary. Dave Hughes may be correct in his work with salinity and currents, i.e. when they get inside the bar they settle out because of the salinity changes, current changes, etc. However, there may be more in it than that, e.g. at the Jumpinpin Bar they seemed to be in the water column more after the change of the tide than in Southport where you have the sand banks right after the mouth of the Bar.

Thomson. Just a remark, Nelson in New Jersey in 1930, found that where oyster larvae penetrated into estuaries, they rise up in the water column at flood tide and drop to the bottom during ebb tide and make their way upstream.

Barber. Someone has done this with mussels in Holland, I believe.

OBSERVATIONS OF PENAEID LARVAE AROUND AUSTRALIA

BY I. KIRKEGAARD
Principal Biologist,
Northern Territory

ABSTRACT

Because the interest of the fishing industry is centred on the adult prawns our knowledge of the larval stages is limited. However, fluctuations in adult fishery must often be caused by failure of part of the larval cycle.

This is not an attempt to erect an all-encompassing hypothesis. In fact it seems more realistic to expect that some species are much more susceptible to variations in stock, induced in the larval phase, than others.

Three types of prawn life cycle are distinguished: prawns which spend both their larval life and adult life entirely in the ocean, entirely in river estuaries, or partly in the ocean and partly in estuaries, with migrations between.

Very few types of prawn spend their entire life in estuarine waters. Most species spend it entirely in oceanic waters.

The most prolific species of prawns, and therefore the most commercially exploited ones, have the mixed life cycle. The eggs are laid at sea, the larvae hatch out and migrate (with the help of currents, though they are capable of swimming small distances) into estuaries, where they change into juvenile prawns and settle on the bottom. The estuaries act as nursery areas where the prawns develop in a sheltered environment with plenty of food. When they reach adolescence they migrate from the rivers and estuaries back to oceanic waters, where they mate and the cycle begins again.

The important commercial species with the mixed life cycle and high levels of abundance are king prawns, banana prawns, and greasyback or greentail prawns.

Possible mechanisms by which the larvae are able to cover long distances, are able to locate nursery areas, and are induced to settle when they reach them, are discussed.

The prediction of the size of the commercial catch before a fishing season begins is an important facet of the management of a prawn fishery.

In the area of investigations into problems directly related to the fishery we should know more of the duration of the post larval phase, where this is a major distributive phase; the factors which attract post larval larvae to nurseries; and the actual in situ salinity preferences and tolerances of larvae and post larvae.

This paper is in part unashamedly speculative, reflecting the fact that we know very little about the strictly larval and (assumed) pelagic phase of the penaeid life cycle. Because it is commercially exploited, we tend to concentrate our thinking on the demersal phase—but just as the larvae have to position juveniles in their nursery zone, so the developing adults must place the larvae in their most suitable zone, and the maintenance of a stock depends as much on the successful positioning of larvae as on any other factor. The answer to stock fluctuations in some cases could be found in failure of parts of the very short larval cycle.

This is not an attempt to erect an all-encompassing hypothesis. In fact it seems more realistic to expect that some species are much more susceptible to variations in stock, induced in the larval phase, than others. Penaeid life cycles in Australian waters can be considered as of 3 types:

The wholly estuarine—where the entire life cycle may be completed in waters of less than oceanic salinity.

The wholly marine—where the life cycle may be completed in oceanic waters.

The mixed cycle—with post larvae and juveniles inshore in waters of less than oceanic salinity and adolescents and adults offshore, but there is a particular type in which post larvae settle in waters of approximately oceanic salinity and juveniles migrate into the lower salinities.

The wholly estuarine cycle appears to be restricted to one known *Metapenaeus*, at most perhaps two other species of *Metapenaeus* and, as a possibility only, *Miyadiella*. Throughout the rest of the world there has only been one other penaeid (a *Metapenaeus*) species suggested to have this type of life cycle. A little more information on *Miyadiella* may

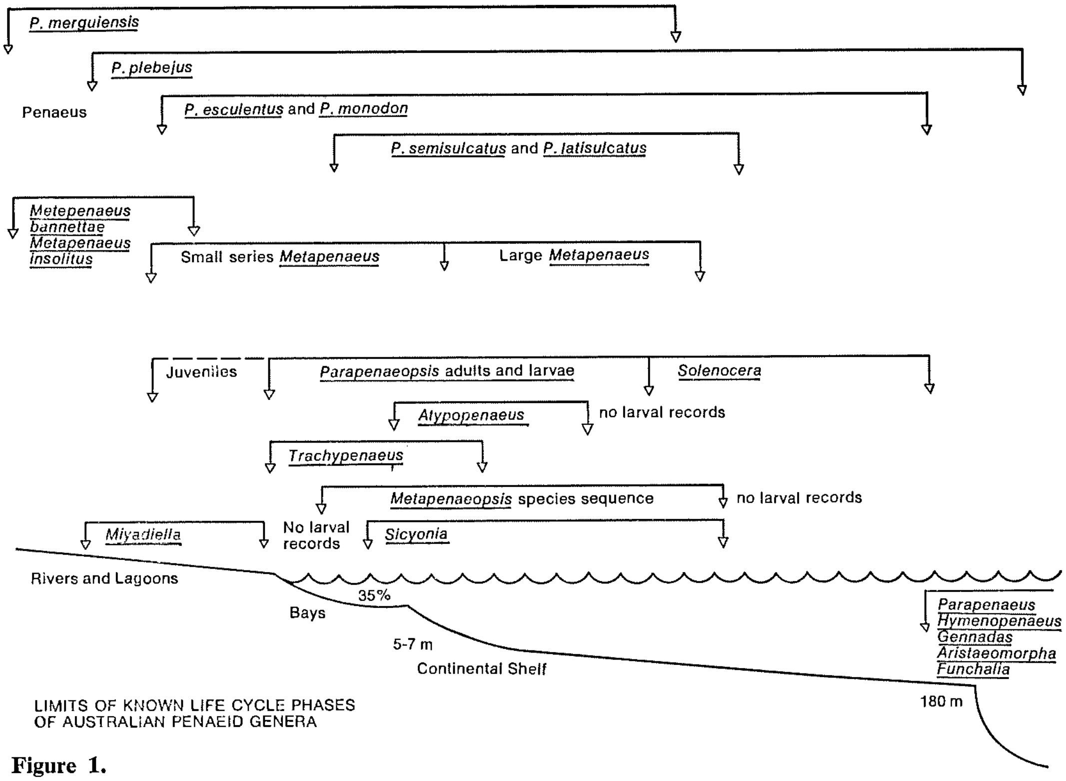


Figure 1.

reveal it as the only penaeid *limited* to rivers for its life cycle. The 'small' *Metapenaeus* appear to be facultative estuarine organisms. The wholly marine cycle claims most genera and species, although many of these show a migration of sorts, with post larvae settling in shallower water than adults. These species have a relatively narrow depth range. The wide ranging examples include two species of *Penaeus*, the same species of which may have a mixed cycle in some parts of the Australian coast and a wholly marine cycle in other areas. *Penaeus esculentus* is probably the best example of this. *Penaeus latisulcatus* appears to have similar variations in behaviour.

The mixed cycle species include what are undoubtedly the most successful penaeids in terms of biomass in a given area, and also those which suffer the greatest recorded variations in numbers. *Penaeus plebejus*, *Penaeus merguiensis* and *Metapenaeus macleayi* illustrate the high levels of abundance which can be attained, while the latter two also illustrate the wide variations in these abundance levels.

The larvae of mixed cycle species have to duplicate the adult migrations, but in reverse, and in an assumed 3-4 weeks instead of 12 months or more. In the case of *P. merguiensis* this requires penetration by pelagic stages to water of about 10% oceanic salinity. The mechanism for this appears to be differential development of the anal gland.

The mechanism suggested for covering the distances involved is the ability to ride currents. This requires the early larvae to carry out diurnal vertical migration. Since even small protozoea show a swimming rate capable of covering 50 m daily this is quite possible. If the stocks of *P. plebejus* on the east coast go through a cycle covering a total distance of 1 300 km, i.e. if the larvae duplicate measured adult migrations, they need only ride a consistent current of 2-3 kts to cover this distance in the 3-4 weeks which we assume for larval development. This is provided by the East Australian Current.

We know very little of the mechanisms which induce settling, or which direct mixed cycle larvae to nursery areas. Advanced *P. plebejus* post larvae have been found well off the edge of the continental shelf. These larvae may be caught in a gyral and be lost to the stock, or they may be able to sustain a degree

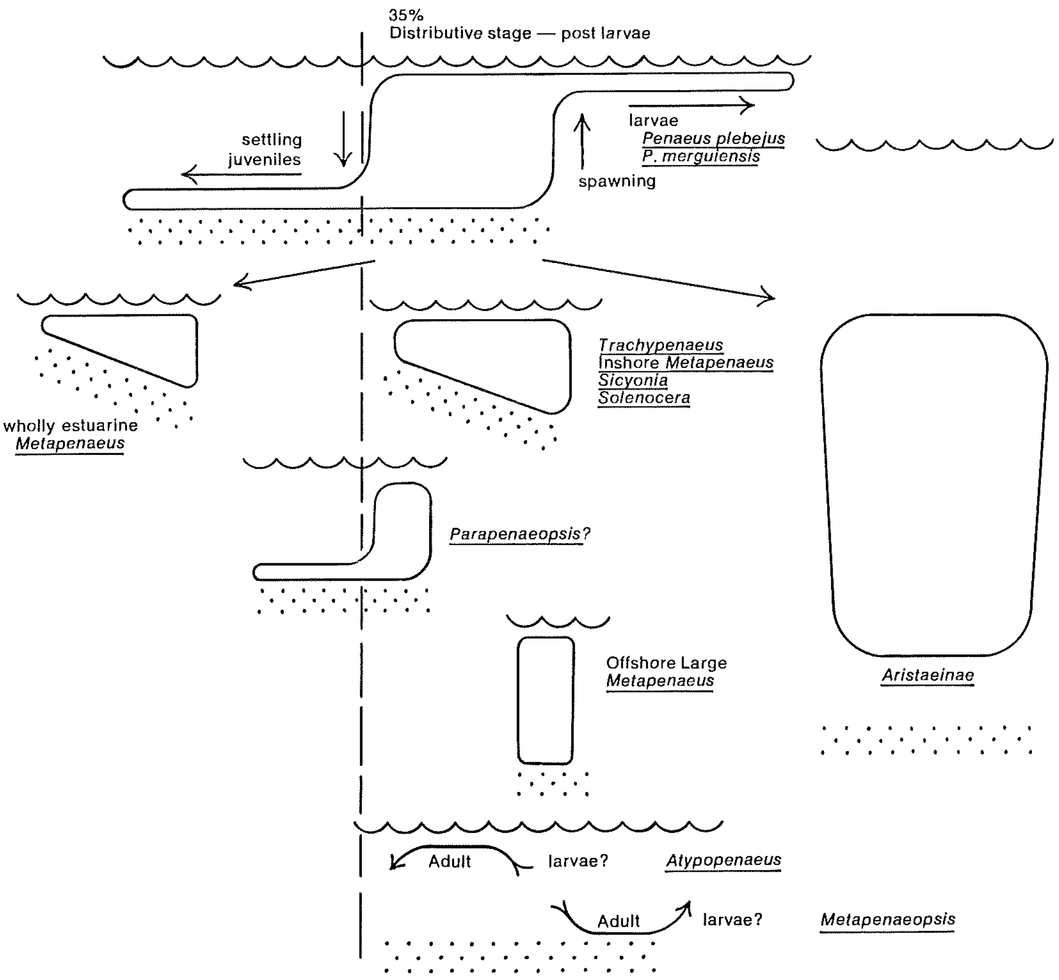


Figure 2.

of arrested development until returned to a favourable environment. There is, for example, strong evidence for a drift of Australian Portunids, as larvae, to New Zealand (which is an unsuitable area for further reproduction) so we have no grounds to assume that all Penaeid larvae are necessarily brought into favourable nursery areas.

The tight aggregations of early post larvae recorded for several mixed cycle species give us good grounds for assuming that there are factors directing their movement to nurseries. Land runoff provides a variety of likely factors from simple salinity gradients to derivatives of soil bacteria. This is an area well worth consideration in assessing the effects of pollution on prawn fisheries.

For *P. plebejus,* Professor Dakin in his early studies off the New South Wales coast has indicated certain morphological changes in equivalent post larvae depending on their being pelagic or settled. Apparently no other investigator has found similar changes in other species, or perhaps we have not troubled to look. If larvae can delay further development for some period, then they are perhaps less susceptible to vagaries of currents or tides than we might expect.

It seems that in practice there are relatively few problems involved for larvae to maintain a mixed cycle. The fluctuations of numbers in these species may be due to circumstances during the larval life, but they could also be a function of available nursery area, operating as a density independent factor. To date there is insufficient data to show what the main cause might be, but in northern Australia, with *P. merguiensis,* there are several possible explanations for observed fluctuations in numbers (if they are real and not just apparent), including interference with mating schools (human intervention) and the observed differences in extent of the coastal swamps during successive monsoon periods. There are few penaeid fisheries where adult catch has been shown to reduce recruitment of juveniles.

Although many of the wholly marine species are relatively unimportant commercially—probably because of their limited distribution—they indicate an interesting problem in larval studies, because while the mixed cycle species are quite capable of undertaking long distribution movements, those species of limited distribution are in fact concerned with maintaining their position during a pelagic phase in a highly mobile medium. It seems more than coincidental that the larvae of these species are practically unknown. There is no authoritative description of *Metapenaeopsis* or *Atypopenaeus* larvae, and the larvae of *Parapenaeopsis* have not been definitively identified. *Parapenaeopsis* may not be strictly marine, because although the larvae and post larvae have not been recorded in estuaries, juveniles of *P. sculptilis* have. Several mixed cycle *Penaeus* show a similar migration of juveniles from the apparent point of settlement of post larvae into areas of lower salinity. The larvae of the *Trachypenaeus* which, though wholly marine, do spatially separate the juveniles from the adult are relatively common. Mysis stages of the 'large' wholly marine *Metapenaeus* have been taken on occasions, but the protozoea are quite rare in collections to date. While this may reflect the relatively lower numbers of these species, the gaps, particularly for the 'large' *Metapenaeus*, are as likely to reflect a behaviour pattern which places these larvae in areas not regularly sampled. Most larval collections are taken at the surface, and at night, as this is the time and place at which commercial penaeid larvae have always been encountered. We now have the prospect of similar larval stages of different species having almost completely opposite patterns of behaviour—to position the adults in the preferred habitat.

There are, of course, other explanations. Possibly the larvae are taken regularly and unrecognised. Since other genera have larvae quite characteristic of the genus, it is reasonable to expect the same differentiation for say *Metapenaeopsis*. On the other hand they may be too sparse. This is also difficult to sustain since the apparently rarer *Sicyonia* and *Solenocera* have been represented in night/surface plankton samples, in numbers of the same general proportion to other genera as are found for adults. In any case, although a given *Metapenaeopsis* species may be quite limited in distribution, the genus as a whole covers a wide range of wholly marine habitats. The picture I have in mind is of a series of restricted cycles which are similar to each other, but all different, in major aspects, to the mixed cycles species.

For anyone who wishes to consider a general hypothesis on life cycles, I would offer the following:

The original penaeid life cycle was probably a mixed cycle, as indicated in the figure.

This gave the orgnisms access to a wide range of habitats with only moderate risk, and is reproduced in whole or in part by extant mixed cycle species.

The phylogenetic tendency has been towards attenuation—firstly of the extensions to the basic quadrilateral.

The general quadrilateral form may also be shifted entirely into estuaries or abyssal depths. In each case this should allow a species to fill a relatively open niche, bypassed by the more abundant mixed cycle species.

It would be premature to try to develop any hypothesis at present. In the future, however, after the known life cycles have been fully determined, such a hypothesis may be useful to predict the likely occurrence of the 'lost' larvae—and in the classical scientific method, support the formulation of a good theory.

One of the advantages of working on adults, particularly of a commercial species, is the sampling capacity represented by the fishing fleet. To duplicate this for larvae would be financially impossible. Since larval numbers do not appear to have a consistent, direct correlation with previous or subsequent adult numbers, there is little justification for spending large amounts of time and money on their study. What then are the practical uses of larval studies?

One thing the presence of larvae does indicate unarguably is spawning success, and, correlated with gonad studies, the onset of spawning in each season. As our fisheries develop to their maximum yields so does the need for accurate stock prediction. It seems that the accuracy of predictions from post larval or juvenile indices of abundance only reach an acceptable level as the stock is approaching maximum sustainable yield point, i.e. when it is most intensively sampled.

Accurate predictions of stock sizes should allow redirection of effort. With penaeids the short duration of the life cycle only allows perhaps six months time to do this, instead of the six years which may be available in, e.g., a rock lobster fishery. Any extension of this six months is time gained. At present our knowledge of larvae has not reached the stage where we can assess the value of further studies in this case, but we may find the needs of the fishery forcing our attention into this area. Larvae of commercial species may also have value in survey operations. Plankton is more easily and quickly sampled than bottom organisms, and it may be possible to survey a new area for say first stage protozoea (on the assumption that they are found near the adult spawning grounds) at far less cost for initial reconnaissance than is incurred in regular trawler samples.

The history of exploitation of some grounds suggests that they are occupied by a 'relict' stock, derived from elsewhere and in no way contributing to its own renewal. While such stocks could be managed, it is doubtful if the costs of investigation of the source and consistency of recruitment could be justified. Not only is the larval investigator denied the sampling provided for adult studies from the commercial fleet, but he is also denied the essential tool of marking known individuals, at least until genetic markers can be developed, or some stain or tracer very much better than those available at present.

As for other uses—apart from production of stock for aquaculture—it seems we still know so little about larvae, even taxonomically, that we do not have sufficient knowledge to assess their value to us as a tool in research. For the non-applied biologist, however, there are some potentially fascinating avenues for investigation. One is to identify the 'lost' larvae of *Metapenaeopsis*, *Atypopenaeus* and *Parapenaeopsis* and plot their distribution. Another is to find parents for the odd larvae of the Aristaeinae which appear around the Australian coast.

In the area of investigations into problems directly related to the fishery, we should know more of the duration of the post larval phase, where this is a major distributive phase; the factors which attract post larvae to nurseries; and the actual *in situ* salinity preferences and tolerances of larvae and post larvae.

DISCUSSION

Neal. Do you have any evidence to support your idea of the larval period of 3 to 4 weeks in the pelagic stage?

Kirkegaard. I would have to say that it is an assumed period based on the general rate of development for those very few species that have been raised from eggs to postlarvae or even part way, but there is no real evidence for it.

Neal. I might just draw an observation with *P. aztecus* in the Gulf of Mexico. We have a peak of abundances of spawning females about October and the only apparent peak in the ingress of postlarvae into the estuaries is about January or February. These are fairly low temperatures probably below 20°C. We are not sure that these are the females that produce this peak of postlarvae, but it is possible.

Kirkegaard. I wish I knew too. Just in explanation—I tried to restrict what I said here to the pre-postlarval phases. I can see a lot of value in postlarvae as can a lot of other people. They are good to work on and they seem to correlate well with stock estimates. The stuff you showed us this morning from the Gulf of Mexico looked good; I don't think anyone comes anywhere near that sort of correlation with strictly larval studies, have they? I am not aware of any if they have.

Thomson. You are making assumptions based on a few aquarium observations, do you regard that rates observed in aquarium situations as comparable to natural situations?

Kirkegaard. No, but they are all we have got.

Penn. I would like to make one comment on your figure that you seem to have left out a whole section which relates to the W.A. coast where you have high salinities in estuaries, or what we call estuaries, doesn't fit your definition obviously, that *P. latisulcatus* in fact goes into very high salinities in a similar way to *P. plebejus* goes into very low salinities by comparison. I think that the spread of distribution is somewhat similar except it goes into a section which you haven't represented in the group here.

Kirkegaard. Do you know what your high salinity represents? Is it in fact a concentration of salinity or is what you're measuring a concentration of some other dissolved solids as well?

Penn. I would almost certainly say salinity and the salinities range up to 45 parts per thousand approximately. *P. latisulcatus* also occur in estuaries in our south coast which are in lower than sea-water salinities so they seem to go through the whole range.

Kirkegaard. Do you have any observations to suggest that the species goes into a similar sort of habitat but one with high salinity in one area and what is apparently similar but with a lower salinity somewhere else. Does this happen at all?

Penn. You are talking about *P. latisulcatus* going into both high and low salinity in one area?

Kirkegaard. No, do you have situations where salinities are above oceanic and somewhere else below and do you have *P. latisulcatus* in the same areas?

Penn. We have both, very similar situations; not much in the way of mangroves but certainly in these high salinities and in Shark Bay there are postlarvae in fact right through the range.

Kirkegaard. In the lower salinities they don't penetrate, is that right?

Penn. They do occur in our, what we call, freshwater estuaries, which go a little below normal sea-water, but nowhere as near as many, but they are, however, caught commercially in very small quantities.

BIOLOGY OF THE BANANA PRAWN *(PENAEUS MERGUIENSIS)* IN THE SOUTH-EAST CORNER OF THE GULF OF CARPENTARIA

BY I. S. R. MUNRO
Principal Research Scientist
CSIRO, Division of Fisheries and Oceanography,
P.O. Box 21, Cronulla, N.S.W. 2230

ABSTRACT

This outline of the life history of the banana prawn (P. merguiensis) is based on a first study conducted in a remote area in which no prawn fisheries had operated previously. The information is derived mainly from biological and environmental investigations carried out by the Gulf of Carpentaria Prawn Survey of 1963-65.

This was a co-operative effort by the Department of Primary Industries, Queensland, the Australian Department of Primary Industry and the CSIRO Division of Fisheries and Oceanography, orientated around a search for prawns in quantities suitable for commercial exploitation.

These studies, not simply exploratory fishing, were the key factor in establishing the presence of the prawn stocks.

Banana prawns form huge 'prawn boils' which can be picked up on echo-sounders or spotted from the air. When a boil is found a few minutes trawling is enough to fill the net. Fortunes have been made in the Gulf banana prawn fishery.

Spawning occurs in open waters, and larvae hatch from the eggs. Over several weeks they metamorphose through four distinct stages, and gradually migrate toward the river estuaries. These are the nursery areas where the juvenile prawns develop in a protected environment and an abundant food supply.

At adolescence the prawns leave the rivers and migrate to deeper water. Males are then sexually mature, but females do not reach sexual maturity until they are 16-32 km out to sea in water of 13-20 m. Here they form the compact schools or prawn boils. Mating takes place here during winter though probably not in the prawn boils, but spawning occurs in deeper water during late winter and early summer.

The Gulf survey concentrated on the south-east corner of the Gulf which is near the geographical centre of banana prawn distribution in Australia and is now the biggest production area for banana prawns in this country. It provides the bulk of the prawn export market to Japan.

INTRODUCTION

The following outline of the life history of the banana prawn (*Penaeus merguiensis*) is based on a first study conducted in a remote area in which no prawn fisheries had operated previously. The information is derived mainly from biological and environmental investigations carried out by the Gulf of Carpentaria Prawn Survey of 1963-65. Some gaps have been bridged by miscellaneous observations by former members of the survey team during monitoring of commercial fishing operations from the port of Karumba during 1966-68. Studies on the stocks of juvenile prawns in the Norman River were restricted to a period of only seven months during 1965, and in order to obtain a full annual coverage, data have been drawn from the first year of sampling in that river beginning September 1969, by the present CSIRO Northern Prawn Project.

It is emphasised that the observations and opinions presented refer specifically to virgin stocks in the south-east corner of the Gulf of Carpentaria. This particular area topographically is not typical of the Gulf as a whole and differs in many ways from banana prawn habitats elsewhere in Australia and the overall range of the species. However the study area is situated towards the geographical centre of the species range in Australia and is one of the largest production areas for the banana prawn fishery of this country. It is possible that certain aspects of behaviour are in response to interaction of stocks with particular local environmental features. Thus some restraints should be exercised in any attempt to extrapolate all conclusions to other fishing areas.

As background to the first basic study it should be recalled that the Gulf of Carpentaria Prawn Survey was a co-operative project conducted during 1963-65 jointly by Queensland Department of Harbours and Marine, Commonwealth Department of Primary Industry and CSIRO Division of Fisheries and Oceanography. The two-year field operation was orientated basically around a search for prawns in quantities suitable for commercial exploitation. By 1962 Governments were aware that intensive fishing and possible over-capitalisation were adversely affecting prawn fisheries along the east coast of Queensland and undertook the survey in an effort to open up new fishing grounds. Being aware also that little was known of prawn biology or of the environmental details of their habitats, opportunity was taken to conduct a variety of scientific investigations in conjunction with prospecting operations by a standard prawn-trawler. Sufficient information on distribution and behaviour of banana prawns was gathered to demonstrate that sizable stocks existed in the area and that these could be harvested over a six-month season in defined localities at predictable times of schooling. It is interesting to note that the basic biological and environmental studies contributed as much to the identification of presence and behaviour of the banana prawn stocks as the systematic fishing search over the area. These first studies have particular value in that they were conducted in an area and environment in virgin condition and that examination was made of a resource which had hitherto been completely unexploited and thus in no way effected by the fishing pressures of man.

PHYSICAL AND CHEMICAL ENVIRONMENT OF THE STUDY AREA

The area which was investigated in detail comprised the south-east corner of the Gulf of Carpentaria within operational distances of 130 to 190 km from the port of Karumba. It covered an area of approximately 25 000 km^2 and was bounded on the north by a line due east from the north-east corner of Mornington Island, on the west by the Wellesley Islands and on the South and east by the mainland coast.

Environment and climate of this portion of the Gulf and its surrounding land has been described in some detail by Munro (1973) but the principal features are outlined here to provide background to the biology of the banana prawn.

Land forms and river systems. The mainland surrounding the study area is part of the so-called Gulf of Carpentaria Lowlands, one of three sectors of the Central Lowlands which are regarded as being one of the six major topographical divisions of the Australian continent. These Gulf of Carpentaria Lowlands consist of gently sloping plains scarcely elevated above sea level but forming a structural basin with a fairly low watershed divide. This divide rises to about 900 m in the Newcastle and Gregory Ranges to the east, to only 370 m in the Selwyn Ranges to the south and gradually slopes westwards to the Barkly Tableland. Much of the down-warped extension of this basin is submerged and forms the floor of the Gulf of Carpentaria.

Numerous streams flow across these gently sloping plains in a radial pattern from their headwaters in higher ground which constitutes, over a distance of about 1 600 km, the perimeter of the Gulf of Carpentaria Lowlands. On reaching the sea these streams discharge at intervals of a few kilometres apart along about 350 km of coastline. These streams can be grouped into ten major basins but except near their headwaters the basins are not separated by watershed divides of perceptible altitude. The principal rivers originate 250-550 km inland and the flat country through which they flow is largely grassland plains which are replaced near the coast by vast arid clay-pans and marshlands. Because of the flatness of the terrain the streams have many tributaries especially in their upper portions but nearer the coast numerous anabranchs and distributaries link some of them together. In their lower reaches through the coastal salt-pans their courses become extremely serpentine. Among Australian drainage systems these rivers rate fairly high in terms of annual discharge, but as they are dependent on rainfall they flow only during the summer monsoonal wet period. For this reason the smaller coastal streams and upper reaches of the main rivers and their tributaries are non-permanent. Only the lower reaches of the principal rivers to a distance of 65-130 km from the sea can be rated as perennial and this is mainly because of tidal influence.

The coastline along the southern shore and the lower reaches of rivers and creeks are narrowly fringed with mangroves. Vast areas of tidal flats comprising deposits of muddy sand fringe much of the southern shoreline. At low tide these exposed flats merge into the salt-pans of the land and the shoreline is discernible only by the narrow line of mangroves. Narrow sandy beaches form the shoreline along much of the coast north of the Norman River.

Topography of the Gulf Floor. The study area has the general shape of a segment of a saucer in which the rim represents the coastline. It is contained completely within the 36.5 m depth contour and shelves very gradually from the coastline and attains a depth of about 31 m at a point north-east of Bountiful Island. The bottom is marked by a series of slightly deeper depressions arranged in radial pattern and converging into a common channel at a point 24 km east of Bountiful Island. These depressions follow seaward from the mouth of each major river. These depressions are narrower and more numerous in the 15-18 m depth zone in the area 32 km seaward of the delta system of Smithburne River, Van Diemen Inlet and Duck Creek. A chart of the contours was published by Munro (1967).

Sediments. The superficial layer of sediments in the south-east corner of the Gulf range from silts and plastic muds through various grades of muddy sands to quite clean sands. Most of these sediments have a high calcium carbonate content derived from fragmentation of molluscan shells and exoskeletons of other invertebrates. Apart from organic matter these sediments are composed of some or all of the following—lutite (finest unidentified silt and clay fractions), quartz sands in a range of particle sizes (rated as very fine, fine, medium, coarse and very coarse on the Wentworth scale), shell fragments (from less than 0.3 mm to inclusions of almost whole shells), granules and small pebbles (mostly of red ferrugineous material) and Foraminifera. The relative content of these components and their mixture proportions varies considerably over the area and over 1 000 combinations were identified by rating relative abundance at absence, trace, low, moderate and dominant and recognising five particle sizes for sands and four particle sizes for shell. One classification based on relative abundance of lutite and dominant grain size of sands produced 134 types of sands and muds, some varying slightly by virtue of particular larger inclusions.

The most outstanding feature is the geographical distribution of lutite, which being of terrestrial origin, decreases in relative sediment content from the shoreline to seaward. Along a quite narrow belt closely adjacent to the shore are the very fine silts and plastic muds composed predominantly of lutite and very fine sand grains. In a somewhat wider belt immediately seaward of the silts are sandy muds containing moderate quantities of lutite. Beyond this and paving much of the Gulf floor are muddy sands with low lutite content. Towards the centre and generally across the north of the study area lutite content drops to trace levels and finally disappears producing wide tracts of clean sands. Some of the sands in the outer areas have relatively high shell content and may have quite high content of red granules and foraminiferal tests. Similar types of cleaner sands occur in patches nearer the coast and one such area of quite large dimensions is situated in the south-west corner seaward of Moonlight Creek.

The quartz sand component usually comprises a mixture within several ranges of grain size. In the inshore silts very fine grains (less than 0.1 mm) predominate. Over most of the area fine grains (0.1-0.3 mm) dominate but are mixed with low to moderate amounts of very fine (less than 0.1 mm) and medium (0.3-0.6 mm) grains, trace to low amounts of coarse grains (0.6-1.2 mm) and traces of very coarse grains (greater than 1.2 mm). Moderate amounts of very fine fragments (less than 0.3 mm), moderate amounts of fine fragments (0.3-3.0 mm) and low to moderate amounts of medium fragments (3-10 mm) represents the typical shell content of the muddy sands and sandy muds which pave much of the area. Coarse shell is regarded as an inclusion and is irregularly distributed throughout the area.

Climate and Oceanography. The Gulf of Carpentaria as a whole is affected by a N.W. monsoonal circulation during December to March and a S.E. to E. monsoonal circulation during May to October. However the southern section including the study area is influenced during summer more by migratory southern pressure systems than the N.W. monsoon. These seasonal alternations in direction of circulation combined with annual range of ambient temperature and a very restricted wet season have marked effects on the hydrology of the region.

The change in direction of prevailing wind flow from predominantly S.-S.E. during winter to N.-N.E. during summer is accompanied by a fall in mean sea level during winter and a rise in mean sea level during summer. During 1963-65 the tide gauge at Karumba indicated a mean annual level at 1.55 m above a datum based on the mean of low water spring tides and a range in mean monthly levels between summer and winter of 1.07 m.

Rain is markedly seasonal and the wet period extends from December to March with a virtually rainless period from July to September. Mean annual rainfalls are of the order of 940 mm at Normanton and 730 mm at Burketown. Cloud cover reaches a maximum of 5-6 tenths during the wet season but decreases to less than 2 tenths during July to September. The shortness of wet season affects the permanency of rivers and the resultant run-off from land establishes a marked salinity gradient from shore to seaward during late summer.

Mean monthly ambient temperatures drop to their minimum (12.8°C) in July and reach their maximum (36.7°C) in November. Although differences between monthly maxima and minima are as low as 8.9°C in February and as high as 17.8°C in April and August, mean monthly maxima remain high (28.9-36.7°C) even during winter when sparse cloud cover gives minimum screening from solar radiation. High evaporation rates result from this exposure to intense solar radiation through all months, and during winter assistance is provided by persistent wind action and negligible precipitation or run-off. The evaporation effects are greatest in the shallow inshore belt where heating is achieved more speedily than in deeper water. During summer prior to the rain, salinities over the whole area rise and attain hypersaline values relative to normal sea water in the shallow inshore belt and tidal parts of rivers.

In surface and bottom layers salinites range from almost fresh water to hypersaline. The highest (37.93 $^0/_{00}$) and lowest (0.46 $^0/_{00}$) values were recorded in the shallow inshore belt during summer respectively immediately before and during the wet period. The major part of the area is never completely stable because of the seasonal effects of evaporation from solar heating and wind action on one hand, and dilution from rain and fresh water river run-off on the other. The salinity gradient established in late summer after the rains is that of increase from shore to seaward. These dilution effects are not overcome until June or July when salinities of 34.00-35.00 $^0/_{00}$ predominate in surface and bottom layers over most of the area. As hotter drier weather approaches evaporation increases these values to 35.00-36.00 $^0/_{00}$ across much of the area by October. Higher evaporation rates in the shallow inshore belt produce even higher salinities there and thus through early summer the salinity gradient reverses in that values decrease from shore to seaward.

For the area as a whole the seasonal range in water temperatures is 16°C. As with salinities the highest (32.7°C) and lowest (16.7°C) recorded values relate to the shallow inshore belt respectively during summer and winter. The Gulf waters undergo heating and cooling in parallel with the seasonal changes in air temperatures, and the extent of heating is largely a function of the seasonal intensity of solar radiation. Because the shallow inshore waters heat faster in summer and cool quicker in winter than deeper waters, temperature gradients are established in surface and bottom layers through all months. For most of the year the gradient is one of increase from shore to seaward. This is established after the wet season and as winter approaches the shallow inshore waters cool relatively quicker than deeper parts. During January most of the area has attained temperatures of 30°C or greater. In February the gradient starts to become established and a progressive drop in temperature over the whole area accompanies the approach of winter. By May the gradient is characterised by rather evenly and closely spaced isotherms. In August the deeper areas have decreased in temperature to 23°C. However during October to December the shallow inshore waters begin to warm up at a rate quicker than deeper water and this produces a reversal in the direction of the gradient, namely a decrease from shore to seaward.

Thus temperature-salinity characteristics vary greatly from shore to seaward and by season. During summer juvenile banana prawns use as nursery areas the very unstable inshore conditions of high temperatures and wide extremes in salinities. However sexually mature prawns seek, for mating and spawning, the stability of lowered temperature and normal sea-water salinity attained in winter in deeper waters offshore.

Tides and Moon. Simple oscillation of tidal flow during flood and ebb phases apparently accounts for the major water circulation in the survey area. Flow is mainly through the wide open area to the north but portion is through the passages between the Wellesley Islands and the mainland.

In this part of the Gulf the tides are diurnal but become semi-diurnal for one to three days during neaps and are then locally known as 'double tides'. A full cycle occupies a lunar month and is divided by the neaps into two fortnightly periods. One is characterised by having time of H.W. approximately coincident with time of moon-rise and the other with having H.W. approximately coincident with time of moon-set. Amplitudes of rise and fall gradually increase and then gradually decrease during alternate weeks. Mean annual ranges in amplitude are 0.46 m during neaps and 3.33 m during springs. Because of the coincidence with moon rise and set, times of H.W. become progressively later each day by increments of slightly less than one hour. Times of H.W. most closely approximate those of moon-rise or set through the top of the springs but there is a gain of several hours during the period immediately before the neaps and a similar time lag during the period immediately after the neaps. At the change of half cycles at each neap time of H.W. sets back 6-10 hours according to season. In terms of time of day, each new fortnightly oscillation begins an hour earlier than the one preceding. This effect brings night tides into the afternoon and then into the morning as a lunar year progresses. H.W. occurs between noon and midnight from November to April and between midnight and noon from May to October. The cycle is not consistently in phase with the moon's quarters. During some months springs correspond with new and full moons and neaps with first and third quarters. In other months the reverse is the case, and thus in transition periods the springs and neaps are out of phase with the moon's quarters.

It is likely that larval stages of banana prawns utilise tidal movements for transport from spawning grounds to nursery areas. The 'balling-up' of adults into compact schools and the associated production of 'mud boils' occurs mainly during periods of minimum water movement, namely near time of H.W. or L.W. slack during neap tides.

GENERAL OUTLINE OF LIFE CYCLE

The overall pattern of the life history is very similar to that of other penaeinid prawns. The cycle involves marine and estuarine phases with a shoreward migration of larvae and a seaward migration of adolescents and adults. The basic principles of the cycle have been demonstrated by Munro (1968).

Spawning certainly appears to occur in open waters and not in estuaries. In typical penaeinid manner the eggs are shed and hatched larvae pass through a metamorphosis involving numerous instars in each of the well-known nauplius, protozoea, mysis and post-larva stages. Throughout this larval phase the various stages are planktonic although not necessarily occupying the upper layers throughout the full day. As development proceeds a migration is made towards the shore from the spawning ground. By analogy with other penaeinid species the larval phase would occupy several weeks.

The planktonic larvae have reached the postlarval stage by the time they enter the saline estuarine reaches of rivers. These parts of the rivers and adjacent Gulf shoreline have fine muddy sediments and are fringed with mangroves. In this environment the post-larvae appear to settle on the bottom. They rapidly develop into small juveniles which remain in the rivers feeding and increasing in size over a period of up to several months.

On reaching adolescence the banana prawns leave the estuaries and begin an offshore migration to deeper water. While in the rivers they are greenish with fine darker speckles. When they move to sea they change to creamy yellow with reddish shades especially on the telson. Males mature earlier than females and appear to be fairly mature sexually when or soon after they leave the rivers. Females are sexually immature when leaving the rivers but they continue to grow quickly and are ready for mating by the time they have travelled 16-32 km to sea and occupy areas of bottom between the 13-20 m contours.

When reaching this depth schooling activity becomes very strong. Periodically they lift from the bottom sediments and 'ball-up' into compact schools slightly above the bottom. These schools may contain many tonnes and their presence is indicated by discoloured water or 'mud-boils' at the surface and their position can be detected by echo-sounder. The commercial fishery operates on schools in this condition. Thus banana prawns can be very vulnerable to capture. The length of time that individuals spend in selected parts of this depth zone is unknown. Stocks as a whole are found in this zone from early March to late September and apparently actively feed and mate there. Individuals may only be present briefly in such areas as they proceed along their migration paths or they may congregate in such areas for longer periods to obtain specific foods.

Schooling activity appears to coincide

largely with periods of little water movement such as at slack water particularly close to neap tides. While mating definitely occurs in this zone, no spent individuals appear in catches and it is most unlikely that spawning takes place there. As the summer approaches individuals no longer school in this depth zone and it seems that they have continued their migration into deeper water, perhaps beyond the study area to spawn in open waters.

Postlarvae and juveniles are present in the Norman River throughout all months but are much more active and abundant during summer. The smallest juveniles caught in such nursery areas appear first in November. Summer appears to be the active growing period for juveniles and adolescents travelling to sea have left the rivers by the end of March. The inference is that spawning takes place offshore early in summer and some spawning activity extends well through the summer period bringing periodic waves of postlarval recruits to the river and inshore nursery areas.

LARVAL PHASE

Plankton tows were made in the Norman River and in several areas through the southern Gulf during 1964-68 to obtain larval stages. Taxonomic studies on this material have been carried out by Kirkegaard (1973). Nauplius stages of the general penaeinid type occurred widely but these could not be identified. Protozoean, mysis and postlarval stages which possessed features associated with members of the Genus *Penaeus* were found in areas seaward of the Norman River mouth. Again these could not be separated specifically until the postlarval instar occurred showing development of the first and second rostral teeth. Postlarvae with this degree of development were divisible into two series; one follows the mode of development of grooved prawns and has been attributed to *P. latisulcatus* (blue-leg king). The members of the other series have been attributed to *P. merguiensis* rather than to *P. esculentus* (tiger) or *P. monodon* (panda) mainly because of the progression in growth of the rostrum. Consecutive instars form a series where the rostrum shows progressive elongation throughout postlarval life up to a stage where it is continuous with the form of rostrum demonstrated for juvenile *P. merguiensis* by Dall (1957).

Postlarvae were present between September to May (nine months) in the Norman River off the settlement of Karumba. Also they were present in the environs of the river mouth and upstream to about Russell Creek (about 10 km from the river mouth). Postlarvae considered to represent this species occurred throughout the central parts of the study area between Mornington Island and the Norman River mouth. Protozoea and mysids of the genus *Penaeus* (possibly *P. merguiensis*) were also found throughout this same period throughout the central parts of the survey area and also to the west of Mornington Island. Postlarvae were taken in at least few numbers during every month. One might assume then that spawning takes place over a protracted period but most of the activity occurs through summer. Distribution of larval stages, especially the protozoea and mysids (if in fact they are *P. merguinensis*), indicates spawning grounds in the deeper parts of the study area near Mornington Island or even further offshore from the mainland coast. The shoreward migration and entry into the Norman River estuary also occurs over a protracted period in all but the very coldest months.

Activity of protozoea and mysids was noticably greater between sunset and sunrise but postlarvae appeared equally active during daylight and dark in the Norman River estuary. However the postlarvae taken in the Gulf itself showed an increase in activity after sunset, and as these presumably were earlier instars their behaviour followed that of the earlier larval stages.

The protozoean stages are most abundant in the plankton during the second quarter of the moon and persist at a lesser level during the third quarter. The mysid stages show similar distribution patterns through these two light phases of the moon but persist in small numbers through the fourth quarter into the first quarter. Postlarvae show no particular peaks of occurrence throughout the complete lunar progression. Assuming that the nauplius stages occupy 2-3 days after hatching of the eggs and the protozoean and mysid stages occupy about another week each, the observed planktonic distribution suggests the possibility that spawning takes place at monthly intervals coincident with, or within a day or two of, new moon (darkest phase).

As already noted most of these protozoean and mysid stages were taken during the hours of darkness. These catches at night refer predominantly to the surface layers. The few taken from bottom layers were caught mainly during daylight. Unfortunately the layer sampled was not recorded in about half the tows from the Gulf but these are likely to be surface horizontal or vertical. The major proportion of these contained protozoea and mysids caught at night and probability is high that they were taken in surface layers also. Thus we have some evidence of diurnal-nocturnal vertical migration and negative phototropism of earlier larval stages while at sea. Postlarvae caught at sea appear to behave likewise. This response to light seems to be lost after the postlarvae enter the Norman River. In their estuarine phase postlarvae occur in both surface and bottom layers during daylight and dark but the greatest number of occurrences and the highest catch rates occurred during daylight.

There is some indication of peaks of abundance of protozoean and mysid stages in the surface plankton at night after the moon rises. As these stages are present mainly during the second and third moon quarters, namely the light phases when moon rise is after sunset and before sunrise, the migration to the surface seems as a response rather to the arrival of night than to the coincidence of increased lunar illumination measured by intensity and duration of incidence.

In the Norman River during September to May postlarvae were found in the plankton on most days sampled irrespective of the age of the tidal cycle calculated with neaps as the midpoint of each cycle. During the same period they appear in the plankton through most of the ebb tide and low slack water but from December to May they remain in the plankton through the first half of flood tide. Their presence during the second half of flood tide approaching high water was observed only in May-June, September and November. The highest observed catch rates were during November at this state of tide during the springs when three consecutive daylight morning tows each of 5 minutes duration took respectively 30, 48 and 107 postlarvae at the surface. As tidal velocity and water transport are at their higher values about the middle of flood during springs, we have a suggestion that postlarvae make use of such tidal flow to assist their migration into the river. At other periods appearance in the surface or bottom plankton might well be just normal daily activity of postlarvae that have already taken up residence in the river.

Occurrences of postlarvae in river plankton, particularly through the ebb into the first half of flood tide, in addition to being distributed between daylight and dark, are divided almost equally between bottom and surface layers. The relative proportion varies with season with a bias towards surface in early summer (September-January) and towards bottom later (February-May). This coincides with reduction in surface salinities after mid-summer rain. During this residence in the river times of low water become progressively earlier changing from evening (1700-2200 hours) in September, through late morning (0700-1200 hours) in January to early morning or night (2200-0600 hours) in May. The incidence of solar light during the late ebb into early flood thus varies considerably and thus it is likely that rising into the plankton is in response to decrease in tidal flow and settling back to bottom sediments is in response to increase in tidal flow. Such a mechanism could retain stocks of postlarvae within the river.

JUVENILE PHASE

The distinctive prolongation of the rostrum and its progressive shortening with increase in age has been demonstrated by Dall (1957). As stated above this is a postlarval character which continues through juvenile growth instars. This feature greatly facilitates positive identification of juveniles of both sexes which have not yet developed characteristically shaped external genital appendages.

In practice it is difficult to distinguish the sex of juveniles having carapace lengths of less than about 10 mm. Thus length frequency data have been divided into three sets representing indeterminates with a range of 4-15 mm, males with a range of 5-31 mm, and females with a range of 7-32 mm carapace length.

Juveniles occur in the lower reaches of the Norman River through all months of the year but numbers vary considerably with season. The following observations are based on 35 061 individuals collected during 2 601 samplings with a miniature beam trawl towed for durations of 15-30 minutes during 1965-70. The data for these years have been combined. The mean trawl effort (in terms of number of shots) was 217 shots per month. The effort fell below this level in July and August and in October and December, the greater reductions being to 170 and 118 respectively during July and August. This reduced effort during late winter is accompanied by a reduction in catch (total numbers and catch rate per shot) but the sampling effort was still fairly high.

Seasonal variation in size of the population occupying the river nursery grounds is very marked. The monthly total numbers of indeterminates, males and females and the mean monthly catch rate per shot reached their peaks in December but fell virtually to zero in August. This represents a build-up in population size beginning in September, maintaining high levels through summer but rapidly falling off after March. This means that greatest numbers of juveniles occupy the river environment during the summer and thus the summer is the growing period for transition from postlarvae to adolescence. The virtual absence of a population in August could well mean that all individuals have achieved their adolescence and departed from the river by winter. However there remains some possibility that those which have not attained size at which seaward migration is undertaken, may winter over in the river but change patterns of activity and thus not be captured by the gear used. The steepness of slope during October to November in the graphs which show total numbers of indeterminate sex and mean catch rate numbers suggest active recruitment to the nursery grounds especially of smaller juveniles during this period. This is consistent with the observation that the highest catches of planktonic postlarvae were taken during the flood of spring tides during November.

The smallest recognised juveniles taken in the beam trawl have carapace length of 4 mm. This particular size group are first noted in the indeterminate sex set in November and remains through to February and March. Their presence during this period supports the contention that juvenile stocks in the river are built and maintained throughout summer months by successive waves of shoreward migrating postlarvae. The proportion of individuals in the indeterminate sex set relative to combined males and females increases to near equality during November to January and exceeds combined males and females in February. During March onwards the proportion of indeterminates to combined males and females becomes increasingly less. This relatively greater abundance of smaller individuals during early summer adds support to the idea that recruitment is heaviest during this period. Disappearance of the 4 mm class interval by March and of the 5 mm class interval through April to October, backed by the falling off in numerical strength of the whole indeterminate set also suggests that active recruitment has ceased by the end of March. Modes in the size frequency distributions of this indeterminate set vary within the range of 9-11 mm.

Variations in size composition and numerical strength of the indeterminate sex set provide clues to the period of active recruitment to juvenile river populations. The falling off in numbers after March and their disappearance in August suggests their complete transition to the more advanced instars which can be distinguished sexually. The male and female sets of larger juveniles occur in the river during all months except August. Their combined numbers are highest during summer but fall off through winter as a result of cessation of recruitment from postlarval arrivals and departures from the river by migrating adolescents. However during September and October they are quite strong numerically and the frequency distributions of each sex show a wide spread of carapace length with modes at 15-16 mm. During these months the strength of the indeterminate sex set is weak and presumably represents earliest arrivals in the new season of recruitment. The population of males and females present in September and October must thus be derived from the previous summer recruitment period. In other words this residual river population has wintered over and no doubt will become the first batches of adolescents to migrate seaward during summer. The modes of the size frequency distribution of both sexes remain at 11-13 mm from November through to July.

Basically there is little change in size frequency distributions through summer into winter suggesting that rate of growth varies little. These frequency distributions thus represent a measure of a mobile population in transit through a particular growth phase. Individuals are entering the population, growing at a certain rate, and departing on a seaward migration after attaining a given size. Individuals are entering and leaving continuously, possibly in periodic waves, but the shape of the population as a whole remains the same. However in September and October the size range spreads and the modal values rise suggesting that those individuals which had not attained sufficient size or for some other reason did not embark on a seaward migration last season, have started to grow again with the approach of warmer conditions. As soon as these larger individuals comprising this residual population from last year's recruitment leave the river in the first waves of the new seasonal migration, the parameters of the river population revert to normal.

The sex ratio between juveniles which can be classified as male or female by virtue of their external genital appendages remains fairly constant and is 52 : 48.

Development of the petasma in males and of the thelycum in females has been described by Tuma (1967). In males the petasma is formed by the joining together of the endopodites of the first pair of abdominal swimming legs (pleopods). The endopodites appear in juveniles of both sexes at a carapace length of 3-5 mm. At this size the sexes can be distinguished only by the slight difference in position of insertion on the pleopods. The thelycal plate as a structure is recognisable in females at a carapace length of about 10 mm. Individuals above this size and lacking the plate are to be regarded as males. Thickening and folding of the endopodites of males occurs at carapace lengths of 15-25 mm and at this size they hook together along their medial edges to form the petasma. With further body growth the petasma increases in relative length and rigidity and assumes the characteristic specific shape as a functional copulatory organ. Most of the juvenile males in river populations are under 20 mm and virtually all are under 25 mm carapace length.

The thelycum in banana prawns is of the closed type consisting basically of right and left hand plates with up-turned labial margins situated on the last thoracic sternite. In the early stages these plates are widely separated but become closely adjacent along their medial margins with maturity. The thelycum is apparently structurally complete when females attain 24-30 mm carapace length. Most juvenile females in river populations are under 24 mm and virtually all are under 30 mm carapace length.

Spermatophores may be visible in the terminal ampoules of the seminal canals of males as small as 21 mm carapace length. This condition and the degree of structural development of the petasma suggests that males (at least some proportion of them) may be sexually mature when or very soon after they leave the river.

Occasionally thelyca are observed to be impregnated in females of 20 mm or less carapace length but the majority attain 30 mm or more before this occurs. Ovaries also may be visible at sizes less than 20 mm but this is more usual above 25 mm and normally above 30 mm carapace length. Thus while some percentage of small males may be incipiently mature sexually the majority of females are still sexually immature when they move from the rivers into inshore waters.

ADOLESCENT PHASE

During the summer months adolescents of both sexes leave the rivers and move into the shallow inshore coastal zone, first congregating near river mouths but moving gradually into deeper water as summer progresses. By the end of summer practically all are adult. They increase in length as they move further from the coastal fringe into deeper waters. This adolescent phase involves mainly depths of 11 metres and under and occupies the period September to March. Length frequency distributions of both sexes have parameters quite distinct from those of the river juveniles and the sexually mature adults. By combining all data irrespective of place, depth and month the length frequency curve for each sex shows three very strong modes. These represent the river juveniles, the coastal adolescents and the adults. When the same data are divided and arranged by months the middle mode representing the adolescents shows strongly only from November to March.

Catch rates of banana prawns taken by commercial trawl gear are highest in shallow coastal areas from late September until about the end of March after which they become highest in the 13-20 m zone. Such inshore catch rates may be of the order of 90 kg per 30 minutes, and as these catches consist of quite small prawns (mainly in the range of 10-30 mm carapace length, weighing 1-20 g and thus having counts per lb heads-on in the range 20-450) the catch by number of individuals can be very large. In this environment the adolescent banana prawns live in association with two species of small greentail or greasyback prawns (*Metapenaeus insolitus* and *M. eboracensis*) and rainbow prawns (*Parapenaeopsis sculptilis*). Shallow water summer catches of trawlers are thus generally a mixture of some or all these and often these species are in roughly equal proportions.

Length frequency distributions of both sexes constructed from combining all samples from each depth zone (the area being contoured at one fathom (1.8m) depth intervals) irrespective of time of year, show a progressive increase in size (measured in terms of total size range and position of mode) from 2-15 m. In the 9 m and 11 m zones (more clearly so with males) are two distinct modes; the one below 30 mm represents later stages in the growth of these migrating adolescents and the one above 30 mm represents young adults. Some individuals, possibly the earlier migrants from the rivers attain adult or near adult size at reaching depths of 9 m. Others, possibly the ones leaving the rivers towards the end of summer, move with the migrating schools into depths of 13-15 m before the adult size is attained.

When the adolescents first move outside the river mouths in September their numerical strength as a group in both sexes is very weak. The numbers in both sexes rapidly grow as summer proceeds and reach maxima in March. The increase in size of the adolescent population through summer is accompanied by a falling off in size of the adult population. Through summer both sexes show two modes in the monthly total length frequency distributions; the group below 30 mm representing the adolescents increases in strength and the one above 30 mm representing residual adults from the previous year correspondingly falls off in strength. In April the mode below 30 mm is virtually lost and the one above 30 mm predominates with a position at about 32 mm in males and 34 mm in females. In effect the adolescents in both sexes have now reached the size of small adults and length frequency distributions throughout the following winter months continue to show only a single size group. At the end of March this population of smaller adults is still in waters of 11 m or less and is now ready to migrate into deeper waters and become mating adults.

As already noted the joining of the petasma in males occurs mainly at sizes 15-25 mm carapace length and that spermatophores may become visible in the terminal ampoules of the seminal canals of males as small as 21 mm carapace length. The range in size of males rated as adolescent while inhabiting coastal shallows is 12 to about 33 mm carapace length. Accordingly a large percentage of these are included in the 15-25 mm carapace length range and exhibit the condition of unjoined petasma. Likewise this range in size of adolescent males includes a large percentage of individuals with carapace lengths in excess of 21 mm and having spermatophores visible. During the summer months most males less than 25 mm have an unjoined petasma but most males greater than this size have their petasma joined and visible spermatophores. These phenomena in the sexual development of males appear to be characteristic more of the adolescent phase in the 2-11 m coastal zone than in the river phase where virtually all males are less than 25 mm and the majority less than 20 mm carapace length. By the time these adolescent males as a group attain a size range with modal length in excess of 30 mm it can be rated as a population of young but sexually mature individuals capable of mating with females.

Also it has been noted already that the thelycum in females appears to be structurally complete at 24-30 mm carapace length. However a better criterion of sexual maturity in females is the impregnation of the thelycum as a result of mating. This condition is found mainly in individuals of a size in excess of 30 mm carapace length that have moved into deeper water. This condition does occur, although extremely rarely, at smaller sizes, the smallest recorded being at 18 mm carapace length. The range in size of females rated as being adolescent while inhabiting coastal shallows is 14 to about 36 mm carapace length. The majority of individuals in this length range have carapace lengths of less than 30 mm and have not been impregnated. Thus it follows that the majority of females while in this adolescent growth phase are not yet ready for mating.

The second criterion of sexual maturity in females is the visibility of the ovaries. The ovaries are not visible normally until carapace lengths of 29 mm or over are attained, although visible ovaries have been observed in females as small as 17 mm. During the summer months the ovaries are visible mainly in females with carapace lengths in excess of 30 mm comprising larger residual individuals from the previous season and a lesser percentage of the larger and more precocious adolescents near the end of summer. By April, when most of the adolescents have attained adult size, the percentage with visible ovaries rises sharply. This rise accompanied by a parallel increase in the number with impregnated thelyca, marks the attainment of sexual maturity in females and the beginning of their migration into deeper water for mating. As most of the adolescent females in the shallow coastal waters during summer have not attained 29 mm carapace length, the percentage with visible ovaries in this group is very low. Sexual maturity in females thus is not attained during the adolescent phase in depths of 2-11 m during summer.

ADULT MATING PHASE

By the end of March the population of adolescent males and females falls off in the shallower coastal areas because recruitment from the rivers has almost halted and adolescents have increased in size and become young sexually mature adults. At this point in growth when the water temperatures are beginning to decrease and salinities are becoming more stable, banana prawns begin to move into deeper waters. The seaward migration continues through the winter and schooling is very active in the 13-20 m zone from March through to late September.

Although the rate of growth in both sexes is relatively slower in the deeper water adult phase than it is in the shallower water adolescent and river juvenile phases, actual growth does continue through winter into early summer. By combining all samples irrespective of time of year, both sexes exhibit length frequency patterns characterised by decrease in size range and upwards progression in modal size as the migration proceeds into deeper waters. The majority of individuals in both sexes taken in depths of 13-27.5 m have carapace lengths mainly in the range of 30-40 mm. Males are relatively smaller than females and few attain more than 35 mm carapace length. The mode in the length frequency distributions of adult males is at 33-34 mm, tending to the higher value in the relatively few individuals in the deeper waters. Besides being relatively larger than males, the females continue growing over a longer time period in their seaward migration. The mode in length frequency distributions of adult females moves from a position at 33-34 mm at medium depths in early winter to 37-38 mm in late winter and to 39 mm in mid summer. The same data re-arranged according to depth instead of month show stabilisation of the mode at 37 mm for females in depths of 20 m or more.

Adults seem to be most numerous in the 13-20 m depth zone during late March to the end of September. Schooling activity by these sexually mature adults is very marked in certain parts of this zone, especially in an area of irregular bottom 32 km and further seaward of the Smithburne River delta system. It is in this zone that the major fishing activities are concentrated on capture of schools in 'balled-up' condition. Such schools may contain many tonnes and consist almost entirely of banana prawns with little contamination by other prawn species or trash fish. The schools tend to be compact and rise only a metre or so above the bottom sediments. The schools may remain compact in 'ball' form 2-4 m thick or may disperse vertically to some degree and exhibit the well-known 'Christmas tree' form. The schools are often accompanied by schools of fish which tend to position themselves directly above or slightly to one side of the prawn mass. The prawn schools generally show up on echo-sounders but may be confused with markings produced by fish schools on less sophisticated detectors. Apparently the individuals making up these 'balls' lift out of the bottom sediments rather rapidly and more or less simultaneously, and in so doing disturb the sediments producing discolouration of the water to the surface layers, making the so-called 'mud-boil' which helps fishermen detect schools in shallower waters.

Early investigations suggested that this type of schooling activity was coincident with times of least water movement. Such conditions of decreased water movements are attained at slack water of low tide or high tide. During neaps the rise and fall in tidal amplitude is very small and the tides become semi-diurnal instead of diurnal. During some periods of the year turbulence due to wind or other influences additional to the normal tidal components may produce three or even more rises and falls daily over several days. As the direction of flow is alternating frequently and amplitude is changing little during such conditions, horizontal velocity is greatly reduced and there is virtually no water movement over several days. Greatest schooling activity has been associated with such conditions during neaps and extends a few days either side of the neaps. As tidal amplitude increases schooling activity comes closer to the time of slack water. Schooling at slack tide may occur either at low or high water and thus either during daylight or night. During the winter fishing period high water characteristically occurs during daylight and low water at night.

The pattern of this activity needs more investigation particularly in the form of correlation between commercial catching times and tidal activity. It would appear that as schooling becomes active when water movement diminishes, this could represent a mechanism to maintain near static position relative to a preferred area of bottom (e.g. for feeding) while the prawns emerge from their buried positions in bottom muds to perform some particular function. Such functions may be that of ecdysis, cleansing or mating. Samples taken from 'balled-up' schools indicate that little ecdysis and mating activity occurs during the peaks of schooling of this type. Twenty-two trawl catches in the 40-770 kg range during 1964-65 are accepted as positive indications that schooling was very active and samples of 50-60 individuals were taken from each of these catches.

If ecdysis was the reason for lifting out of the sediments one would expect to find a high percentage of soft-shelled individuals of either or both sexes. Only four catches contained 1-2 soft-shelled males (3-8% of male component) and only three contained soft-shelled females (2 with one individual and one with 10 individuals, respectively 4% and 37% of female component). Such scarcity of soft-shelled individuals suggests that ecdysis in either sex is no more active during schooling than at other times or places.

If mating was the reason for schooling or was rather active during the schooling one would expect to find males in hard-shelled condition and a high percentage with spermatophores or associated gelatinous materials attached to petasma. Also one would expect to find a high percentage of females in soft-shelled condition and that the majority of these would have spermatophores freshly implanted in their thelyca. As the spermatophore is lost on ecdysis and females can only be impregnated while soft-shelled, those in soft-shelled condition and carrying spermatophores must have very recently mated. In 17 (of the 22) samples taken during 1965 only six contained males bearing spermatophores on the petasma. Four samples had one individual (4-5%), one had two individuals (7%) and the other had six individuals (22% of male component). Of all samples taken during 1965 males carrying a spermatophore on the petasma were noted in 87 indicating that males are in readiness to mate under a variety of circumstances. The low incidence of such males in the schools and their presence at other times suggests that the males are not actively mating during schooling, at least not at a greater rate than at other times.

Similarly females with impregnated thelyca were observed in 159 samples during 1963-65, and all but 54 of these samples contained some soft-shelled females. However 88 only contained some soft-shelled females which were impregnated and thus had very recently mated. In the 22 samples from the large schools 12 contained females with impregnated thelyca (5-56% of female component) but in only two of these cases were the impregnated females in soft-shelled condition (four individuals or 15% and one individual or 4% of female component). The low incidence of such females in the schools and their presence at other times suggests that they, like the males, are not actively mating during schooling, at least not at a greater rate than at other times.

Of all males sampled in the Gulf (10 363, Norman River material excluded) 56.3% (5 831) had spermatophores visible in the terminal ampoules. This condition occurs over the size range 21-39 mm carapace length, with the primary mode in the length frequency distribution at 33 mm corresponding with that of adults. A minor second mode occurs at 27 mm representing the precocious males of the adolescent group. This secondary mode shows from December to March when much of the total population is made up of adolescents in the 2-11 m zone. During this phase 31-43% of the males have become mature sexually to this extent. These percentages rise to above 90% in April to June but fall off again to 16% in November. Presumably this indicates that most activity by males is during winter (April to September). The presence of spermatophores on the petasma interpreted as identification of males imminently ready to mate was observed from January to the end of July in 1965 (nothing observed prior to 1965 or from August-December 1965). This condition occurred mainly in the 15-18 m zone west of the Smithburne and involved males in the count per pound (heads-on) 12-27, mainly 13-16. This may mean that mating occurs principally in the schooling areas but not necessarily while schooling is at a peak.

Of 8 373 females sampled in the Gulf only 5.4% (455) had impregnated thelyca. These were mainly in the range of 28-41 mm carapace length with a mode in size frequency distribution at 35 mm, a size which corresponds to the mode in the frequency distributions of the younger females found from summer through to the end of June. The condition has been observed in depths over the range 2-27.5 m and in every month.

The frequency of occurrences is highest from April to July but the percentage in the female component rises from less than 0.5% during summer to about 20% in May and June. These larger occurrences again are in the 15-18 m zone west of the Smithburne and involving females in the count per pound (heads-on) 13-16 mainly. It might be inferred that mating is principally with younger females during winter in the schooling area but not necessarily while schooling is at a peak. Visibility of the ovaries indicating advancement in the ripening of the ova does not correspond with time of impregnation and, as will be discussed under spawning, is more characteristic of larger females in late winter and early summer.

ADULT SPAWNING PHASE

In males the presence of spermatozoa packs (spermatophores) in the expanded terminal ends of the vas deferens (terminal ampoules) signifies attainment of maturity in ripening of the testes. As already indicated this condition is attained by the majority of males during their adolescence in the coastal shallows and is sustained through winter growth and migration into deeper waters. The presence of spermatophores in the terminal ampoules or on the petasma is only an indication of readiness for mating and has nothing to do with the actual spawning act of females. Females continue to grow and mature their ovaries through winter into summer. Through this phase the females are still accompanied by males but it seems likely that the major mating activities are largely completed by the end of winter.

Tuma (1967) has described the development of ovaries to maturity and has categorised five stages in development based on macroscopic and histological characters. His stages I-III represent progressive increase in the size of the ovary and the ripening of part of the stock of ovarian cells. In Stage I all these cells are uniformly small and stain blue with haematoxylin-eosin dyes. Stage II shows activity in that portion of these cells have increased in size but still stain blue. Stage III is more advanced development in which a large portion of the ova have increased considerably in size and stain red while the remainder remain unchanged in size or staining properties. In Stage IV the large ova have increased to their maximum diameter and are characterised by rod-shaped bodies arranged radially around their periphery. At this point the ova are considered mature and ready for spawning. Stage V represents the spent and recovering phase in which the ovaries have become flaccid from the discharge of ripe eggs and those which have not been shed are undergoing absorption.

This course of development is apparent externally by degree of visibility and colour change. Tuma (1967) points out that during Stages I-II the ovaries are translucent and thus difficult to see through the abdominal terga. The colour changes from pale buff to yellow through Stage III to olive-green during Stage IV and to greyish-green in Stage V.

These colour changes and resultant visibility of the ovaries serve as a field indication of advanced development and ripeness. Of 8 373 females sampled in the Gulf, 22.6% (1 897) had visible ovaries. Length frequency distribution of these individuals was mainly in the range 28-45 mm and had a mode at 37-38 mm carapace length. The position of this mode coincides with that of the size frequency distribution of all adult females combined. As indicated above the mode for adult females shifts with age from 33-34 mm in March-April, when it replaces that of the summer adolescent population, to 39 mm in November. The position of the mode at 37-38 mm for individuals with visible ovaries indicates that this condition applies mainly to the larger females which are characteristic of the period embracing late winter and early summer. Females with visible ovaries have been observed through all months but their percentage varies greatly with season. It falls to about 6% in summer and reaches a peak at 63% in September at which time the mode in the size frequency distribution has risen to 38 mm carapace length.

By the end of September these larger females with mature or near mature ovaries disappear or at least cease to school throughout the mating grounds west of the Smithburne. The fishing season thus ends in this sector and those vessels remaining in the fishery disperse towards and beyond Mornington Island where the operations are based on nocturnal species such as tigers, Endeavours and blue-leg king prawns. Smaller quantities of larger adult females are taken in the mixed catches from these grounds but the percentage of them with visible ovaries rapidly decreases as summer proceeds.

Tuma (1967) examined the frequency distributions of the five ovarian stages in relation to female carapace length for 139 individuals sampled during 1964-65. Stage I, being essentially the virgin condition, is basically characteristic of individuals smaller than 30 mm carapace length. The developing stages II and III occur mainly in sizes above 27 mm carapace length. Ripe ovaries (Stage IV) are confined to larger females, namely those in the range of 30-45 mm carapace length. Spent females (Stage V) were represented by only two individuals, suggesting that actual spawning occurred mainly outside the study area or that females died soon after shedding their eggs.

Further examination of Tuma's raw data (1964-65) reveals that Stage I is found only during March to July and virtually all individuals larger than 30 mm carapace length with quiescent ovaries were the ones in which development had been arrested by parasitisation with the bopyrid *Epipenaeon*. Stage II (49 individuals) occurs from March through to November but is more frequent between March and July. Stage III (46 individuals) occurs in all months except December without noticeable peaks of abundance. Stage IV (14 individuals) also has wide seasonal spread with slight increase from September to January, but samples being small the pattern may have no significance. One Stage V was taken in 16.5 m in late May, being a female of over 40 mm carapace length. The Stages II-IV occurred mainly in the 13-20 m zone but a small percentage, especially individuals of smaller size, occurred in the shallower inshore zone.

More extensive sampling of female gonads was carried out from commercial trawler catches during 1967 (653 individuals) and 1968 (1 256 individuals). These data (Tuma, unpublished) refer mainly to the Smithburne area (winter) and Bountiful-Mornington Islands area (summer) but no observations were made in June. Stage I (17 individuals) occurs from March to May. Stage II (448 individuals) occurs from February to September, being more abundant (total numbers and percentage of totals) from February to May. Stage III (576 individuals) occurs in all months except January but is more abundant numerically from February to July and represents a greater percentage of totals from July to December. Stage IV (516 individuals) occurs throughout all months and although more abundant numerically during March to April, shows no significant seasonal peaks in terms of percentage of totals. Of the totals sampled through these years 27% had fully ripe ovaries. Stage V (23 individuals) accounted for 20% of totals sampled during September but appears in small numbers during November to December and February to May. These spent ovaries were from three areas, namely N.W. of Mornington Island in 20-24 m during September (12), S. of Bountiful Island in 13.7-15 m during November, December, February and May (6), and on the inshore margins of the Smithburne grounds in 9-15 m during March and April (5).

These series of ovarian samples were identified in groups only with the carapace length frequency distribution of the catch from which they were taken. Generally Stages III and IV predominate where carapace length distribution were mainly in the range 33-39 mm. Stage V occurs only where samples included individuals above 36 mm and mostly where the samples included individuals in the 39-45 mm carapace length range.

Such observations on ovarian maturity in relation to season and area seem to indicate that while ripe ovaries are present throughout the whole year they are basically characteristic of the larger females. Developing stages are more abundant during early winter and this is because the greater part of the population is composed of young smaller adults. By the time females are large enough to leave the schooling grounds (including the Smithburne area) most have ripe ovaries and have had a number of opportunities to mate with males. If spawning takes place on these schooling grounds, a very high percentage of spent ovaries (Stage V) should occur there, especially as populations are large and the rate of fishing high. Most spent ovaries are taken from September to February near Bountiful and Mornington Islands and these seem to be associated with the larger females. As sampling in this period and area is relatively low compared with that on the schooling grounds, greater significance can be placed on the presence of the relatively few numbers of spent ovaries from there. Their presence suggests that at least some spawning takes place in or near the study area and that this is a summer activity of the larger females in a different area to that used for mating in winter. The few spent ovaries taken in the environs of the Smithburne fishing grounds during March and April might well belong to larger females who have lived for a year, spawned and have joined the new season's adolescents moving to the mating grounds. It could also be argued that they are late spawners. Similarly it might be argued that the ones with spent ovaries found in early summer near the islands may have migrated back into the study area after migrating elsewhere in late winter to spawn. At least the presence of spent ovaries points to summer as the spawning period and this is supported from studies of larval stages and river juveniles.

The drop off in abundance of adults and the scarcity of Stage V during summer could well mean that most individuals migrate out of the study area and may undertake long journeys to spawning grounds. It is interesting to note that schools of larger individuals of which the bulk of the female component are in the 39-45 mm carapace length range have not been observed in the study area. Samples have been obtained from commercial catches off Weipa in 15-22 m during October 1967. The female component of these was entirely in the 36-48 mm carapace length range with the 39-42 mm group predominating strongly. Surprisingly their ovaries were in developing Stages II and III. If these had been migrants from the southern Gulf one would expect all ovaries to be ripe and perhaps many of them spent by October.

Some further indication of mating and spawning seasons is given in the corresponding seasonal changes in condition (length-weight relationship) of both sexes. Mean monthly weights (10 358 males and 8 373 females) of individuals in each one millimetre size class interval (carapace lengths) have been plotted for each sex. Above about 25 mm carapace length males tend to show a building-up in relative weight during February to June and then a dropping off in relative weight from July to January. This suggests that the testes have shrunk and lost weight as they have ceased to actively manufacture spermatophores after mating activity during winter. The females, especially those in size class intervals above 33 mm tend to show a building up of relative weight from late summer through to August and September and then a falling off in relative weight by November. Such differences in condition would be consistent with the increase in bulk and weight of ovaries during development and ripening in winter and the shedding of eggs or reabsorption of unspawned ova during summer, especially as the condition changes more dramatically in the larger females which appear to be the spawners. These condition changes correspond with the seasons of mating and spawning derived from gonad histology, spermatophore production and insemination, appearance of larvae in plankton and the recruitment of juveniles to river nurseries.

GENERAL BIOLOGY OF JUVENILE, ADOLESCENT AND ADULT PHASES

In the foregoing discussions the life cycle has been divided into four phases. The first has dealt with identification of larval stages and the behaviour of larvae and postlarvae in the plankton. Discussions on the three succeeding phases has concentrated mainly on geographical and seasonal distributions in relation to size, attainment of sexual maturity and delineation of mating and spawning areas and times. Other aspects of the biology of the non-larval phases warrant discussion as follows.

Nocturnal/diurnal behaviour. Some evidence of vertical migration during the hours of darkness has been noted for larvae but this appears to have been lost by the time post-larvae take up residence in the river. No evidence has been found regarding selection of daylight or dark as period of activity for either juveniles in the river, adolescents in the coastal shallows or adults in deeper waters. In all zones banana prawns appeared equally active throughout the day and night periods and in this respect contrast with tigers, blue-leg kings and Endeavours which have marked preference for coming out of the sediments at night. The catches of these nocturnal species tend to increase progressively towards midnight and then decrease again. Banana prawns are taken in at least small numbers over most of the area to 27.5 m irrespective of time of day. Their availability in quantities above trace levels appears to be in response to factors other than a simple nocturnal/diurnal rhythm but behavioural studies of this type are beyond the scope of the present investigation.

Migrations. The shoreward migration of planktonic larvae has been demonstrated. A general seaward migration from the river nursery grounds at early adolescence has been demonstrated by the change in parameters of size frequency distributions of populations with respect to depth and season. The general pattern of these migrations in relation to depth and season has been discussed above for each of three growth phases. However as marking experiments were not included in the present investigations, nothing can be documented about the actual paths of individuals migrating from the Norman River or other streams. Similarly nothing can be said about the contribution to mating schools in specific areas (e.g. Smithburne grounds) from particular nursery areas. After departure from mating grounds it is not known whether individuals disperse or move on as schools along specific paths to other parts of the study area or elsewhere in the Gulf.

Food. Because of the impracticability of examining gut contents immediately after capture, studies on food organisms were abandoned. The activity of the enzymes in the digestive gland continue during storage and stomach contents speedily become unrecognisable. In common with other penaeinids banana prawns feed on or in the bottom sediments after the postlarvae settle. It is suspected that food consists in part of detrital carrion and that small living demersal organisms are preyed upon. Possibly also some vegetable materials are included in the diet from time to time. Adults at sea exhibit a variety of colour from pale cream with pink telson to bright orange. At times the pink increases in intensity and area, including the legs. In this condition they are known as 'red-legged' or 'night' prawns and the pale phase is known as 'day' prawns. However occurrences in relation to time of day are not consistent and it is thought that the greater intensity of red pigments is coincident with a specific feeding phase involving carotenoids of vegetable origin.

Sex Ratio. As stated above it is difficult to distinguish sexes in juveniles with carapace lengths less than 10 mm. Forty-one per cent of those sampled (35 061 individuals) from the Norman River were in this indeterminate category. The remaining 59% (20 646 individuals) had a mean ratio of males to females of 52 : 48 combining all months. This proportion was fairly constant throughout the year, males being slightly more numerous than females in all months except April when the proportion reversed to 49 : 51. The explanation for this reversal is not clear but it does happen in the same month as the percentage of indeterminates reaches a minimum, marking the end of entry of postlarval recruits into the river.

Adolescent and adult individuals (18 736) from all depths of the Gulf have a mean ratio of males to females of 55 : 45 combining all months. Again males are generally rather more numerous than females in these more advanced stages. Males remain relatively more numerous than females in all months except January and September when the proportions equalised with the ratios of 50 : 50 and 49 : 51 respectively. Males showed particularly greater predominance in early summer when ratios of males to females rose to 63 : 37 in October and 66 : 34 in November. The samples during these two months consisted in their major part of larger sexually mature individuals of both sexes. The presence of spent ovaries and occurrence of larval stages in the plankton indicate that at least some spawning has taken place in the study area, and it is possible that death of females after spawning may have reduced the proportion of females. The ratio of males to females in December at 59 : 41 also reflects this trend but by December large numbers of adolescents have left the rivers and tend to predominate numerically over larger adults in samples from the Gulf and mask the relative reduction of proportion of adult females.

Growth rate and life span. Prawns like other crustaceans progress in growth through a series of instars during all phases of larval and adult form. The number of ecdyses during each of the larval stages cannot be determined until banana prawns are spawned in aquaria and the larvae reared through all stages from hatching to adult facies. Also there seems to be no way in the field of determining the number of ecdyses carried out by wild stocks of prawns during their juvenile, adolescent and adult phases. There are no indications of whether the number of ecdyses varies between individuals in reaching a given size or whether ecdysis is in response to attainment of a size or to some rhythmic periodicity. Size frequency distributions show up three major size groups and progression of modes in both sexes. The size frequency distributions of the various instars in each of these groups is completely masked. While one can observe the progress of growth, through the period of a calendar year, of the population of the area as a whole, there remains no known method of determining the age at any given time or the rate of growth of a particular individual.

The presence of soft-shelled individuals of either sex is an indication that ecdysis has taken place very recently. Combining all samples from the Gulf irrespective of depth and month the proportion of soft-shelled individuals is 6.6% of the total individuals (18 736), 6.3% of males and 7.1% of females. However there are variations according to season suggesting two periods of particular activity. In both sexes the highest values are in January and February (16.3% and 14.4% respectively for males) (14.5% and 12.4% respectively for females). This rise is foreshadowed during December when 6.8% of males and 8.2% of females are soft-shelled. The size frequency distribution of the soft-shelled individuals in both sexes corresponds to that of the adolescents which have recently migrated from the river into the Gulf shallows. The bulk of the soft-shelled individuals at this period are thus of less than 30 mm carapace length. This rise in proportion of soft-shelled individuals helps to confirm a phase of active growth of the adolescent group. As would be expected soft-shelled individuals from April onwards are found mainly amongst the adult group. In May proportions rise to 10.9% in males and 13.4% in females. This may possibly be associated with mating activity as one would expect to find females in a condition suitable for impregnation, namely with soft shells.

In the study area virtually all males are 39 mm or less carapace length and the mode of the size frequency distribution of all samples combined is positioned at 33-34 mm carapace length. The position of this mode progresses from that of the river community through the adolescent phase and manifests itself by the end of March as that of the young adult population at 31 mm carapace length. It moves upwards to 32 mm during April and May and to 33 mm in June and July. By August it has attained a maximum at 33-34 mm which signifies that growth of males as a whole has ceased. By November and December this adult group disappears from the Gulf population and is replaced by the new season's batch of adolescents. It follows that growth of males is completed in rather less than one year, probably in 6-8 months for the average individual. The disappearance of the adult population in early summer and the immediate replacement of it by a new crop of adolescents strongly supports the concept of an annual crop and an average life span of less than one year for the majority of males.

As discussed under the adult spawning phase, females as a whole grow relatively larger and continue to grow over a longer period than males. All females in the study area are 46 mm or less carapace length and the mode of the size frequency distribution of all samples combined is positioned at 37-38 mm carapace length. As with males the position of this mode progresses from that of the river community through the adolescent phase and manifests itself by March and April as that of the young adult population at 33-34 mm carapace length. At this point the adult female population as a whole has attained the same amount of growth as that of males at the end of their growing period. The mode moves up to 34-35 mm in May, to 35 mm in June, to 36-37 mm in July, to 37 mm in August, to 38 mm in September, to 38-39 mm in October and reaches its maximum at 39 mm in November. As with males there is a corresponding decline in the adult component of the Gulf population during December to the end of February, followed by a replacement by the new season's crop of adolescents. The pattern is parallel to that of males with the exception that growth continues over a longer duration and in the later stages growth involves ripening of ovaries in addition to making increments of length and weight. Growth to maturity and presumably spawning is completed by the average individual female in a year or slightly more or less. This achievement together with the apparent replacement of mature adults each year also suggests the dynamics of an annual crop. However there is evidence that banana females continue to grow into a group which has a size frequency distribution characterised by having its mode at about 41 mm carapace length. These have not been located in the study area but any females migrating out of this area may continue to grow to this size and larger. A set of samples in this category was taken at Weipa in October, and as these had ovaries mainly in the ripening Stages II and III, they could well be individuals which had spawned at the end of the first year and were entering a second year of life.

Weight/Length Relationship. The weight/length relationships have been investigated for males and females separately. Samples comprising 6 450 definite juvenile males from the Norman River and 10 363 adolescent and adult males from the Gulf have been combined to give a coverage in carapace length range of 6-42 mm. The data have been grouped at one millimetre size intervals and a curve fitted by the method of linear least squares. Its regression is

Table I. Conversion of carapace length to count per pound (whole prawns)

Carapace Length (mm)	*River Indeterminate Sex*	*River Males*	*Gulf Males*	*River Females*	*Gulf Females*
6	1 382	2 268			
7	1 421	992		2 268	
8	1 010	878		1 260	
9	731	555		992	
10	540	456		447	
11	408	395		405	
12		300	349	310	
13		240	227	241	
14		192	206	193	193
15		157	150	163	158
16		129	120	131	122
17		108	105	110	108
18		93	87	96	90
19		79	78	80	78
20		68	66	69	66
21		61	57	61	58
22		53	49	52	50
23		48	43	49	44
24		43	38	43	39
25		34	35	38	34
26		32	30	33	31
27			27	30	27
28			24	26	25
29			21	24	22
30			19	24	21
31			17	20	19
32			16	18	17
33			15	20	15
34			14		14
35			13	16	13
36			12		12
37			11		12
38			11		11
39			10		11
40					10
41					9
42			9		9
43					8
44					8
45					8

$$W = 0.001153\, L^{2.905}$$

A similar curve has been derived for females including 6 080 definite female juveniles from the Norman River and 8 211 adolescents and adults from the Gulf. These combine to give coverage of 7-45 mm carapace length. Its regression is

$$W = 0.001273\, L^{2.862}$$

These curves are fairly similar up to carapace length of 20 mm. In both sexes there is a considerable degree of scatter either side of the mean especially as length increases. These fluctuations have been noted already as being, at least in part, seasonal as a result of ripening and subsequent shrinkage of gonads, namely shrinkage of the testes after mating in males over 25 mm and shrinkage of ovaries after spawning in females over 33 mm carapace length. In the above equations W = weight in grams and L = carapace length in millimetres.

Throughout the text of this paper carapace length in millimetres has been used as the measure of size. The fishing industry is more familiar with assessment of size in terms of count per pound. This count may be given in terms of heads-on (whole prawns) or heads-off (tails only). The rate of recovery is approximately 70% of whole weight. The weight/length curves described above give the conversion from carapace length (mm) to weight (g) and thus it is possible to calculate mean count per pound for each one millimetre class interval of whole prawns. This conversion is provided here in Table I.

LITERATURE CITED

DALL, W. (1957). 'A revision of the Australian species of Penaeinae (Crustacea Decapoda: Penaeidae).' *Aust. J. mar. Freshwat. Res.*, 8(2), pp. 136-230.

KIRKEGAARD, I. R. (1973). 'The fauna of the Gulf of Carpentaria. No. 3, Larval stages of Penaeidae (Crustacea: Decapoda).' *Fish. Notes Qd.* (n.s.), 2, pp. 58-70.

MUNRO, I. S. R. (1967). *Gulf of Carpentaria—southern part. Depth contours. 23 x 32 in.* Dept. Harbours and Marine Qld. Brisbane.

MUNRO, I. S. R. (1968). 'The prawn, its habitat and life. The life of the banana prawn. Predicting when to catch banana prawns.' *Aust. Fish. Newsletter*, 27(1), pp. 25-28, 33.

MUNRO, I. S. R. (1973). 'The fauna of the Gulf of Carpentaria. No. 1, Introduction and Station Lists.' *Fish. Notes Qd.* (n.s.), 2, pp. 1-38, Append. 1-3.

TUMA, D. J. (1967). 'A description of the the development of primary and secondary sexual characters in the banana prawn, *Penaeus merguiensis* De Man (Crustacea: Decapoda: Penaeinae).' *Aust. J. mar. Freshwat. Res.*, 18, pp. 73-88.

DISCUSSION

Somers. You took a lot of samples where you actually found a percentage of soft-shelled animals in the catch. Have you any idea at all, the period of time that they stayed soft and how long it takes them to harden their shell?

Munro. No notion whatsoever. What I point out is that this was a survey looking for a resource, and while we were looking for the resource we made a lot of biological observations. Nothing was particularly well planned statistically and lots of gaps could be filled in now, being wise after the event. So all we bothered to do was to note when the soft shells occurred. The samples taken were brought aboard and put on ice and subsequently refrigerated, and I believe a percentage may have hardened up after they had been frozen.

Dredge. In your river sampling, did you find any particular habitat preference of juveniles, did they tend to congregate in any particular zone of the rivers in relation to either salinity, turbidity or presence of vegetation?

Munro. No, in the context of this paper. I would not be prepared to answer this one; Stan Hynd would be better qualified to answer. We only started this work in 1965 and then Northern Prawns started a bigger program. A lot of the work is being written up and still is continuing on size/sex composition of the river stocks. We sampled although we did not at first know where to sample; we just poked around and found that there were certain places better than others that were convenient to sample in. I am sure that there are some preferences but I had better not elaborate myself on that.

SESSION 2

POPULATION DYNAMICS

CHAIRMAN: DR. C. LUCAS

AUTHORS

C. LUCAS	I. SOMERS
J. W. PENN	D. SMITH

T. WHITE

THE COLLECTION AND USE OF LANDING STATISTICS

BY C. LUCAS
Research Scientist
CSIRO, Division of Fisheries and Oceanography
P.O. Box 21, Cronulla, N.S.W.

ABSTRACT

While it is highly desirable, the collection of landing statistics for the Australian prawn industry is not easy, and there is no general easy formula for obtaining the data.

The system of compulsory monthly returns (and in some cases effort measured in days or hours trawled and principal blocks fished) is cheap and seems to have worked successfully in South Australia and Western Australia, where there is limited fishing and a low number of boats and processors. In other cases it has not worked, particularly where the fishery is near a large centre of population such as Brisbane or Sydney. The returns contain false data or have not been completed. With the above exceptions this method is virtually useless.

A voluntary system, usually based on a daily log book, has had limited success. Although not every fisherman completes a log book those that are completed are accurate and reliable. Major problems with this method are finding suitable people in each major port—to make daily contact with the fleet—and the cost, which is of the order of $30 per person per week.

Identification of age classes in stock and estimation of natural and fishing mortality can be obtained from statistics of catch and effort and total catch processed in fisheries involving long-lived species. But prawns have a recruitment period of some three months, a life span of essentially less than twelve months, and a migratory behaviour—particularly as juveniles—so it is virtually impossible to distinguish week or month classes in the catch and apply the conventional techniques.

Recruitment fluctuates from year to year and it is important for management purposes to have an estimate of upper and lower levels. Total annual catch and annual catch-effort give an approximate magnitude. Shorter period catch and effort records define fishing time and area and determine the period. Effort records in conjunction with tag recaptures may produce estimates of natural and fishing mortalities which allow a more refined estimate of recruitment to be made.

It is politically useful to know the catch, the number of boats and processing plants operating, and some estimate of the cost structure. When faced with group pressures the administrator with records at his fingertips has concrete evidence on which to base discussions and recommendations.

Landing statistics collected in Australian prawn fisheries include catch and effort records from fishing boats and total catch processed by commercial buyers. The use of such statistics in other fisheries on long-lived species has been well documented in the textbooks on population dynamics (see Gulland 1965). In those fisheries there are numerous age classes in the stock which may be identified and natural and fishing mortalities estimated. However, in prawn fisheries which have a recruitment period extending over some three months, a life span essentially less than twelve months, and a migratory behaviour particularly as juveniles, it is virtually impossible to distinguish week or month age classes in the catch and hence to apply the conventional techniques for estimating mortalities.

There are, however, four valuable uses of the landing statistics.

(a) There are annual fluctuations in recruitment. These are probably due to natural causes but it is important for management purposes to have an estimate of the upper and lower limits. Total annual catch and annual catch/effort gives a first approximation to the order of magnitude of recruitment. If other information such as estimates of natural and fishing mortalities are known then of course more refined estimates of recruitment may be obtained.

(b) Catch and effort records allow definition of the extent of the fishery in time and area. The recruitment period may be determined. This is followed by the fishery on the adults usually in another area and then finally the season is completed when catch rates drop to an uneconomical level. For example, *P. plebejus* in Moreton Bay has a recruitment period to the juvenile fishery (20 mm to 35 mm carapace length) from October to December, followed by a fishery on adults in the adjacent offshore areas until about the following August.

(c) Effort records taken together with tag recaptures may allow estimation of fishing and natural mortalities. Essentially, this can be done by assuming number of tags recaptured per unit fishing intensity is proportional to the tagged population during that time period. This usually means making some assumption about catchability. There is evidence to suggest that catchability is a function of lunar cycle (Penn and also White—this seminar).

In Moreton Bay there is no evidence of catchability varying with lunar cycle. On the deepwater offshore grounds (110-146 m) off Mooloolaba there is a very pronounced lunar cycle with best catches on the full moon. On the grounds off the Gold Coast (37-55 m) best catches occur on the new moon. On the grounds off Tin Can Bay (37-55 m) best catches sometimes occur on the new moon and sometimes on the full moon. Thus in south-east Queensland, while there is some evidence of a lunar cycle, no clear-cut general pattern emerges.

There is also the further complication that catchability may be a function of fishing effort. For example, inspection of echo-sounder traces revealed that when a school of banana prawns is being fished the prawns may rise off the bottom and fill the water column up to 18 m and are therefore not catchable with conventional trawl gear.

(d) Simply to know the catch, the number of boats and processing plants operating and some estimate of the cost structure, is politically useful. Sometimes fishermen or processors may exert pressure on politicians for such restrictions as licence limitation. By having catch records at his fingertips, the administrator has concrete evidence on which to base further discussions. Of course, if he also has estimates of mortalities, growth, variation in annual recruitment, and market trends, then he is able to be more precise in his discussions and recommendations.

The collection of landing statistics in Australian prawn fisheries is carried out by State Fisheries Departments, CSIRO, and the Department of Primary Industry. The type and method of data collection varies with each agency but can broadly be categorised into two main types. The first is a compulsory monthly return filled out by fishermen and/or processors in which details are obtained of catch and in some cases effort measured in days or hours trawled and principal blocks fished. In some fisheries this system appears to have worked successfully, notably in South Australia (see References) and Western Australia (Hancock, 1973) where there is a limited entry fishery and a low number of boats and processors. In other cases, the system has not worked, particularly where the fishery is near a large population centre such as Brisbane or Sydney with the result that the returns contain false data or have simply not been completed. This collection method is cheap but with the above exceptions is virtually useless.

The second type of data collection is a voluntary system usually based on a daily log book. This has met with limited success. In those ports where an employee has daily contact with the fleet the results have been satisfactory. Although not every fisherman completes a log book those that are completed are accurate and reliable. In ports where there is no daily contact the results have been unsatisfactory. Much of the success or otherwise depends on locating suitable personnel in each major port, and one such system is to employ semi-retired people on a part-time or contract basis, essentially to be on the jetty each morning to collect a log sheet. The major problems are finding suitable people, particularly in the more remote areas, and secondly, the cost, which is of the order of $30 per person per week. In this system, however, there is also the added advantage that such data as tag recaptures and catch samples can also readily be collected.

Voluntary returns are readily available from established processing firms in the form of monthly weights processed by species from each landing port. In some cases more detailed information is available. In fisheries near large population centres some of the catch is sold privately and the data not available. Since it is probably not declared in income tax there is a natural reluctance to divulge details. The best one can do is make a 'guesstimate'.

Thus the collection of landing statistics in Australian prawn fisheries, while highly desirable, is not easy to obtain and there is no general easy formula for obtaining the data.

LITERATURE CITED

GULLAND, J. A. (1965). 'Manual of Methods for Fish Stock Assessment.' *FAO Fish. Tech. Pap.*, 40.

PENN, J. W. (1973). Tagging experiments with the western king prawn, *Penaeus latisulcatus* Kishinouye. National Seminar on Prawns, Maroochydore, 1973.

WHITE, T. (1973). Factors affecting the catchability of a penaeid shrimp, *Penaeus esculentus*. National Seminar on Prawns, Maroochydore, 1973.

DEPARTMENT OF FISHERIES, SOUTH AUSTRALIA (date unknown). *The South Australian Prawn Fishery*.

HANCOCK, D. A. (1973). 'Why Log Books?' *Fish. Ind. News Serv.*, W.A., 6(1).

DISCUSSION

Neal. I think that there is a serious problem in doing the kind of thing that I did the other day, that is lumping a number of stocks together. I did it because we simply do not have any means of identifying the stocks. I wanted to ask if you or anyone here is working on this problem or has any ideas about means of identifying individual stocks?

Lucas. You mean possibly by means of tag-recapture experiments looking at migrations?

Neal. Yes, this type of thing. We have looked at chemical techniques, looking for differences in enzymes, some genetic difference of some kind, and really not coming up with anything at all promising and it is of particular interest to us because we are faced with the problems of some estuaries being virtually destroyed and we do not know how this is going to affect the fishery. We would like to be able to identify the stocks that are associated with particular estuaries and, of course, from the population dynamics point of view, we would like to be able to identify the breeding populations of the individual stocks.

Lucas. I do not know of any work that has been done in Australia, outside of a limited number of tag-recapture experiments. For example, with the king prawn on the east coast; in one year some tag-recapture experiments were carried out, some of the prawns moved over a fairly extensive distance, we came to a conclusion. The following year the work was repeated, we came to a different conclusion. Other experiments, here I am thinking of those of Nick Ruello, have indicated that migrations of the order of 400 miles do occur. The situation is by no means clear-cut, it does appear that there could be quite a lot of mixing and I do not think that at this point we are able to say with any certainty that a particular estuary contributes this much percentage to that fishery. I certainly do not think that we can get to that stage and I am not sure really what we can do about it.

Neal. I do not know either. One other comment. Although we have tried the log books on a number of occasions, we have never really been pleased with the results for some of the reasons you have indicated and the procedure we are using now is that of interviewing a portion of the captains as the vessels are landing. We have people who work on a full-time basis, interviewing the captains and obtaining their landings, discussing with them on a very informal basis, a person-to-person basis, how they fished and how many days they fished and, as I mentioned the other day, about 10% of the total landings are interviewed this way. We feel that it is effective and we get pretty good effort and information on where they have fished.

Lucas. That is interesting because it does appear that we may be attempting to do something like this in the Gulf prawn fishery, mainly because we have not been sufficiently satisfied with other techniques and we might have to follow along these lines too.

Evans. I would like to address my question to Dr Neal if I could. I feel one of the problems with the catch and effort system in Australia is that they are trying to extract too much information from the fishermen, particularly in the unit of effort side of things. Could Dr Neal tell us what their unit of effort is and just how much detail they are getting from this sort of information.

Neal. We have been very aware of this problem. What we are using now is simply days fished. We will talk to the fisherman: if he has been out eight days, after talking to him a little bit, you find he has lost a day on account of weather or maybe he spent half-a-day moving from one location to another. This is very nice with the brown shrimp when they are fishing only at night. Now, some of the big new trawlers are fishing around the clock which brings in additional complications. They do not catch as much during the day as at night. But we have used essentially just number of days fished.

Hancock. From Western Australia, I must say something in defence of log books. In fact we have a system which costs a fair amount of money and of course I have to justify having staff do this, but we believe that with the licensing limit in fisheries you have to get good statistics, there is no question about it, and we have a combination of log book issue to all fishermen. We get something like 95% return from our fishermen and close supervision and interviews just in the way that Dr Neal has suggested. But I think that the basis for any successful log book system is what you have already said, you must have supervision, you must win the confidence of the fishermen that you are not going to use the information against them and above all you must give publicity to it and explain to them why they are doing it. We find the biggest reason why people won't fill in log books is because they do not know, they think they are being taken for a ride, that the information is not being used and it is just a waste of their time. In fact I had an example of this recently in the Abrolhos Islands where a fisherman very proudly showed me his log book issued to him by the Department and he told me all the things he was putting in it. He said he had every sort of predator recorded here, and I said 'that is marvellous, aren't you a wonderful person?' He said 'But I am not going to give it to you.' So I said 'Why? You have been working with the Fisheries Department for about five years now and you know our method and systems'. He said 'I am not going to give it to you because these men down the road do not know why they are filling in log books'. He knew and he did not think he had to tell the other ones so we had to make a job of explaining it to them.

Lucas. I cannot agree more with the need for explanation.

TAGGING EXPERIMENTS WITH THE WESTERN KING PRAWN *PENAEUS LATISCULATUS* KISHINOUYE

BY J. W. PENN
Research Officer, Department of Fisheries and Fauna
W.A. Marine Research Laboratories,
P.O. Box 20, North Beach, Perth, W.A.

ABSTRACT

Two tagging methods for adult Western king prawns (Penaeus latisulcatus) *have been tested in the unexploited king prawn population in Cockburn Sound, Western Australia.*

The effects of the numbered toggle tag, on the prawn in terms of growth, initial tagging mortality, and long term tagging mortality have been investigated for different sizes and sex of prawns.

A full scale field trial of the toggle tag in a simulated commercial fishing experiment has been conducted, to determine population parameters. A discussion of the biological problems encountered with the use of prawn tagging data will be presented.

INTRODUCTION

The application of marking and tagging techniques to investigations of penaeid prawn stocks began in 1934 when Petersen disc-tags were used in the study of *Penaeus setiferus* in the Gulf of Mexico (Lindner and Anderson, 1956). Although these experiments provided valuable information the tags were suspected of physically damaging the prawns, resulting in a loss of swimming ability (Costello and Allen, 1961). The development of a new technique of marking penaeids using injected vital stains (Menzel, 1955) appeared to be an improvement on the Petersen tagging method and was subsequently used in field experiments by Costello and Allen (1960). However, dye marking, although a rapid method, was found to have limited use because of the disadvantage of not allowing individual identification of the prawns.

More recently, mechanical tags have again been used on penaeid prawns: Ruello (1970) reported the successful use of Atkin-tags on both *Metapenaeus macleayi*, and *Penaeus plebejus*; Bearden and McKenzie (1972) cite the field use of Floy internal Anchor-tags on *Penaeus setiferus*; and Lucas *et al.* (1972) reported the aquarium testing of Floy anchor-tags and Petersen discs concurrently with vital stains.

Aquarium testing of vital stains, by the author, on adult *Penaeus latisulcatus* proved of limited value because of the high mortality of control animals which indicated that the prawns, even without the added stress of marking, were in poor condition. A second disconcerting feature of the aquarium experiments was the frequent occurrence of zero or negative mortality which has also been reported by Costello and Allen (1961) and Lucas *et al.* (1972). Although Costello and Allen suggested a possible prophylactic effect of the dye, the reduction in moulting and general activity of the marked prawns observed by the author, suggested that since most mortality occurs at the moult, the less active marked prawns were less likely to be cannibalised, and therefore had greater probability of survival than the controls. Because of these problems and because of the lack of individuality with the dye marking techniques, further testing was confined to mechanical tags, the results of which will be reported here. The two tags selected for testing were the Atkin-tag and a new type of toggle-tag. The toggle-tag was chosen because it appeared to combine all of the best features of the tags currently available, i.e. the attachment thread is fine and flexible, the tag is light-weight and, using a Floy fish-tag gun, is rapid to apply.

Because of the problems in realistic assessment of the effects of marking on individuals held in aquaria, and the extrapolation of such results to the natural field situation, the testing of tags reported here was carried out in the protected population of western king prawns in Cockburn Sound (Figure 1).

Section A of this account deals with the series of experiments, which firstly resulted in the selection of the toggle-tag as most suitable for commercial fishery application, and secondly in the assessment of the resultant effects of the tags on survival, growth, and reproduction of adult western kings. In total, 14 000 toggle-tagged and 1 000 Atkin-tagged prawns were released.

Section B describes the use of 13 000 toggle-tags in a simulated fishing industry situation, generated by the use of a chartered commercial twin-rig trawler on the population of prawns in the test area. The estimation of population number, natural, fishing and total mortality, and catchability from the results of a series of three mark recapture experiments is presented, and some of the problems in application of mark-recapture data to penaeid prawn stocks are discussed.

A. EVALUATION OF TAGGING METHODS

Materials and methods

(a) Tag Types. The two tags used were:

The toggle-tag (Plate 1): A 10 × 6 × 0.5 mm plastic numbered label was attached to the prawn by threading it onto a flexible PVC toggle 35 mm long (0.5 mm diameter) which was passed through the mid-lateral region between the first and second abdominal segments and secured by a 10 mm 'T' bar at each end. The combined weight of the toggle and label is 0.06 g. The toggle-tags were applied with a Floy FD 67 tagging gun normally used for internal anchor-tags. The toggles used were in cartridges of thirty.

The Atkin-tag: a 10 × 6 × 0.4 mm PVC label was attached to the prawn by a 0.2 mm monofilament nylon thread passed mid-laterally through the integument between the first and second abdominal segments. The use of this tag has been described by Ruello (1970) who threaded the nylon laterally through the centre of the first abdominal segment.

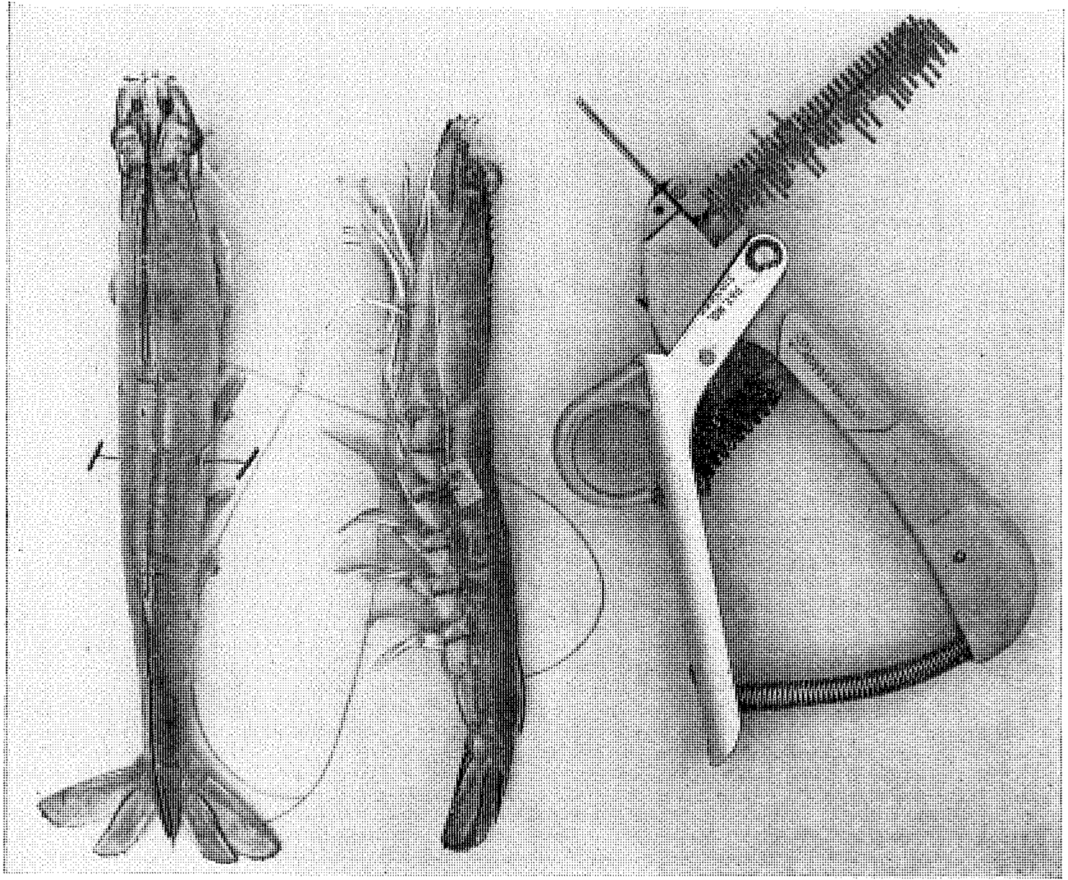


Plate 1. Toggle-tagged prawns with tagging gun.

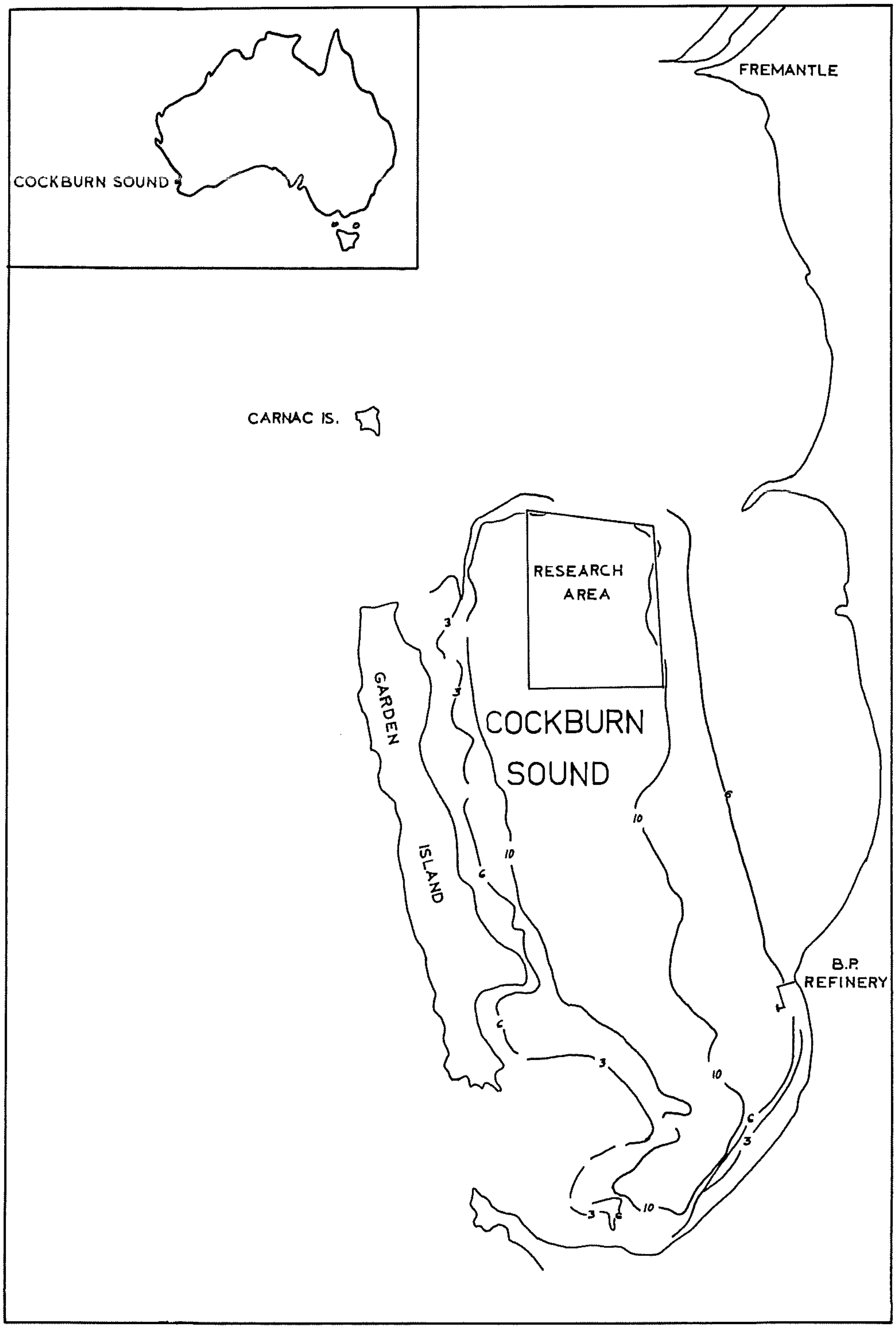


Figure 1. Cockburn Sound test area.

(b) Capture and handling of prawns. Prawns were taken from the population in the test area (Fig. 1) by the use of a standard 18 m head rope net (5.08 cm mesh wings, 4.5 cm mesh codend). Standard trawls of 30 minutes duration were used throughout the project. All recapture trawling was carried out using a standard pattern of six trawl shots over the test area each night. The research vessel *Flinders* was used throughout the program. (All other trawling in Cockburn Sound is prohibited.)

The prawns caught were held on board in a deck tank, with fresh sea-water circulating continuously, until either marked or measured. All prawns, except those injured or dead, were returned to the test areas at the end of the night. Prawns unfit to release seldom amounted to more than 20% of the catch. The loss of these individuals was the only fishing mortality to which the population was subjected during the course of the tag evaluation experiments.

(c) Tagging procedure. Each prawn was taken in turn from a compartment in the deck tank, its carapace length (C.L.) measured to 0.1 mm, and then tagged with either a toggle-tag or an Atkin-tag. The tagged prawns were then placed in another compartment of the deck tank until release 2-12 hours later. Individual measurement and tagging using the two methods under comparable conditions allowed either 150 toggle-tags or 60 Atkin-tags to be applied continuously per operator-hour. The rate of application of the Atkin-tags was slowed down in large size prawns due to the difficulty of holding them while the tag was being inserted. In later experiments utilising toggle-tags a three-man team was used, one operator taking each prawn from the tank and measuring it, the second tagging the prawn and the third recording the details of each prawn. This system was preferred as it decreases the time of air exposure of each individual prawn to approximately five seconds, while allowing continuous application rates of 300 per hour.

(d) Release of prawns. Unmarked prawns were released at the surface, but tagged prawns were released from a cage (0.6 × 0.45 × 0.45 m) which was lowered to the bottom (18 m), to reduce the probability of predator mortality.

(e) Initial tagging mortality cage. Experiments to measure initial mortality utilised a 1.8 × 1.8 × 0.9 m cage (1 × 1 cm mesh covered) which was lowered to the bottom with the prawns enclosed. The cage sank into the sediment sufficiently to allow the prawns to bury normally.

(f) Aquarium facilities. For aquarium observation a maximum of 20 adult king prawns were held in a 1.5 × 0.6 × 0.37 m tank with 6 cm of sand on the bottom. Fresh sea-water was continuously circulated through the tank at a rate of 270 *l* per hour.

Experimental design

Experiment 1. From 6 to 22 January 1971, 1 807 toggle-tagged and 946 Atkin-tagged Western king prawns were released into the test population in Cockburn Sound (Fig. 1). (Modal sizes for males 35 mm C.L. and females 46 mm C.L.) Recaptures were made by trawling for five days following the full moon in each succeeding lunar month. A standard pattern of six 30-minute trawl shots, following dusk each night, was used for both capture and recapture trawling.

Experiment 2. 10 600 toggle-tagged prawns were released in the test population during the period, from the 15 April to 13 May 1971. Approximately equal numbers of red, yellow, white and transparent labelled tags were used. The majority of the tagged individuals were from the recently recruited 0 + age group and were of modal sizes 32 mm C.L. and 35 mm C.L. for males and females respectively. Recapture trawling was carried out as in Experiment 1.

Experiment 3. 2 723 toggle-tagged prawns (yellow tags only) were released in the test population from 3 to 9 November 1971. Modal sizes for males and females were 35 mm C.L. and 43 mm C.L.

Recapture trawling was carried out as in Experiment 1.

Recapture trawling following each of these experiments continued to the start of and during the next experiment, giving continuous lunar monthly samples from the population from January 1971 to January 1973.

Experiment 4. Initial tagging mortality was assessed by placing 60 toggle-tagged and 60 untagged control prawns into the cage previously described. The prawns were held in the cage from 1830 hours on 1 February 1972 to 1900 hours on 4 February 1972. The cage was then retrieved and the results recorded.

A second trial using 50 tagged prawns and 50 controls was carried out from 2400 hours on 28 February 1972 to 1900 hours on 2 March 1972, when the cage was retrieved and the results recorded.

Results and discussion

Physical effects of the tags

(a) Toggle-tagged prawns were observed in aquaria to swim, bury and moult normally. The only visible damage from the tag was at the point of entry of the toggle where a small black scar occurred, but this scar is lost at the first moult. After subsequent moults it was noticed that the scar tissue through the musculature around the tag, also moulted and was left as a fragile tube around the shank of the toggle. Removal of the tags from recaptured prawns revealed a hollow tunnel through the body which apparently sealed off the tag from the musculature.

(b) Atkin-tagged prawns held in aquaria were able to moult successfully, but did retain the first abdominal segment of the moult if the tag was attached through the middle of the segment. Resiting of the tag, between the first and second segments of the abdomen alleviated this problem. The small black lesion noted by Ruello (1970) at the point of entry of a tag at the centre of an abdominal segment occurred, but was lost after the first moult.

The absence of the black scar on recaptures of both toggle and Atkin-tagged prawns was found useful as an indication of whether or not moulting had occurred in the field experiments.

The flexibility of the nylon thread in the Atkin tag, or the soft PVC thread of the toggle-tag would appear to be the reason that these tags cause little damage. By comparison, Floy anchor-tags used by Bearden and McKenzie (1972) with a semi-rigid nylon shank were found by the author to cause considerable scarring, which recurred with each successive moult, indicating continuing damage from the tag. In addition the rigid shank tags were observed by the author to slow the burrowing of tagged prawns compared with either toggle or Atkin-tagged prawns.

Survival of tagged prawns

(a) Recapture Rates

The percentage recoveries of toggle-tagged and Atkin-tagged prawns for the five-month period following release were recorded. These percentages (males and females separately) together with the maximum time taken to the last date of recovery for each experiment are presented in Table 1.

The similarity of the recovery percentages for toggle- and Atkin-tagged prawns from Experiment 1

Table 1. Percentage recovery and maximum time out for toggle and Atkin-tagged prawns during 1971

	Recovery percentage			*Max. time to recap.*
	Total	*Male*	*Female*	
Exp. 1 Jan. 71 Toggle-tags	4.14	4.95	3.05	273
Exp. 1 Jan. 71 Atkin-tags	4.67	5.90	3.60	197
Exp. 2 April 71 Toggle-tags	0.75	0.47	0.97	267
Exp. 3 Nov. 71 Toggle-tags	3.31	2.17	3.86	180

(Table 1) indicate that prawns marked with both tag types had similar chances of survival over a five-month recapture period. Also presented in Table 1 are the rates of recovery from Experiments 2 and 3, when only toggle-tags were used. The differences in recovery of males and females in Experiment 1 raised the possibility of a sex-related mortality effect, favouring the survival of males over females for both tag types. In the subsequent releases, Experiments 2 and 3, the situation reversed and females dominated the recoveries. It was noted however, that the sex dominating the recoveries, was related to the sex-ratio in the untagged population, i.e. 56% of the untagged catch during the Experiment 1 recovery period were males, while during Experiment 3, 52% of the untagged catches were female. (Experiment 2 recoveries were too few to make reasonable comparisons.) These data suggest that the difference in recovery percentages for males and females was a natural phenomenon, relating to different catchabilities for each sex, and not a sex dependent mortality related to tagging.

This possibility of different catchabilities for each sex, which change during the year, will need consideration when comparing the results of mark recapture experiments from different times of the year.

(b) Long term survival

The evaluation of long term tagging mortality for both toggle and Atkin-tagged prawns, was investigated in Experiment 1. The rates of recapture of each tag group have been compared with the catch rate of the untagged (1 + age group) population, for the four-month period following release, i.e. February to May 1971. The data for each group; toggle, Atkin and untagged, has been fitted to the equation:

$$(c/f)_t = (c/f)_0 e^{-Zt}$$

where c/f is the catch per mile.

The differences between the values of Z for each set of data have then been compared using a 't' test. The parameters of the equation for each line are presented in Table 2.

Table 2. Parameters of the exponential curves fitted to the catchrates from Experiment 1

	$(c/f)_0$	*Slope (Z)*	*Variance (Z)*
Controls	171.60	— 0.6003	0.0273
Toggle-tagged	1.42	— 0.7740	0.0256
Atkin-tagged	0.69	— 0.6294	0.0103

The 't' tests failed to show a significant difference between the slopes of the recapture curves for each of the tag types, or between each tag and the controls.

In fact the recapture rates were better represented by straight line relationships, than the expected exponential used above. The slopes of the lines for the tag recoveries could not be compared to that of the controls because of the differences in original numbers in each group. The data for each group were therefore adjusted to the same initial number before the slopes were compared. The adjusted straight lines of best fit and the adjusted data points for each group have been plotted in Fig. 2.

The close agreement of these three lines is taken as indicating that both tags have insignificant effects on long-term survival of the prawns compared with the control group.

Secondly, the ratio of predicted catch rates at time zero of 1.7:1, compared with the ratio of actual numbers released, 1.9:1 (1807 : 946) generally supports the conclusion that the tags have similar effects on survival, with a tendency slightly to favour the Atkin-tags as noted in the recovery percentages in Table 1.

(c) Sex and size related survival

To determine the effects of the tags on prawns of different size and sex, the distribution of the sizes of the recaptured prawns at release have been plotted against the size distribution of all prawns released (sexes separated) for each tag in each experiment.

The plots for each tag type

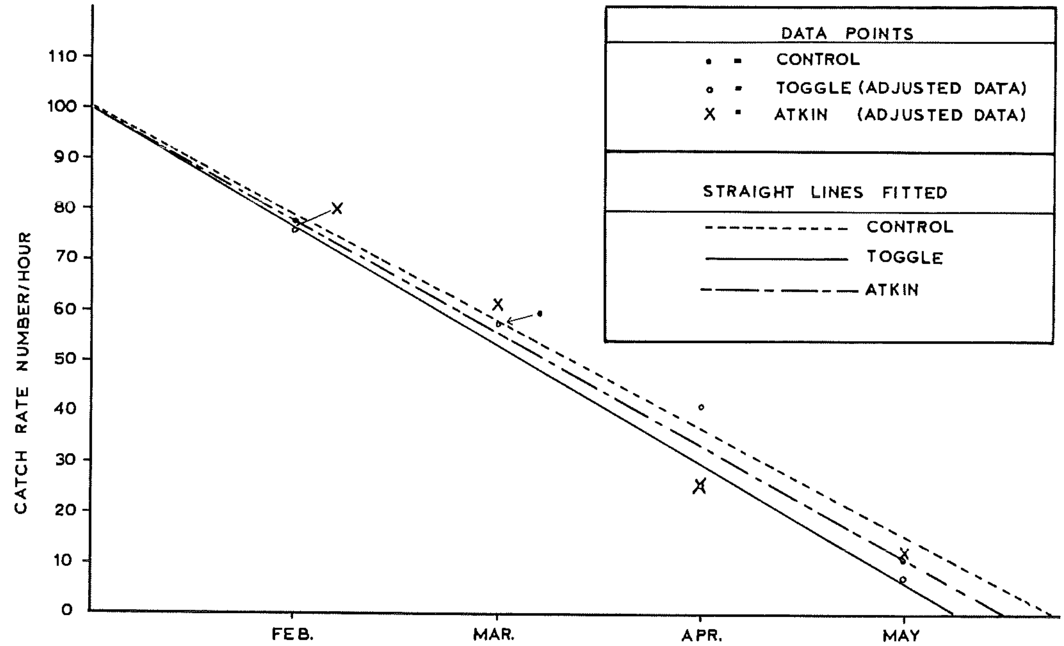


Figure 2. Catch rates for control, toggle and Atkin-tagged prawns fitted to straight lines.

presented in Fig. 3 indicate that recoveries in all experiments using toggle-tags follow a similar size distribution to that of the release group. This is taken as indicating that within the size range tested, the survival of all sizes are similar. Atkin-tagged recoveries, although not radically different to the release distribution did show a slight bias towards survival of smaller sizes of both sexes. This may be related to the additional difficulty of attaching Atkin-tags to larger animals.

(d) Effects of tag colour on survival

To examine the possibility of the mortality of toggle-tagged prawns being related to tag label colour, approximately 10 000 prawns in four groups of 2 500 were tagged with four different label colours (transparent, white, yellow and red) during April and May 1971.

The number of recoveries for each tag colour presented in Table 3 were compared with the expected number from the release data using a chi-square test. The sum of the chi-square values was found to be 3.09 with 3 degrees of freedom, indicating that there was no significant difference at the 95% level between the recaptures of each different label colour. However, it was noticed that all the yellow, and some of the white recaptures were generally picked up on the sorting tray, but red and especially clear tags were almost never picked up until the individual prawns were being later measured or counted. Considering this selection effect with different tag colours, even with trained personnel, the use of different tag colours in a commercial fishery situation would undoubtedly cause inconsistencies in the recovery rates.

Table 3. Recoveries of 4 label colours

	Clear	*White*	*Yellow*	*Red*
Release No.	2466	2422	2372	2400
Observed recoveries	14	20	24	18
Expected recoveries	19.4	19.1	18.7	18.9

These colours were chosen because they represent the complete range from black to white for animals not able to distinguish colours. In addition the white, yellow and red colours are popular tag colours chosen for ease of identification by fishermen. The transparent labels were regarded as a control group, in each of these situations.

(e) Initial tagging mortality

Although the previous data indicate that toggle-tags have little effect on the long-term survival of the prawns, the possibility of initial tagging mortality occurring before recaptures are taken and hence going

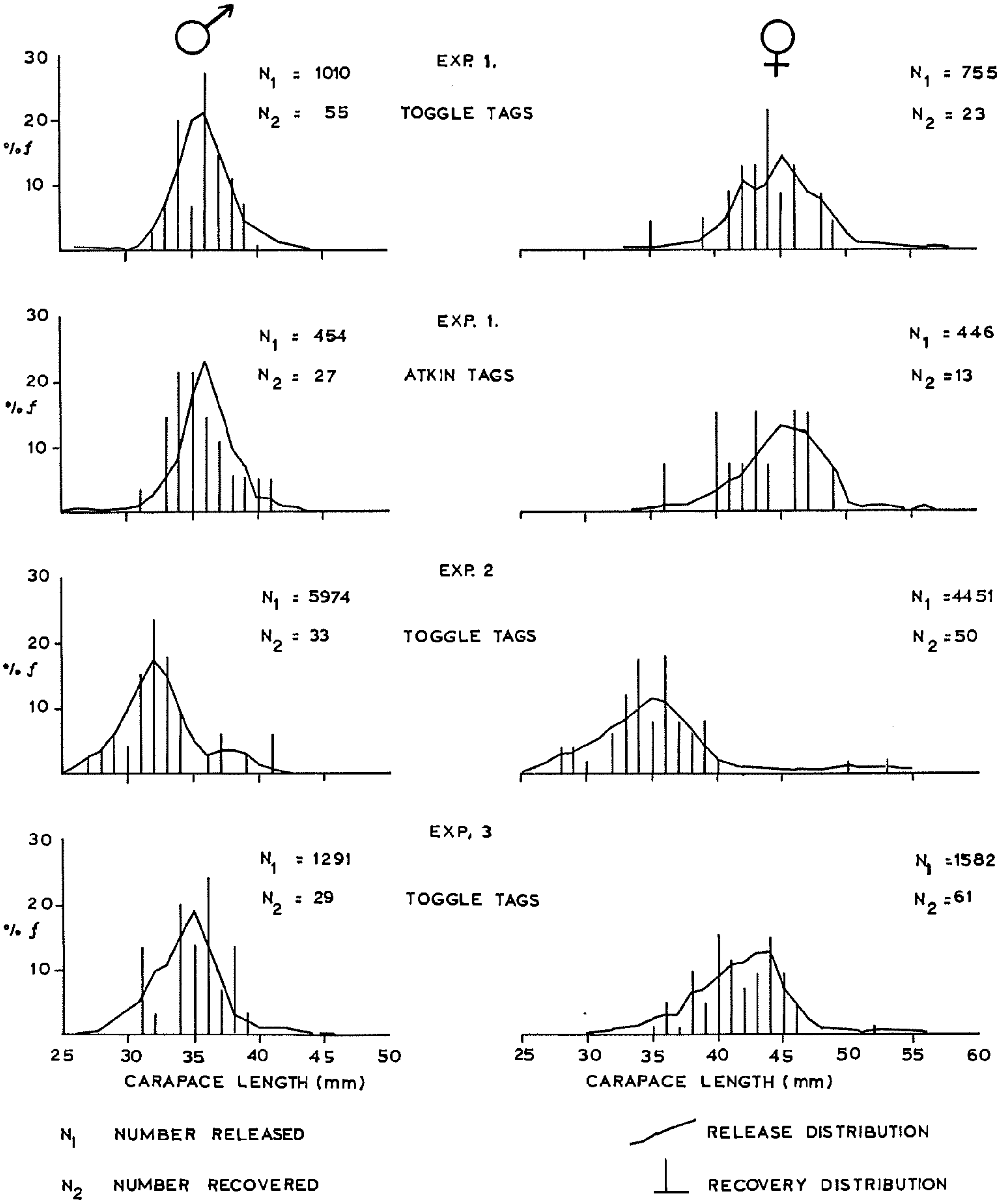


Figure 3. Size distribution of tagged prawns at release compared with the release sizes of recaptured prawns.

unnoticed has not been shown.

In aquarium experiments it was observed by the author that if tagged prawns survived more than 72 hours after tagging, then little further mortality occurred until the next moult, usually 20-30 days later. On this basis those prawns which die from a variety of causes up to 72 hours after tagging (initial tagging mortality) can be considered separately from the remaining survivors which are subjected to both the natural mortality processes and the long-term mortality effects of the tag.

To extrapolate aquarium initial tagging mortalities to the field situation is regarded as unrealistic, because the added stress of transporting the prawns to the aquarium kills many prawns which in the field would have probably been tagged and released. In addition to aquarium mortalities the effects of predation at release must also be considered.

Initial tagging mortality in the use of toggle-tags was therefore examined in the following categories: Firstly, losses from the direct effect of tagging were recorded. These were found to be insignificant during the 2-12 hour period that the prawns were normally held on board the vessel before release. Secondly, the mortality during the first three days, before recoveries usually occur, was investigated in the following cage experiments:

Experiment 1. On 1 February 1972, 120 prawns, which had been held on board the vessel for 20 hours, were divided into two groups, one of which was then tagged with toggle-tags, and the second used as controls. Both controls and tagged individuals were then placed in a cage, at a depth of 18 metres adjacent to the test area. After 72 hours the cage was retrieved and the prawns recorded in the following categories; live, recently dead (less than one day), dead and decomposing (dead more than one day) and missing (assumed decomposed and lost).

Experiment 2. On 28 February 1972 a second trial, using 100 recently caught prawns (held four hours before tagging) was conducted in a similar manner, i.e. 50 prawns were tagged with toggle-tags and the remainder used as controls. The cage was retrieved after 66 hours and the results recorded.

The data from both of these experiments, presented in Table 4, have been used to estimate the proportion of tagged prawns lost, compared with the control group.

Table 4. Initial tagging mortality cage experiments

	Experiment 1		*Experiment 2*	
	Toggle-tag	*Control*	*Toggle-tag*	*Control*
Live	24	30	20	36
Dead (one day)	7	7	2	1
Dead (two days and missing)	29	23	22	13
Total	**60**	**60**	**50**	**50**

The initial tagging mortality percentage has been estimated from these data by the following formula:

$$\frac{(\text{control survivors} - \text{tagged survivors}) \times 100}{\text{control survivors}}$$

Using the numbers of prawns which had died within one day of the conclusion of the experiment, i.e. dead (one day) in Table 4, an approximation to the initial tagging mortality at two days from release, could be estimated, e.g. in Experiment 1

$$\frac{(310 + 7) - (24 + 7)}{30 + 7} \times 100 = 16\%$$

The initial tagging mortalities calculated in this way are as follows:
Experiment 1. 16% relative to 48 hours, and 20% at 72 hours.
Experiment 2. 40.5% relative to 48 hours, and 44.5% at 66 hours.

The confining effects of the cage are suspected of creating an additional mortality, but this would have been taken into account by comparing the tags and controls. A 20% loss is used in section B, to indicate an order of magnitude for initial tagging mortality in the Cockburn situation.

Thirdly an attempt to assess the likelihood of predation of tagged prawns at release, was carried out by monitoring the activity around the release cage by use of a 200kHz echo-sounder. Two releases on each of two occasions failed to show any additional activity around the position of the released prawns (the release position was marked by the trace from the release cage). Predators of western king prawn known from trawl catches) to be in the area at the time included:

Mulloway, *Sciaena antartica,*
Tailor, *Pomatomus saltator,*
Eagle ray, *Myliobastus australis,*
Shovel nose ray, *Aptychotrema vincentiana.*

These observations are taken as indicating that in Cockburn Sound, large predators were not a problem to the released prawns for the period of approximately 20 minutes from release.

Growth of tagged prawns

The recaptures of each tag type from each experiment were compared with the growth of the control (untagged) population using the following method:

For each tagged prawn recaptured, let L_t equal its length at time *t*. Secondly, for control group let x_t equal the mean length at time *t*.

Then, $x_t - L_t$ is the size of the recaptured tagged animal relative to the mean size of the controls at time *t*.

The increment, $I = (x_2 - L_2) - (x_1 - L_1)$ then becomes a measure of the relative change in size of the recaptured animal with respect to the average size of the controls between times 1 and 2.

When this increment has a positive sign, the recaptured tagged individual has grown faster than the average control animal, conversely when the increment is negative the individual has not grown as fast as the controls during the period it was free. By plotting each recapture's increment against time, any effect of the tag on growth rate can be demonstrated. This method assumes that the mortality, immigration, and emigration in the control population is not size dependent during the period of the experiment. The data for both toggle- and Atkin-tagged recaptures from Experiment 1, and toggle-tagged recaptures from Experiments 2 and 3 are presented in Figure 4.

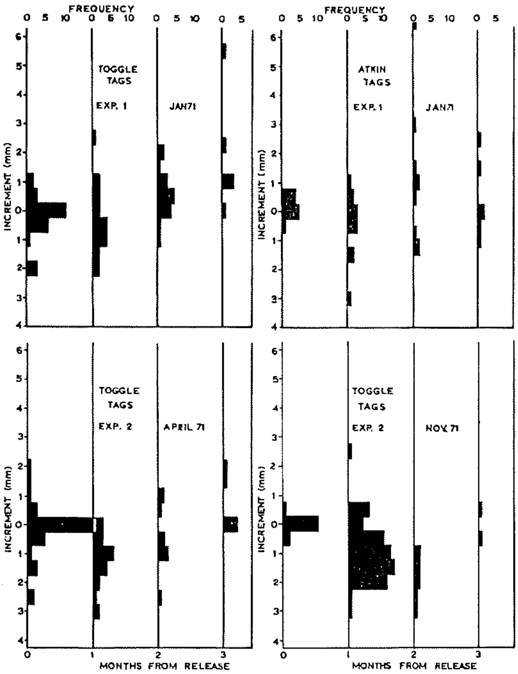


Figure 4. Growth of tagged prawns compared with the mean growth rate of untagged prawns.

These data indicate that both the toggle- and Atkin-tagged recoveries in Experiment 1, and the toggle-tagged recoveries in Experiment 2 did not grow as fast as the average control during the first month after release, but in subsequent months they apparently grew faster than the controls. The toggle-tagged recoveries from Experiment 3 (November) also grew less than the controls during the first month, but unlike recoveries

Table 5. Comparison of ovary development of tagged and untagged female western king prawns in December 1971

*Ovary Stage**	*Stage 2 developing*	*Stage 3 early maturity*	*Stage 4 ripe*	*Number examined*
Toggle-tagged	55%	27%	18%	44
Untagged population	54%	39%	7%	1572

* Ovary stages are equivalent to those defined by Tuma (1967).

from Experiments 1 and 2, did not recover as quickly in the subsequent months.

The slower growth of all the tagged prawns during the first month from release suggests that the effect of the tag is to cause the prawns to miss a moult, or to moult with a greatly reduced increment after tagging. Zero growth at the moult, probably due to handling and/or tagging, was a common problem in aquarium studies by the author on adults of this species. Increased growth of recoveries from later months could be caused by: (i) tagging mortality selecting against the weaker, slow growing individuals; or (ii) recruitment of smaller individuals to the untagged population, either of which would depress the growth of the control group. Selective fishing mortality of larger individuals, causing a depressed mean growth rate, suggested by Ricker (1958) would not appear likely in this case, as fishing mortality during these experiments was negligible. The continued slow growth of tagged individuals in Experiment 3 coincided with the period of maximum spawning (January) suggesting that the combined stresses of spawning and tagging could have had a detrimental effect on growth.

Regardless of the causes of the variations in growth rate of tagged prawns, the fact that all tags in all releases varied considerably from the control mean growth rate especially during the first moult, indicates that further work on this aspect is required before meaningful growth increments can be obtained from tag recoveries.

Spawning of tagged prawns

To examine the effects of the toggle-tag on spawning, 2 723 tagged prawns were released in November 1971, prior to the expected peak of spawning activity.

Forty-four females were recaptured 30-45 days later and of these 57% had moulted and 55% had spawned. 29% of those which had spawned also showed development of the ovary toward a second spawning. A comparison of the percentages of tagged and untagged females in each stage of development (visually determined) during this period is presented in Table 5.

Although more tagged than untagged females were ripe during the December recovery period, the total percentage of females showing development, i.e. stages 3 and 4 combined, was similar for each group.

On this evidence it appears that the toggle tags have had no effect on the spawning ability of female western king prawns in the test area.

Conclusions

On the size range of western king prawns required to be tagged (i.e. adults above 30 mm of carapace length), the toggle and Atkin-tags were found to affect the prawns in the following ways:

(a) The physical effects of the tag on the body of the prawn were the same for each tag, i.e. a small amount of scarring which was lost at the first moult.

(b) The survival of tagged prawns as indicated by the recapture percentages and the rates of recapture for each tag could not be shown to differ significantly.

(c) Mortality related to size was not evident with toggle-tags, but for Atkin-tags there was a trend towards smaller sizes having a better survival, possibly due to the difficulty of attaching the Atkin-tags to larger individuals.

(d) Growth of both toggle and Atkin-tagged prawns during the first month from release was retarded, but in subsequent months appeared to be faster than the average control animal. Because both tag types showed reduced growth initially it is suggested that this is a more general phenomenon possibly related to the effects of both capture and handling.

(e) Toggle-tagged females were found to be capable of normal ovary development, as were Atkin-tagged female eastern king prawns (*Penaeus plebejus*) Ruello, 1970.

The only major difference between the two tagging methods in these experiments was therefore the speed with which the tags could be inserted, i.e. 150 toggle or 60 Atkin-tags per operator hour. For use in a commercial fishery on adult king prawns the toggle-tag was therefore selected as the more functional tag. Atkin-tags however, although slow to insert, have been shown by Ruello (1970) to be useful for tagging smaller individuals for which the toggle-tags are probably unsuitable.

ESTIMATION OF POPULATION PARAMETERS

Methods and materials

The yellow label toggle-tag described in section A was used in the three mark recapture experiments reported here. The procedures used in the capture, handling, tagging and release of prawns aboard the research vessel *Flinders* were the same as those described in section A. All live prawns taken by *Flinders* were tagged and released.

Additional fishing effort during the experimental period was supplied by a chartered 19 m twin-rigged commercial trawler which was experienced in fishing for western king prawns. Personnel aboard the chartered vessel, *Ca-Den*, individually counted and inspected the prawns for tags, in addition to recording the duration and location of each shot. For the purposes of combining the effort of the two vessels into standard hours, the *Ca-Den* hours were adjusted to *Flinders* hours by the ratio of the catch rates in number per hour, on occasions when both vessels were fishing at the same time (i.e. 31% of the experimental period).

Temperatures for Cockburn Sound during the experimental period, in the form of daily maximum and minimum temperatures were available from the BP Oil Refinery jetty near the test area.

At the beginning of these experiments the modal carapace length of the prawns in the test area were 32 mm for males and 36 mm for females, while at the end of the experiment the prawns had grown to modal sizes of 34 and 41 mm for males and females respectively.

Experimental design

Three groups of tagged prawns were released in the Cockburn Sound test population at lunar monthly intervals with each release beginning 2-3 days after the full moon. The timing of each experiment and the numbers released were as follows:

Release (1)
28.8.72 - 1.9.72, 3 856 tags released.
Release (2)
25.9.72 - 3.10.72, 4 742 tags released.
Release (3)
23.10.72 - 1.11.72, 4 781 tags released.

Trawling by *Flinders* to catch prawns for both tagging and recapture purposes was carried out using the standard trawling procedure described in section A. Releases of tagged prawns were spread randomly throughout the test area.

Additional recapture sampling by *Ca-Den* from 29 August to 15 November 1972 was carried out using a standard pattern of trawling spread equally over the test area. Both tagged and untagged prawns captured by *Ca-Den* were removed from the population to represent fishing mortality.

Results and discussion

Estimation of population parameters for penaeid prawn stocks are difficult, firstly because of the high rates of growth, recruitment and mortality, which characterise these short-lived species, and secondly because of the small size and frequent moulting of the individuals. This restricts the methods of marking which can be used. The toggle-tagging method described in section A of this paper appears to overcome many of the usual marking problems (for adult sized prawns), but in turn the use of this tag in the controlled fishing experiment highlighted some of the problems in analysis of tag-recapture data for small crustaceans such as *P. latisulcatus.*

Estimates of population size

The number of prawns in the test population was estimated on three occasions, one lunar month apart, using the recapture data from the three tag releases (Petersen method). In addition, attempts were made to estimate population number using the catch per unit of effort data during the same period (DeLury method).

(a) Petersen method

The Petersen single census method of estimating population number from mark recapture data has been modified by Bailey (1951) to give almost unbiased estimates. Bailey's modified form of the Petersen equation is given by:

$$N = \frac{M\ (C\ +\ 1)}{R\ +\ 1}$$

where: M = the number of individuals marked.
C = the catch or sample taken for census.
R = the number of recaptured marks in the sample.
N = the estimate of the size of the population at time of marking.

The large sample variance (V) for N is given by Bailey (1951) as approximately equal to:

$$V = \frac{N^2\ (C\ -\ R)}{(C\ +\ 1)\ (R\ +\ 2)}$$

The assumptions made in the aplication of these formulae and the justification for each assumption are as follows:

(1) Marked and unmarked individuals suffer the same natural mortality: the data presented in section A indicate that the toggle-tag does not affect the long-term mortality of the prawns, but an initial tagging mortality estimated at approximately 20% should be subtracted from the number of tags released. Estimate of population numbers have been made both with and without a 20% reduction in the effective tags.

(2) Marked and unmarked prawns have the same vulnerabiilty to the fishing gear: aquarium observations indicated that swimming and feeding were not affected by the tag, which suggested that vulnerability to the gear had not altered.

(3) Marked animals do not lose their marks: the loss of toggle-tags is unlikely because of the design of the tag and has not occurred in aquaria, therefore tag loss was regarded as negligible.

(4) Marked and unmarked prawns mix randomly: as the tagged prawns were released randomly throughout the test area to assist mixing, and because the recoveries in each shot were usually from a variety of release days, the random mixing of both populations was assumed.

(5) All marked prawns are recognised and reported: in this closed experiment unreported recaptures were considered to be negligible.

(6) Recruitment to the population during the recovery period is negligible: as recruitment of young prawns to the test area is predominantly from February to May, and the experimental period was timed to avoid the recruitment period, dilution of tags by recruitment was assumed to be negligible.

(7) Migrations: emigration from the fishery would be expected to effect marked and unmarked prawns equally, but the question of dilution of the marks by immigration needs to be considered. However there has been no indication from the experimental observations of any substantial movement of adult prawns into the area, the recorded changes in abundance have been attributed to changes in catchability.

For the purposes of producing comparable estimates of population size from each release, the recovery sampling periods were standardised as the 22 days starting four days before the new moon in each month. Recoveries prior to the start of the sampling period have been deducted from the number released, which makes the additional assumption that the mortality of tagged prawns from release to the start of the sample period was negligible.

The data for each release, assuming zero initial tagging mortality, together with the population estimates and 95% confidence limits are presented in Table 6. However, recognising that initial tag losses of up to 20% are likely, a second series of estimates of N have been made to indicate the effect of such a loss. These data are presented in Table 7. The 'accuracy' (the difference between the true value and the estimate at the 0.95 confidence level) of the estimates N_1, N_2, and N_3 calculated both with and without initial tag mortality were found to

Table 6. Population estimates using Bailey's modification to the Petersen method after Ricker (1958)

Release No.	*M**	*C*	*R*	*N*	1.96 *S.E.*
1	3 827	25 310	82	1 167 051 (N_1)	249 168 (21%)
2	4 710	33 573	162	970 144 (N_2)	148 120 (15%)
3	4 706	24 073	131	858 275 (N_3)	145 466 (17%)

* Effective tags released.

be 21%, 15% and 17% respectively, and the bias of the three estimates, when examined using the technique described by Robson and Regier (1964) was found to be negligible at the 95% confidence level, i.e. the product of M and C was $>4N$ in all three estimates. Under Robson and Regier's criteria these estimates have accuracies which are between those useful for management, and those useful for research, i.e. 0.25 and 0.1 respectively.

Since the assumptions made in the use of this method were generally well satisfied, the population estimates adjusted for initial tagging mortality presented in Table 7, have been taken as representing the absolute numbers of prawns in the test area at the start of each recapture period.

(b) DeLury method

An attempt to calculate population size, using the DeLury method on the catch and effort data for the whole experimental period, gave erroneous results, in the form of infinitely large population sizes, suggesting that the assumption of equal catchability was not satisfied. An increase in catchability was expected at this time of year because the catch rate during the same period of 1971 increased dramatically at a time when recruitment was minimal. Lunar variations in catchability also precluded the use of the DeLury method on shorter (less than one month) periods of data.

Although DeLury estimates could not be used in this experiment, Iversen (1962) used the DeLury method concurrently with the Petersen method to produce two population estimates within 4% of each other for the Tortugas stock of *Penaeus duorarum*. As the DeLury method could only be applied to selected data from the Tortugas fishery, it would appear that the method is not generally applicable to penaeid stocks and the agreement of Iversen's two estimates may have been due to chance.

(c) Multiple census methods

Multiple census techniques for population estimation, such as the Schnabel method used by Barr (1971) on *Pandalus platyceros*, are less applicable to western king prawns because the additional mortality from trawl capture and handling at recapture would be expected to severely bias the rate of second-time recoveries. In early Cockburn Sound tagging trials during 1971, all recaptures which were alive were re-released, but only one prawn was ever recovered twice, which indicates the low probability of success of such methods.

The single census method, in contrast to the fishing success (DeLury type) and multiple census (Schnabel type) method, was found most applicable in terms of the assumptions required, and the population estimates presented in Table 7 are considered to be the best possible for the western king prawns in the test area.

Table 7. Population estimates from Table 6 data, but including an initial tagging mortality of 20%

Release	*M**	*C*	*R*	*N*	1.96 *S.E.*
1	3 062	25 310	82	933 762 (N_1)	199 361 (21%)
2	3 768	33 573	162	776 115 (N_2)	118 496 (15%)
3	3 765	24 073	131	686 656 (N_3)	116 379 (17%)

* Effective tags released.

Estimates of instantaneous mortality rates

Using the method described by Ricker (1958) instantaneous total mortality rates for the test population during the period of the simulated fishing experiment have been calculated, i.e.

$$\frac{N_t}{N_0} = e^{-it} \qquad (1.)$$

where N_0, is the population size at the start of the period.

N_t, is the population size at time t.

i, is the instantaneous total mortality rate ($= Z$)

t, is the number of units of time during which the mortality occurs.

Using the total mortality rates (Z) obtained, the rates of fishing (F) and natural (M) mortality have been estimated using the relationship.

$$\text{Rate of exploitation} = \frac{F}{F + M}(1 - e^{-(F+M)})$$

(Ricker, 1958)

Where 'rate of exploitation' is defined as the ratio of the catch taken during the period and the number in the population at the commencement of the period.

The values for Z, F and M calculated by these methods for the first two recapture periods are presented in Table 8. Table 8 also includes an approximation for F during the third recapture period which was made by assuming M to be zero and simply estimating the rate F from Equation (1.). This method when applied to the previous two recapture periods caused F to be under-estimated by approximately five per cent.

Since these estimates are based on population sizes which may be biased because of initial tagging mortality, the mortality rates have also been similarly calculated from population sizes adjusted to compensate for an initial tag loss of 20 per cent. The values presented in Table 9 are given to indicate the range of values obtained for the mortality rates in the test population during the experimental period.

These rates for total (Z), fishing (F) and natural (M) mortality are generally less than those estimated for other commercially exploited penaeids (*Penaeus duorarum, P. setiferous, P. aztecus*) from the Gulf of Mexico (summarised by Berry, 1971).

The instantaneous mortality rates relative to weekly periods listed by Berry, range from 0.02-0.55 for M, 0.02-0.96 for F, and 0.11-1.51 for Z, in contrast to the weekly rates of 0.01-0.04 for M, 0.006-0.014 for F, and 0.03-0.04 for Z in the test population.

Because of the large range of Z values presented by Berry (1971) an attempt has been made to establish a realistic upper limit for Z in the test population, by assessing the effects of a series of different Z values on a population over a 12-week period. The relationship between Z and the proportion of the population remaining after 12 weeks is presented in Fig. 5. In addition the relationship between Z and proportion of the population remaining after periods of 26 and 52 weeks have also been included in Fig. 5. The graph shows that with a minimum surviving population of 0.5 of the original size after 12 weeks, then the maximum weekly value of Z possible is approximately 0.06. On this basis the Z values of 0.03-0.04 per week estimated for the test population are regarded as realistic.

In comparison, the fishing mortality rates alone, for the Tortugas fishery estimated by Berry (1971) range during a year from 0.02 to 0.16 per week. Rates of 0.14-0.16 per week acting over a period of 12 weeks could be expected from Fig. 5 to reduce the population to 14%-18.5% of its original size, which appears inconsistent with the decrease in catch rate, which occurred when the mortality was estimated at this level. When the swept area method, used by Berry (1971)

Table 8. Instantaneous mortality rates for western king prawns

Period	*No.*	*Instantaneous mortality rates*					
		Total (Z)		*Natural (M)*		*Fishing (F)*	
		Daily	*Weekly*	*Daily*	*Weekly*	*Daily*	*Weekly*
1 : 4/9 – 3/10/72	1 167 051	0.00616	0.04312	0.00519	0.03635	0.00097	0.00677
2 : 4/10 – 1/11/72	970 144	0.00422	0.02957	0.00253	0.01767	0.00170	0.01897
3 : 2/11 – 23/11/72	858 275	—	—	—	—	0.00129	0.00905

Table 9. Instantaneous mortality rates based on population estimates incorporating an initial tag loss of 20%

Period	No.	*Instantaneous mortality rates*					
		Total (Z)		*Natural (M)*		*Fishing (F)*	
		Daily	*Weekly*	*Daily*	*Weekly*	*Daily*	*Weekly*
1 : 4/9 – 3/10/72	933 762	0.00617	0.04315	0.00495	0.03469	0.00121	0.00846
2 : 4/10 – 1/11/72	766 115	0.00422	0.02956	0.00210	0.01469	0.00212	0.01487
3 : 2/11 – 23/11/72	686 656	—	—	—	—	0.00162	0.01136

was applied to the test population during the experiment, a fishing mortality rate of 0.17 per week resulted. Such a rate would have considerably reduced the test population during the experiment, which clearly did not occur. This result suggests that the method used by Berry gives over-estimates of *F*, and hence *Z*, indicating that the mean weekly rate of 0.09 for the Tortugas fishery over the year could be too high (a rate of 0.09 for *F* acting over half a year would reduce the population by 90% from fishing alone). This is taken as additional evidence that the lower mortality rates from the test population are probably realistic for an exploited stock.

Although the values for *Z* and *F* presented may be biased to some extent and therefore should not be regarded as absolute values, they do however serve a useful purpose as an indication of the range of *Z* and *F* values likely to occur in an exploited stock of adult western king prawns.

Estimates of catchability

Variations in catchability are probably the greatest problem in producing valid population parameters in fisheries exploiting a single year class such as for the western king prawn. A knowledge of the factors affecting catchability is therefore essential to the planning of mark-recapture experiments on these annual stocks. The experiments reported here were timed to coincide with the period when an increase in catchability was expected, so as

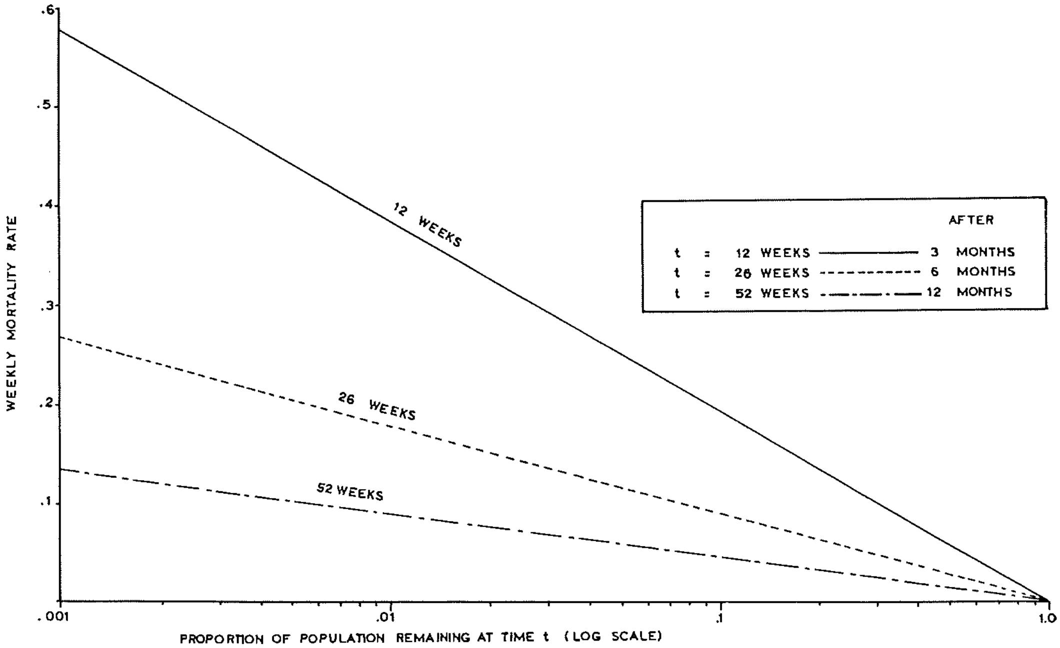


Figure 5. Simulated effects of weekly instantaneous rates acting over 12, 26, 52 weeks plotted against the proportion of the population remaining at the end of the period.

to demonstrate the effect of such changes. Ricker (1958) has defined catchability as 'The fraction, of the whole fish stock under consideration, which is caught by a defined unit of effort actually used'. In these experiments the defined unit of effort was chosen as one hour of standard trawling effort by the *Flinders* using an 18 m head rope commercial trawl, and the whole fish stock was assumed to be in the test area.

Catchability (q) has been estimated for the test population from:

$$q = \frac{F}{f}$$

where q is the mean catchability for the period.

F is the instantaneous fishing mortality co-efficient for the period.

f is the total hours of standard effort over the period.

The assumptions made by the use of this equation were that fishing and natural mortality rates were constant throughout each recapture period. As bias in the population estimates is carried through to the estimates of catchability via the fishing mortality rate, the values for q during each recapture period were estimated for the test population both with and without adjustment for an initial tagging mortality of 20 per cent. These results together with the mean temperature for each recovery period are presented in Table 10.

Table 10. Catchability estimates and temperature during the three months of the experiment

Release	q_1*	q_2*	*mean temperature*
1	0.000158	0.000197	17.5°C
2	0.000378	0.000472	18.5°C
3	0.000442	0.000555	20.2°C

* q_1 : estimated from mortality rates not adjusted for initial tagging mortality.

* q_2 : estimated from mortality rates adjusted for an initial tagging mortality of 20%.

The possible causes of variation of catchability in a commercial fishery situation can be assigned to one or both of the following factors; firstly, changes in the intensity of effort applied to the stock can alter catchability, and secondly, an individual's 'vulnerability' to the fishing gear may change causing a variation in catchability.

The estimation of catchabiilty for the test population was simplified in comparison with the normal fishery situation, because the effects of changes in application of effort, on catchability, described by Garrod (1964) have been avoided. This was achieved in the experimental situation by standardising the distribution of effort applied by each vessel. *Flinders*' effort, consisting of six 30-minute shots per night, was spread uniformly over the test area, with each shot traversing the entire width of the grounds. Similarly the effort by the chartered trawler *Ca-Den* was also regulated to cover evenly the test area.

The second category of factors affecting catchability, i.e. changes in vulnerability to the gear, appear to have been the most likely cause of the variation in catchability observed in these experiments. The term vulnerability was used in this context by Morrissy (1973) to describe a freshwater crayfish's behavioural and physiological response to a baited trap. The term vulnerability is used in the present context to indicate the probability of an individual being above the substrate (which is a function of behavioural and physiological factors) and hence vulnerable to the capture unit (trawl). Although the factors contributing to an individual's vulnerability in this case are less directly related to its response to the capture unit, the term is used to separate these factors from the fishing intensity effects on catchability.

During these experiments, obvious changes in catch rates (indicating changes in vulnerability) with lunar cycle were observed for both marked and unmarked prawns. This variation corresponded with data presented by Fuss (1963) which showed that the proportion of prawns active, i.e. above the substrate and hence vulnerable to the gear, varied with lunar cycle. To avoid these short term changes in vulnerability, so that long term trends could be examined, each recapture period was standardised with respect to lunar cycle. The estimates of catchability presented in Table 10 are therefore mean values over a lunar cycle. The variation in these values is therefore regarded as a direct result of long-term changes in the vulnerability aspect of catchability.

A further problem in the assessment of the catchability estimates presented, is that they may be biased as a result of bias in the population estimates. Because of this possible bias, these estimates cannot be regarded as absolute values, but since the bias is likely to be the same for catch estimate, they can at least be regarded as indices and the trend in catchability examined.

The trend of increasing catchability over the test period (Table 10) is of special interest since it supports the hypothesis that vulnerability, and hence catchability, increases during the spring period. The obvious environmental change which could have caused the increase in vulnerability was the rise in mean monthly temperature of 2.7°C, which occurred during the three months of the experiment. The effect of increasing temperatures on another penaeid, *Penaeus duorarum*, has been documented by Fuss and Ogren (1966) who found that increases in temperature, especially in the lower half of the animal's normal temperature range, caused increased activity, which would result in increased vulnerability. For *P. latisulcatus*, activity change with temperature is therefore considered the most likely explanation of the change in catchability.

Amongst the physiological changes which could be correlated with the temperature increase during the experimental period was the onset of ovary development in the females. Because the fully developed ovary in the western king prawn makes up approximately 10% of the total body weight (author, unpublished data), the additional food requirements for females during the spawning season could be expected to increase foraging activity, and hence vulnerability.

Support for the hypothesis of increased vulnerability of the females during the period of ovary development is also available from the recaptures from the tag release in November 1971 (reported in section A). The recaptures from this period were biased towards females suggesting that they were more catchable. Situations such as this when the females are apparently more catchable than the males is an additional difficulty in comparing mark recapture data for different times of the year. Further work on the factors affecting catchability in penaeid stocks is required before population analyses of other penaeid stocks are attempted.

Conclusions

Estimates of population size were made using the single census, Petersen method, on the tag recapture data from the test population as this method was found to be most applicable to the data available. Other population estimation techniques such as the fishing success method (DeLury type) could not be applied because the assumption of constant catchability could not be justified. The more sophisticated multiple census methods (Schnabel type) were also not applicable due to the physical characteristics of the prawns and the method of capture.

The population estimates produced were, on the basis of their accuracy and negligible bias, considered to reasonably represent the test population for the purposes of estimating total, natural and fishing mortalities. Although these rates are generally at the lower end of the range of mortalities cited in the literature, they are well within the maximum rates considered realistic for the experimental population.

Of the data presented in the text the long-term trend in catchability was the most interesting, because such variations in catchability related to temperature have the greatest potential for causing inconsistencies in the catch-effort relationship for a penaeid stock. An understanding of the behavioural and physiological factors relating to these changes in catchability are therefore considered basic to the estimation of population parameters for these stocks and further experimental observations are required.

LITERATURE CITED

BAILEY, N. J. J. (1951). 'On estimating the size of mobile populations from recapture data.' *Biometrika*, 38, pp. 293-306.

BARR, (1971). 'Methods of estimating the abundance of juvenile spot shrimp in a shallow nursery area.' *Trans. Am. Fish. Soc.*, 100(4), pp. 781-86.

BEARDEN, C. M., AND MCKENZIE, M. D. (1972). 'Results of a pilot shrimp tagging project using internal anchor-tags.' *Trans. Am. Fish. Soc.*, 101(2), pp. 358-62.

BERRY, R. J. (1971). 'Shrimp mortality rates derived from fishery statistics.' Contr. Bur. Comm. Fish. Biol. Lab. Galveston Texas, 282.

COSTELLO, T. J., AND ALLEN, D. M. (1960). 'Notes on the migration and growth of pink shrimp (*Penaeus duorarum*).' *Proc. Gulf Caribb. Fish. Inst.*, 12th, pp. 5-9.

COSTELLO, T. J., AND ALLEN, D. M. (1961). 'Survival of stained, tagged and unmarked shrimp in the presence of predators.' *Proc. Gulf Caribb. Fish. Inst.*, 14th, pp. 16-20.

FUSS, C. M. (1964). 'Shrimp burrowing behaviour and responses to mechanical stimulus. *Modern Fishing Gear of the World* 2, Fishing News (Books) Ltd, London.

FUSS, C. M., AND OGREN, L. H. (1966). 'Factors affecting activity and burrowing habits of the pink shrimp, *Penaeus duorarum* Burkenroad.' *Biol. Bull.*, 130(2), pp. 170-191.

Garrod, D. J. (1964). 'Effective fishing effort and the catchability coefficient *q*.' *Rapp. P-v. Réun. Cons. perm. int. Explor. Mer.*, 155, pp. 66-70.

Iversen, E. S. (1962). 'Estimating a population of shrimp by the use of catch per effort and tagging data.' *Bull. Mar. Sci. Gulf Caribb.*, 12(3), pp. 350-398.

Lindner, M., and Anderson, W. W. (1956). 'Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*.' *Fishery Bull.*, Fish Wildl. Serv. U.S., 56, pp. 555-645.

Lucas, C., Young, P. C., and Brundritt, J. K. (1972). 'Preliminary mortality rates of marked king prawns *Penaeus plebejus*, in laboratory tanks.' *Aust. J. mar. Freshwat. Res.*, 23(2), pp. 143-9.

Menzel, R. W. (1955). 'Marking of shrimp.' *Comml Fish. Abstr.*, 8(8), p. 3.

Morrissy, N. M. (1973). 'Normal (Gaussian) response of juvenile marron, *Cherax tenuimanus* (Smith) (Decapoda : Parastacidae), to capture by baited sampling units.' *Aust. J. mar. Freshwat. Res.*, 24, pp. 183-95.

Ricker, W. E. (1958). 'Handbook of computations for biological statistics of fish populations.' *Bull.* Fish. Res. Bd Can. 119, 300 pp.

Robson, D. S., and Regier, H. A. (1964). 'Sample size in Petersen mark-recapture experiments.' Trans. Am. Fish. Soc., 93(3), pp. 215-26.

Ruello, N. V. (1970). 'Prawn tagging experiments in New South Wales.' *Proc. Linn. Soc. N.S.W.*, 94(3), pp. 277-87.

DISCUSSION

Lucas. You have in your later estimates taken the figure of a 20 per cent initial tagging mortality, looking at the experiments you did in the cage, why did you not take a 60 per cent?

Penn. The main problem was that I was not at all happy with the cage experiments. These experiments were an attempt to get a measure of initial tag loss, but I feel that they were a very poor attempt. Initial tag loss is one of those things that you cannot really measure, and I do not think that there is any way of actually getting at it in the field situation. There were problems, as I mentioned, with the animals getting caught up in the cage, also we were not too sure whether the animals had sufficient room to bury at the bottom of the cage, which we had shown in aquaria, to definitely increase the mortality. Since we do not have a good measure of initial tag loss, all of the values for population size, mortality, etc., from the tagging experiments should be regarded as indices and the main reason that I have put them in is to look at changes in catchability over the period.

Lucas. But there does seem that there is a mortality, possibly due to the tag, but also another mortality that is just due to the handling effects. I wonder if Dr Neal would like to make some comment on initial tag mortality.

Neal. It is very amazing here we have a very similar problem but I think we too have held marked shrimp in cages and aquaria and never been satisfied with an estimate of initial mortality or tagging caused mortality, but by chance we also used the 20 per cent figure, not because that was what we observed in the cages but because we felt that it was fairly realistic, and fairly workable. I have a question about your mortality estimates. Of course your fishing mortality is not one that can be interpreted in terms of a fishing mortality that occurs with a fleet operating on a population because you have just one vessel, but you do have then a means of getting the natural mortality? I wonder how you feel about the effect of the emigration from the area, did you have any measure of this or any evidence of it?

Penn. From the biological observations that I made, there did not appear to be any reason to suspect that prawns were emigrating from the area. There is not really anywhere they can go, the rest of the coastline is very bare sand, almost like desert. We also have three-year classes represented in the fishery which led us to believe that prawns probably stayed there. All of the evidence although circumstantial pointed to the fact that they were not leaving the area. This still leaves the problem of animals coming into the area from somewhere else and there is a possibility of their coming from the other end of Cockburn Sound where I did mention that there was a small population, but in the earlier tagging experiments we did go into the other areas to see if any of our tags moved there, and we did not catch any, although we put in sufficient effort to have caught some, so there does not appear to be any movement that we can pin down in the area.

Neal. Well, I am glad to see your estimates. I think they may be useful. We are not happy with the high estimates that we have obtained in the Gulf of Mexico and it is very easy with a few calculations to see that they are too high for any long-term basis.

Penn. I was able to use Berry's paper to look at the fishing intensity in the Gulf of Mexico, where he made his calculations of mortality, and the fishing intensity that we generated were in fact about the same as Berry quoted for the Tortugas area in the Gulf of Mexico, on the pink shrimp. So the two areas, I feel, have a lot more in common than first meets the eye. When I used his technique, an area swept method, to estimate mortality in our area, the fishing mortality came out to 0.17 per week. This value is way out of bounds for our particular population, even taking a rough estimate of what was left of the population after our 12 weeks. I took 50 per cent as the maximum decline in the population, which from Fig. 5 gives a maximum mortality rate of something like 0.1 per week which would reduce the population by 50 per cent over the 12-week period of the experiment, therefore 17 per cent was so far out that I consider that his technique is not reasonable for estimating mortality rates for prawns, where as our estimates, although we only have two values, do seem to fit into the sort of picture we would expect.

Lucas. I would just like to comment on the way in which the estimates of *F* and *M* are made. We could not use the classic sense of looking at rates of captures per unit fishing intensity. This method that Jim Penn has used allow us to overcome the problem of long-term tagging mortality because we are looking at absolute numbers of prawns on each of three months and any long-term tagging mortality in one month, if it is the same as the next month. So this method does allow us a way of estimating *M* which is free from the long-term tagging effects. So I think it is a quite useful technique in itself, quite apart from the rest of the paper.

Zed. Could I ask you whether you have done any work on trying to estimate recruitment and whether you have got any ideas of separating the recruitment from catchability in the capture information?

Penn. I have not discussed it in this paper, as I intend to get out another paper on the biological background to the Cockburn Sound population. We did estimate recruitment rates, by looking at the catch rates of individual 1 mm size groups in each month. This showed that the recruitment reached a peak in March-April depending on which year we were talking about, and then declined to a minimum in December. The experiment described in this paper was in fact timed on the previous year's data, to be at a time when the recruitment was low, and the catch rate was going up. In fact, the catch rate in the previous year went up nearly as high over summer as it was in the peak recruitment period, after having gone down to quite a low level mid-winter. We did get a relationship in this data indicating that increasing temperature gives an increase in availability of prawns to the capture unit, and we were able, by timing this experiment during spring, to separate catchability from recruitment. To do it earlier in the year would have been impossible because the two factors compound one another.

GROWTH OF EASTERN KING PRAWNS *(PENAEUS PLEBEJUS)*

BY I. SOMERS
Experimental Officer
CSIRO, Division of Fisheries and Oceanography
13 Beach Road, Deception Bay, Queensland

ABSTRACT

In describing the rate of growth of an animal with a life span of several years, incorporation of seasonal fluctuation in the rate of growth into mathematical models is unnecessary.

In Moreton Bay, Queensland, recruitment of postlarval king prawns occurs mainly during the winter and early spring. Migration to the deeper offshore areas occurs throughout the summer months, and these prawns form the basis of a winter fishery. Somewhat less than 5% of the catch (and hence the parent stock) in the offshore fishery consists of a previous year class, which thus makes the effective life span of the eastern king prawn of the order of 12 months.

From the results of tagging experiments and from observation of changes in composition of nursery stocks it appears that the growth of the animal is retarded during the colder months of the year. The shape of the growth curve is either a direct result of temperature dependent fluctuation in the rate of growth, or possibly a characteristic size-dependent metabolic rate, or even a combination of both.

A method was derived to formulate a mathematical model in terms of the second possible solution but the results suggested that it is more than likely a temperature dependence which invalidates the use of simple models for the east coast king prawn.

INTRODUCTION

The basic aim in this paper is to find an expression which will accurately determine the size (in terms of length or weight) at any given age. It must agree with observed data yet be in a mathematical form compatible with expressions for yield.

The von Bertalanffy growth equation

$$\frac{dW}{dt} = nW^m - kW \qquad (1.)$$

not only satisfies the above criteria but also gives physiological significance to the parameters involved.

In words: the instantaneous change in body weight, W, is given as the difference in rates of building up and breaking down of body tissues. n and k are constants of anabolism and catabolism respectively. The rate of anabolism is proportional to the m^{th} power of the weight but the rate of catabolism is proportional to weight itself.

Von Bertalanffy further shows that the range of m is $\frac{2}{3} \leqslant m \leqslant 1$ according to the metabolic type of the animal concerned.

(1) $m = \frac{2}{3}$. This growth equation applies to animals obeying the surface rule of metabolism. The growth in weight curve for this type has an inflection at approximately one-third its asymptotic weight. The growth in length curve for this type has no inflection. This is the type most widely used in fisheries work.

EXAMPLES—Lamellibranchs, fish, mammals.

2) $m = 1$. This growth type corresponds to animals whose respiration rate is proportional to weight instead of surface area. The growth in weight and growth in length curves are both exponential and no steady state is attained.

EXAMPLES—Insect larvae, Orthoptera, Helicidae.

(3) $\frac{2}{3} < m < 1$. This growth type corresponds to a metabolic type intermediate between surface and weight proportionality. The major difference with this type is in the length growth curve which attains with an inflection a steady state.

EXAMPLES—Planorbidae.

Values of m outside this range falsify the physiological interpretation and will therefore be discarded.

For values of m, $\frac{2}{3} \leqslant m < 1$, integration of Equation (1.) leads to the growth equation:

$$W_t = \left[\frac{n}{k} - \left(\frac{n}{k} - W_0^{(1-m)}\right) e^{-(1-m)kt}\right]^{1/(1-m)} \quad (2.)$$

where W_0 is the weight at $t = 0$, which in the case of proportionate growth ($W = qL^3$, where L is a measurement of length and q the proportionality constant. For *Penaeus plebejus* the most convenient measure of length is that of the carapace and for this paper L will refer to this.) can be transformed to

$$L_t^{3(1-m)} = \frac{nq^{(m-1)}}{k} - \left[\frac{nq^{(m-1)}}{k} - L_0^{3(1-m)}\right] e^{-(1-m)k_t} \quad (3.)$$

which when $m = \frac{2}{3}$, reduces to the equation

$$L_t = L\infty - (L\infty - L_0)\, e^{\frac{-k}{3}t} \quad (4.)$$

or alternatively

$$L_t = L\infty \left(1 - e^{\frac{-k}{3}(t-t_0)}\right) \quad (5.)$$

where t_0 is the theoretical time (relative to the origin) at which the length of the animal is zero.

Lucas (personal communication) obtained the value 0.583×10^{-3} for q ($R = 0.99$) when the weight is measured in grams (g) and the length in mm.

Equation (3.) is of the form:

$$X_t = A\,(1 - Be^{-kt})$$

which is suitable for fitting using the method of Fabens (1965) using data in the release-recapture form. Hence we can calculate n and k for values of m over the range $\frac{2}{3} \leq m < 1$. The value for t_0 or equivalently L_0 cannot be calculated using this method but can be set by knowing length at birth or alternatively length at recruitment.

METHODS

The information collected with respect to growth of *Penaeus plebejus* covers two discrete size ranges and is in two different forms.

Mark release experiments using Petersen disc-tags were only possible with prawns of carapace length greater than approximately 19 mm. The number of returns from prawns released at a size smaller than this was insignificant. The prawns were released over the period 21-26 September 1971 in Moreton Bay in approximately 7 m to give them some time to grow before entering the fishing area.

Because of the relatively short life span and relatively long and variable recruitment period to the nursery areas, time classing of individuals is very difficult and poorly defined. However, from observations over a twelve-month period it was possible to choose a 'sufficiently' narrow period of recruitment followed by a 'sufficiently' long period of little or no recruitment on which to base estimates of growth over the size range concerned, approximately 2.5 mm to 11 mm carapace length. The nursery areas sampled extend as far south as the Broadwater and as far north as Deception Bay. The information obtained in this manner is in the form, length at time ($L_i t_i$), where L_0 is length at recruitment. This can readily be transformed to recapture form (L_0, L_i, t_i) where L_0 is the length at release, L_i the length at recapture and t_i is the time difference between release and recapture.

PRELIMINARY ANALYSIS OF DATA

A method of transforming recapture data for the whelk *Dicathais* is described by Phillips and Campbell (1968). Although this method does not seem suitable for animals whose growth pattern is a series of moults, it can be readily modified to give estimates of growth rate at various release lengths. The method of using average slope to estimate the rate of growth is substituted by a linear regression over a recapture interval of approximately three moults. This method has the advantage of neglecting the origin in calculating the slope of the regression line. This is considered essential because, although animals may be released at the same length, they may be at different stages of the inter-moult period.

In order to reduce the variance caused by

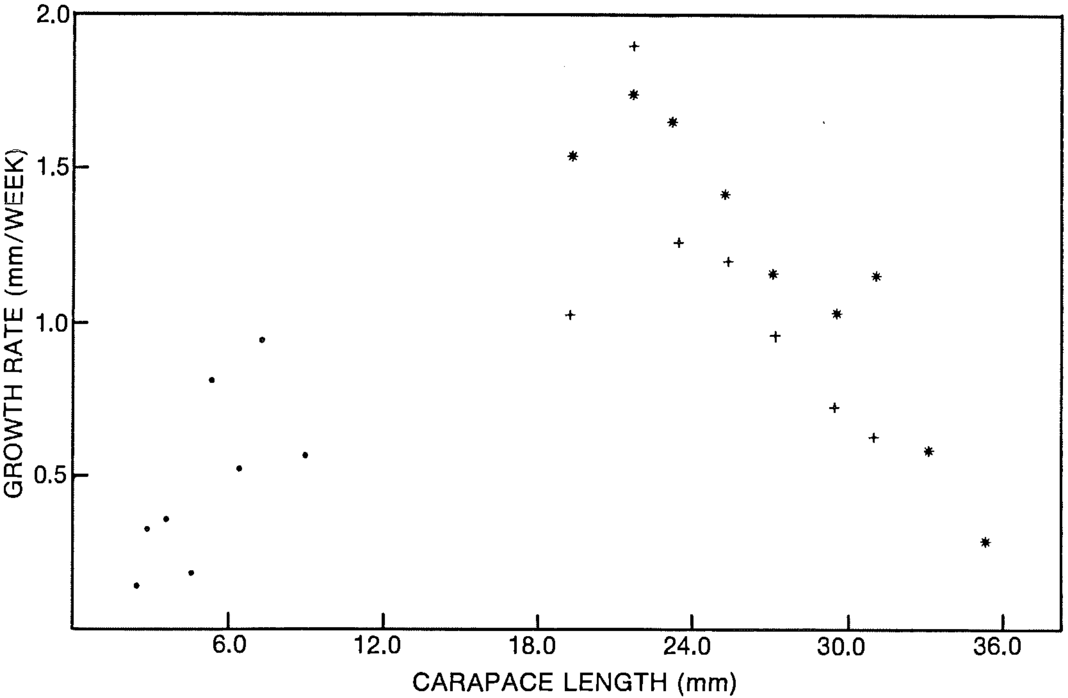


Figure 1.

this little or no increase in length during the intermoult, and therefore, further increase the accuracy, the mean time between release and recapture for prawns with similar growth increments over the same range should be used.

The growth rates for the juveniles were estimated from the increments in the mean length of the population over the sampling period. The results for both are given in Fig. 1.

From the spread of points in Fig. 1, it would seem that $\frac{dL}{dt}$, or the instantaneous growth in length, does have some maximum value and, therefore, that any attempt to fit the whole range of data to a von Bertalanffy growth curve with $m = 2/3$ would prove inaccurate. More likely is the possibility that m actually lies in the range $2/3 < m < 1$, and therefore, that *Penaeus plebejus* has an anabolic rate intermediate between surface and weight proportionality.

RESULTS

DATA FROM NURSERY STOCKS. The length frequency information obtained from the nursery areas within Moreton Bay is summarised in Table 1. The population mean for each sampling period is difficult to define because of the difficulty in defining the population involved. Without wishing to become too far detached from reality the mean, m, was defined as:

$$M = \left[\sum_{i = MAX - 1}^{MAX + 1} i.f_i \; / \sum_{i = MAX - 1}^{MAX + 1} f_i \right] - 0.5 \text{ mm}$$

where f_i is the number of prawns in the i^{th} size category taken over the size categories derived from the initial recruitment stock. The major problems in defining the population are those caused by continuous recruitment to the stock. In the data chosen, the relative disappearance of prawns in the smaller sizes (1-1.9 mm), (2-2.9 mm) over the initial period (May to early July) suggests that recruitment is at a minimum during this

Table 1. Length frequency table—nursery stocks

Length category	1	2	3	4	5	6	7	8	9	10		
Mm carapace length	0-0.9	1-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9	9-9.9	⩾10.0	Mean
May		227	2 882	541	238	85	58	29	18	13	39	2.58
June		43	1 539	1 059	338	150	64	46	26	19	52	2.88
June		3	445	1 308	545	235	89	47	21	21	41	3.53
July		6	157	564	619	293	150	78	41	35	65	4.32
July		101	464	299	473	365	176	100	45	29	47	4.71
August		107	1 196	215	139	213	217	140	84	48	86	6.36
August		116	1 552	1 706	349	148	152	183	125	78	99	7.44
September		315	1 057	989	1 028	716	193	93	68	79	135*	9.30
September		49	1 628	993	534	468	367	156	48	26	85*	10.40

Length category	11	12	13	
Mm carapace length	10-10.9	11-11.9	12-12.9	⩾ 13.0
September	51	27	9	48
September	35	23	19	9

time. Recruitment after this time interferes, it is assumed, only very little with this initial population.

The linear relationship between $\log_e(M)$ and time is given in Fig. 2. The regression equation results in the following relationship between carapace length and time:

$$L_t = 2.467\ e^{.0914}{}_t \qquad R = 0.997$$

where L_t is mm carapace length and t is weeks.

Time $t = 0$ is taken as at the first sampling period.

Although the effect of recruitment upon the above estimates is minimised by choice

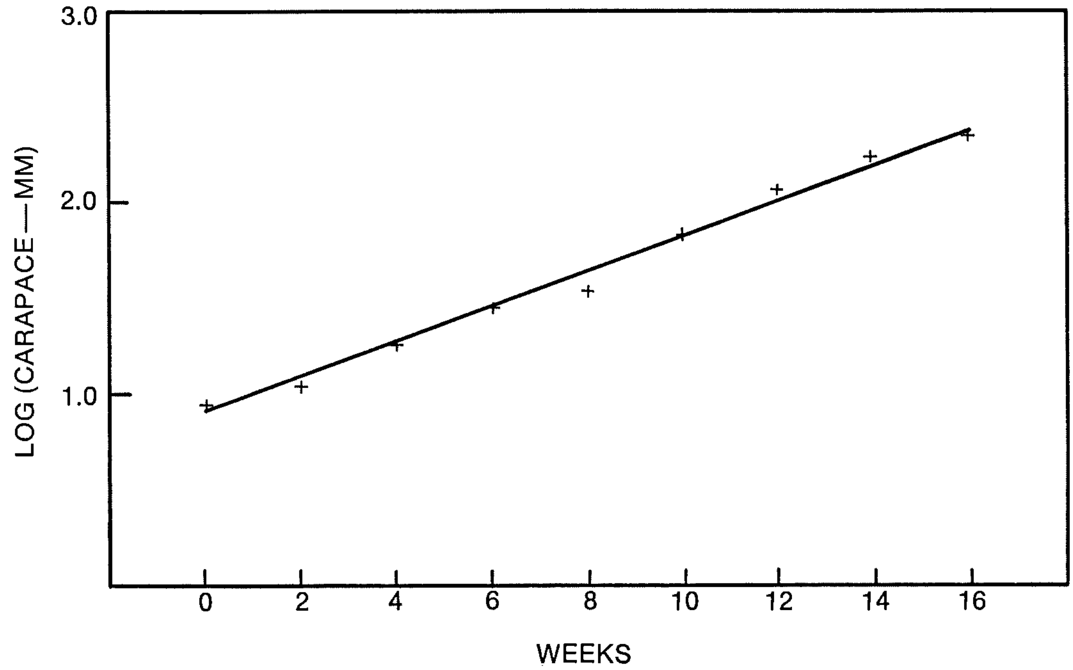


Figure 2.

of the data for analysis, the effect of emigration from nursery areas to deeper water is very difficult to assess. The population mean length would probably have the tendency to reach a maximum value asymptotically in the later weeks of sampling. The equation above may, therefore, represent a minimum value for the average growth rate over this size range.

RECAPTURE DATA. A computer program was developed by Fabens (1965) to produce least square estimates for the parameters A and K from Equation (4). By modifying this program it was possible to produce, from recapture data, estimates for k and n from Equation (1.) and subsequently the asymptotic length, L, for values of m over the range $\frac{2}{3} \leqslant m < 1$.

The program also calculates the following with respect to the actual length recaptured Y_A and its expected value Y_E, calculated from length released, time out and the parameters calculated:

(a) Mean absolute value $(Y_E - Y_A)$ (DIFF).

(b) Slope of regression of Y_E upon Y_A (SLOPE).

(c) Point at which this crosses the vertical axis (ZERO).

The results of this are summarised in Tables 2 and 3.

The juvenile data was readily transformed from its original form of length at time to recapture form. This combined set of data was analysed using the same program and the results of the fittings are summarised in Tables 4 and 5.

DISCUSSION

There may seem to be a reasonable exponential fit ($m = 1$) to the data for the nursery stock, however the narrow range of data involved makes extrapolation outside this range very dubious.

A similar situation occurs with the larger prawns as can be seen from the results of the analysis of recapture data. Although parameters n and k are very sensitive to small changes in m, the goodness of fit parameters, DIFF, SLOPE and ZERO, all remain fairly constant. This is due to the fact that changes in the shape of the growth curve, caused by changes in m, do not occur within the range of data analysed. The fact that $L\infty$ also remains relatively unchanged may be attributed to its relative closeness to the range of data.

When both ranges of data are analysed together the overall fitting was far less accurate. Unrealistic values for $L\infty$ were obtained over the whole range of m. The value was, however, rapidly aproaching a realistic value as m was increasing. The goodness of fit was also improving with increasing m and although the physiological interpretation breaks down, the best empirical fit would be found for values of $m>1$. Nelder

Table 2. Results of analysis on recapture data for male *P. plebejus*

M	*n*	*k* *Week*$^{-1}$	*WINF* *g*	*LINF* *mm*	*SLOPE*	*ZERO* *mm*	*DIFF* *mm*
0.667	7.743	0.231	37.8	40.2	0.785208	5.941	1.244829
0.683	6.961	0.248	37.5	40.1	0.785524	5.930	1.244881
0.700	6.276	0.267	37.1	39.9	0.785820	5.919	1.244939
0.717	5.676	0.289	36.8	39.8	0.786097	5.909	1.245070
0.733	5.152	0.313	36.4	39.7	0.786355	5.899	1.245213
0.750	4.695	0.341	36.1	39.6	0.786593	5.890	1.245362
0.767	4.297	0.372	35.8	39.4	0.786811	5.881	1.245515
0.783	3.954	0.409	35.5	39.3	0.787010	5.873	1.245673
0.800	3.660	0.451	35.2	39.2	0.787188	5.865	1.245836
0.817	3.412	0.501	34.9	39.1	0.787348	5.858	1.246004
0.833	3.207	0.562	34.6	39.0	0.787487	5.852	1.246176
0.850	3.045	0.636	34.3	38.9	0.787607	5.846	1.246353
0.867	2.928	0.728	34.0	38.8	0.787707	5.841	1.246534
0.883	2.860	0.847	33.7	38.7	0.787787	5.836	1.246720
0.900	2.852	1.006	33.5	38.6	0.787847	5.832	1.246910
0.917	2.925	1.228	33.2	38.5	0.787887	5.828	1.247107
0.933	3.125	1.562	33.0	38.4	0.787908	5.825	1.247308
0.950	3.562	2.118	32.7	38.3	0.787908	5.823	1.247512
0.967	4.568	3.231	32.5	38.2	0.787889	5.821	1.247732
0.983	7.811	6.570	32.2	38.1	0.787850	5.819	1.247994

Table 3. Results of analysis on recapture data for female *P. plebejus*

M	*n*	*k* *Week*$^{-1}$	*WINF* *g*	*LINF* *mm*	*SLOPE*	*ZERO* *mm*	*DIFF* *mm*
0.667	7.271	0.165	85.3	52.7	0.806047	5.910	1.386586
0.683	6.506	0.180	83.3	52.3	0.806412	5.894	1.386039
0.700	5.838	0.196	81.4	51.9	0.806743	5.879	1.385496
0.717	5.256	0.215	79.6	51.5	0.807042	5.866	1.384956
0.733	4.748	0.236	77.9	51.1	0.807306	5.853	1.384420
0.750	4.307	0.259	76.2	50.8	0.807537	5.841	1.383947
0.767	3.925	0.286	74.7	50.4	0.807735	5.831	1.383478
0.783	3.596	0.318	73.2	50.1	0.807898	5.821	1.383010
0.800	3.314	0.354	71.7	49.7	0.808026	5.813	1.382542
0.816	3.076	0.397	70.4	49.4	0.808121	5.805	1.382116
0.833	2.879	0.449	69.1	49.1	0.808182	5.799	1.381698
0.850	2.722	0.513	67.8	48.8	0.808208	5.794	1.381278
0.867	2.607	0.593	66.6	48.5	0.808199	5.789	1.380856
0.883	2.536	0.696	65.4	48.2	0.808156	5.786	1.380434
0.900	2.519	0.833	64.3	48.0	0.808079	5.784	1.380009
0.917	2.574	1.025	63.2	47.7	0.807967	5.783	1.379583
0.933	2.740	1.313	62.2	47.4	0.807821	5.783	1.379162
0.950	3.112	1.793	61.2	47.2	0.807640	5.783	1.378742
0.967	3.976	2.755	60.2	46.9	0.807425	5.785	1.378371
0.983	6.774	5.640	59.3	46.7	0.807176	5.788	1.378001

Table 4. Results of analysis on combined
(1) Data from nursery stock (2) Recapture data from male *P. plebejus*

M	*n*	*k* *Week*$^{-1}$	*LINF* *mm*	*SLOPE*	*ZERO* *mm*	*DIFF* *mm*
0.667	2.498	0.009	329.0	0.857	3.49	1.6189
0.683	2.198	0.012	291.3	0.867	3.21	1.6155
0.700	1.943	0.015	261.3	0.877	2.94	1.6119
0.717	1.725	0.019	236.7	0.887	2.68	1.6081
0.733	1.539	0.024	216.0	0.986	2.43	1.6042
0.750	1.381	0.030	198.3	0.905	2.20	1.6002
0.767	1.248	0.037	183.0	0.913	1.98	1.5960
0.783	1.135	0.045	169.5	0.921	1.77	1.5917
0.800	1.041	0.056	157.6	0.928	1.58	1.5873
0.817	0.964	0.068	147.0	0.935	1.40	1.5827
0.833	0.902	0.084	137.5	0.941	1.24	1.5779
0.850	0.854	0.104	129.0	0.947	1.09	1.5731
0.867	0.821	0.129	121.3	0.953	0.95	1.5680
0.883	0.804	0.163	114.3	0.958	0.83	1.5628
0.900	0.805	0.209	180.0	0.962	0.72	1.5575
0.917	0.831	0.274	102.3	0.966	0.63	1.5520
0.933	0.896	0.372	97.0	0.970	0.54	1.5461
0.950	1.033	0.538	92.3	0.973	0.47	1.5402
0.967	1.342	0.873	87.9	0.976	0.40	1.5341
0.983	2.328	1.883	84.0	0.978	0.35	1.5277

(1961) describes a method whereby this empirical fit might be achieved. In doing this however we are becoming detached from what really is happening and we might just as well find the least squares polynomial fit of the form

$$W = a_0 + a_1t + a_2t^2 + \ldots$$

The most likely cause of this discrepancy in *m* is probably the effect of temperature variation over the period in which the data was collected.

Indeed there is evidence to show that the $L\infty$ values obtained from the recapture experiments could be a direct result of a slowing down of growth during the winter months of 1972.

Table 5. Results of analysis on combined
(1) Data from nursery stock (2) Recapture data from female *P. plebejus*

M	*n*	*k* *Week*$^{-1}$	*LINF* *mm*	*SLOPE*	*ZERO* *mm*	*DIFF* *mm*
0.667	2.267	— 0.036	*	0.877	3.40	1.7137
0.683	1.977	— 0.035	*	0.887	3.11	1.7093
0.700	1.730	— 0.032	*	0.897	2.82	1.7050
0.717	1.522	— 0.030	*	0.906	2.55	1.7008
0.733	1.346	— 0.027	*	0.915	2.30	1.6966
0.750	1.197	— 0.023	*	0.924	2.06	1.6924
0.767	1.072	— 0.018	*	0.932	1.84	1.6882
0.783	0.968	— 0.011	*	0.939	1.63	1.6843
0.800	0.880	— 0.004	*	0.946	1.44	1.6808
0.817	0.809	0.006	A lot	0.952	1.27	1.6772
0.833	0.751	0.018	2038.4	0.958	1.11	1.6737
0.850	0.706	0.033	1082.4	0.963	0.97	1.6700
0.867	0.675	0.053	700.8	0.968	0.84	1.6663
0.883	0.656	0.079	510.5	0.972	0.73	1.6626
0.900	0.653	0.114	398.3	0.976	0.63	1.6590
0.917	0.671	0.165	325.0	0.979	0.54	1.6554
0.933	0.720	0.243	273.6	0.982	0.47	1.6517
0.950	0.825	0.374	235.8	0.985	0.40	1.6479
0.967	1.067	0.637	206.9	0.987	0.35	1.6439
0.983	1.843	1.433	184.1	0.989	0.31	1.6397

* Undefined

Length frequency information from catches in the deep water fishery off Mooloolaba in the winter months (Lucas, personal communication) show an average maximum value closely approximating the $L\infty$ values obtained from the recapture experiments (47-48 ♀, 39-40 ♂). However they also show a small but distinct peak (<5%, 55 mm ♀, 44 mm ♂ that could possibly entertain the idea of a previous year class.

Ursin (1963) describes a method of incorporating the effect of temperature in the von Bertalanffy growth equation and it may be in this direction that a more appropriate model lies.

CONCLUSIONS

When considering the growth of nursery stock over the winter months (May-October) a value of $m = 1$ (exponential growth) will give a satisfactory fit to observed results.

As far as the exploited stage is concerned, the normal von Bertalanffy expression with $m = ⅔$ will give a satisfactory fit. The value for t_0 should be chosen so that length at birth is substituted for length at recruitment to the exploited stage (at least 19 mm). The value obtained for $L\infty$ is not necessarily the asymptotic maximum length but merely the length attained asymptotically in the winter months caused by the drop in temperature.

Because of the relatively short life span of *Penaeus plebejus*, the seasonal effect upon growth cannot be simply eliminated by considering year classes as in longer living animals. Hence any expression for the overall growth of *Penaeus plebejus* will need to incorporate the variable, temperature.

In any fit to such data the range of co-ordinates is more important than the actual number of data points.

LITERATURE CITED

ALLEN, K. RADWAY (1966). 'A method of fitting growth curves of the von Bertalanffy type of observed data.' *J. Fish. Res. Bd Can.*, 23(2), pp. 163-179.

BERTALANFFY, L. VON (1960). 'Principles and theory of growth' in *Fundamental Aspects of Normal and Malignant Growth* (Wiktor W. Nowinski ed.), Elsevier, Amsterdam, pp. 137-259.

BEVERTON, R. J. H. AND HOLT, S. J. (1957).' 'Fundamentals of the theory of fishing—the primary factors.' *Fishery Invest.*, Lond., II, 19, pp. 31-35.

CAMPBELL, N. A. AND PHILLIPS, B. F. (1972). 'The von Bertalanffy growth curve and its application to capture-recapture data in fisheries biology.' *J. Cons. perm. int. Explor. Mer.*, 34(2), pp. 295-299.

FABENS, A. J. (1965). 'Properties and fittings of the von Bertalanffy growth curve.' *Growth*, 29, pp. 265-289.

KURATA, H. (1962). 'Studies on the age and growth of crustacea.' *Bull. Hokkaido reg. Fish. Res. Lab.*, 24, pp. 1-115.

LUCAS, C. (manuscript). Population dynamics of the king prawn, *Penaeus plebejus*, in south-east Queensland.

NELDER, J. A. (1961). 'The fitting of a generalisation of the logistic curve.' *Biometrics*, pp. 89-108.

PHILLIPS, BRUCE F. AND N. A. CAMPBELL (1968). 'A new method of fiting the von Bertalanffy growth curve using data on the whelk Dicathais.' *Growth*, 32, pp. 317-329.

RICHARDS, F. J. (1959). 'A flexible growth fluction for empirical use.' *J. exp. Bot.*, 10, pp. 290-300.

URSIN, ERIK (1963). 'On the incorporation of temperature in the von Bertalanffy growth equation.' *Meddr Danm. Fisk.—og Havunders*, 4(1), pp. 1-16.

DISCUSSION

Lucas. In the sampling of the juveniles, you estimated that you could separate out an age class for one particular instance of recruitment where you had a pulse and this was followed by no more pulses. What about the recruitment period in September, were you able to find a case there where you could separate out an age class?

Somers. Not exactly. In actual fact the recruitment period in September was quite extensive and therefore eliminated any attempt at identifying an isolated pulse. With this variable and yet continuous recruitment pattern over several months the growth model for the yearly stock becomes a much broader model rather than an isolated curve.

Lucas. This would largely be based on the fact that the large catches in Moreton Bay on the juvenile in the actual fishery are of 20-30 mm carapace length, the peak occurs in December. Now if that peak is the peak following the recruitment in say September of the 2-4 mm carapace length then this means quite a considerable increase in the growth rate in the summer months as against the winter months. Quite a big difference.

Somers. Exactly.

Maguire. Do you think that this type of approach has got relevance to prawns, is it going to work?

Somers. No. The approach I just annotated was more a matter of what we did and what we found. The actual von Bertalanffy model can be used if they do conform over that period of time, but it just becomes a matter of fitting an appropriate curve to the data. Because of the environmental effects the $L\infty$ value is not actually the asymtotic length these things grow to, nor do the k values obtained compare to that of other animals, and it is more or less only an easy way, a quick and simple way, of incorporating your data into yield equations.

Maguire. If I remember correctly from Nick Ruello's work on school prawns, he did try to fit the von Bertalanffy model into his data and it worked in the sense that the $L\infty$ value turned out to be the large prawns you get in Stockton Bight away from the river.

Somers. This is more or less what we found too. The $L\infty$ values we obtained from the tagging data corresponded very closely to the average maximum size of prawns in the ocean areas in winter months.

Maguire. But you don't really hope to get much more out of it than that?

Somers. Not in that respect, no.

PROTOTYPE MODEL OF THE KING PRAWN DEVELOPMENT IN THE BROADWATER NURSERY AREA

BY D. F. SMITH
Senior Research Scientist
CSIRO, Division of Fisheries and Oceanography
P.O. Box 21, Cronulla, N.S.W. 2230

ABSTRACT

A numerical model of a subsystem of the east coast king prawn fishery has been constructed using the simulation language—CSSL III.

The population model divides the juvenile prawns into various size classes, uses recruitment of planktonic postlarvae as the input, and has loss of 15 mm juveniles to the bay fishery as an output.

The model parameters can be estimated by comparing the model's calculated input/output response to observations taken in the field and minimising the difference between the two sets of observations.

A novel method of verifying the model performance is proposed which employs easily obtained size class frequency data in place of absolute measures of abundance.

To determine the feasibility of simulating the recruitment of king prawns to the Moreton Bay fishery a subsystem of this fishery was studied and modelled. This subsystem, the 'Broadwater nursery area', is bounded by the coast and South Stradbroke Island. Recruitment from the nursery to the bay takes place through Southport bar in the south and via Jumpinpin bar to the north. The input of planktonic postlarvae to the nursery area is by way of Southport bar; the planktonic postlarvae are distributed throughout the nursery area as far as the northern boundary which is defined as the line of zero tidal flow that lies to the south of Jumpinpin bar.

THE SINGLE HABITAT SPATIALLY HOMOGENEOUS MODEL

The model of the king prawn population in the nursery area can best be described by first discussing a far simpler model which does not consider environmental influences or habitat type or distribution. This elementary model is based on the prawn life cycle and is simply the classic population model shown as a flow diagram in Fig. 1. The total prawn population is compartmented into a series of size classes and prawns may be lost from a compartment either through mortality or by maturing and entering the contiguous size class. The equations describing this population model, which are basically those previously published to describe *Tribolium populations* (Landahl, 1955; Taylor, 1967), are as follows:

$$\Delta N_j(s+\Delta t, t+\Delta t) = \Delta N_j(s, t) \cdot p_i(s, t) \quad \text{for} \quad \Delta t < s < [a(j) - \Delta t] \tag{1.}$$

$$\Delta N_j(\Delta t, t+\Delta t) = \Delta N_{j-1}(a(j-1), t) \cdot p_j(0, t) \quad \text{for} \quad 0 \leqslant S \leqslant \Delta t \quad \text{in the } j \text{ th stage} \tag{2.}$$

$$N_j(t+\Delta t) = \sum_s \Delta N_j(s+\Delta t, t+\Delta t) \qquad 0 \leqslant s \leqslant a(j) \tag{3.}$$

and $N_j(t)$, number of prawns in the j th compartment at time, t.

$\Delta N_j(s, t)$, number of prawns in the j th compartment at time, t, which are aged between s and $s - \Delta t$.

$a(j)$, the age span of the j th compartment.

$p_j(s, t)$, probability for prawns in the j th compartment of surviving from age s at time, t, to age $s + \Delta t$.

These three basic equations are used to describe the dynamics of the prawn populations within the compartmental size classes ranging from 2.3 mm to 10-15 mm inclusive. The time-varying numbers of planktonic postlarvae and the recruitment to the bay fishery are not described by equations but are observed variables.[1] They constitute the system input and output and afford an independent check of the parameter estimates obtained for the model of the system.

---

[1] We wish to thank Mr Bruce Hamon for his suggestions on the approach to be taken in measuring the postlarval recruitment to the nursery.

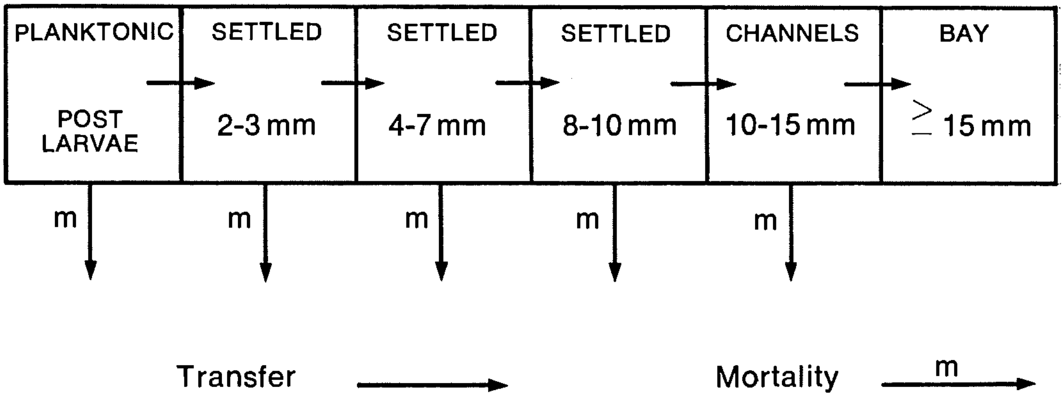


Figure 1. Flow diagram of the basic processes in the single habitat model of the juvenile king prawn population. The compartments divide the total population into size classes and location.

The parameters of Equations (1.)-(3.) are obtained from field studies, tagging experiments, and experiments conducted in the laboratory. Growth studies furnish the values for the $a(j)$s; absolute abundance measurements and habitat area yield estimates of the $N_j(t)$s; length frequency determinations taken over the year yield the measures of the $\Delta N_j(s, t)$s, and calculations of mortality rates furnish estimates of the $p_j(s, t)$s.

These initial estimates of parameter values are refined by inserting them in a model like the one seen in Fig. 1 which has been written in terms of Equations (1.)-(3.). The sums of squares of the differences between the $N_j(t)$s generated by the model and the $N_j(t)$s which were actually observed are minimised by altering the parameter values. This minimising of the sums of squares to obtain 'optimum' parameter values is accomplished with a multiple nonlinear regression program, SAAM 25, (Berman and Weiss, and Shahn, 1962) which permits a global fitting strategy.

Given these parameter estimates one could construct a model to predict recruitment from the subsystem to the bay fishery as a function of a single variable, postlarval recruitment to the nursery area. Moreover, by selecting numbers of prawns as the state variable we are afforded with an independent check of the validity of the model behaviour. Since it is possible to measure both postlarval recruitment to the nursery and recruitment of 15 mm carapace length prawns to the bay one can obtain the time-varying $N_j(t)$ curves for these two compartments. Using the postlarval recruitment curve as the input, the model performance can be evaluated by comparing the predicted recruitment to the bay with the recruitment which has actually been observed.

THE FIVE HABITAT MODEL

One of the reasons for selecting Broadwater as the subsystem of interest is that it contains a variety of habitat types which, taken collectively, are representative of the whole of the Moreton Bay nursery complex. This variety of habitat classifications, sea grass beds, mangroves, mud bottom and sand bottom, requires extension of the model and the program employed to implement the model in simulation studies. In effect, it is necessary to construct a model like that seen in Fig. 1 for each and every habitat type to be represented in the system simulation. Although one could write a set of equations for each habitat type this would be most inefficient as the sets of equations would differ only in the numerical values of the parameter values. This duplication of effort and computing time was avoided by writing the program in a simulation language (CSSL III) which is implemented on the CDC 6600. In CSSL III, the user is permitted to define 'MACROS' which is tantamount to being able to define a function which simulates an entire single habitat model. Thus the function (containing the equations of the model) is defined only once, but can then be called on repeatedly during a simulation run. One can repeatedly invoke this MACRO to incorporate into the model as many habitat types or spatial locations as are deemed necessary.

THE TIME-VARYING PARAMETER MODEL

A model which presumes that the recruitment to one size class is solely a function of the

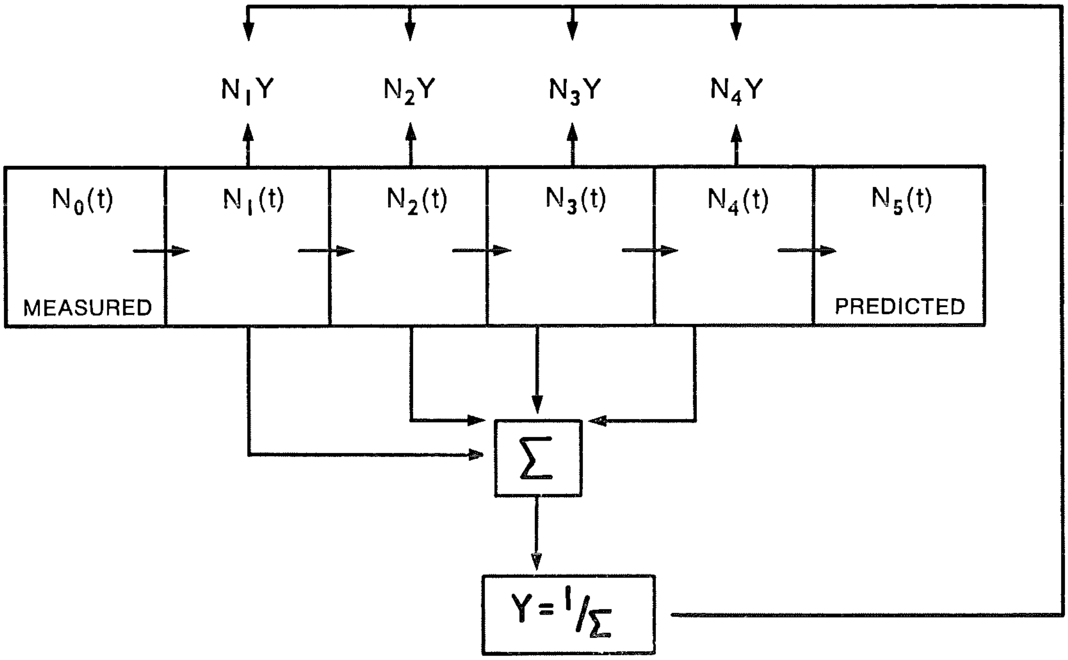


Figure 2. The diagram of Fig. 1 has been redrawn to show how a numerical model can generate size frequency data at various times during the simulation run. The model parameters can be repeatedly adjusted by minimising the difference between the calculated size frequencies and those which have been observed.

number of prawns in the preceding size class cannot be expected to predict accurately the behaviour of the system being studied. Our immediate task is to refine the model performance by replacing the numerical constants appearing in the system equations with time-varying parameters. Thus growth rates, which are functions of *T*, will be converted to $a_j(t)$s which show seasonal variation. Likewise, mortality rates (i.e. $p_j(s, t)$s) will be stated in functional form which considers an average variation with temperature as well as a maximum temperature exposure which increases the probability of death.

THE HYBRID PRAWN NUMBER-SIZE FREQUENCY MODEL

If a predictive model of recruitment to the bay fishery is to find practical employment it must generate an output related to absolute abundance (i.e. numbers of prawns). While postlarval recruitment to the nurseries can be obtained in terms of absolute abundance it would be highly desirable to avoid having to monitor any of the other $N_j(t)$s. We are planning to investigate the feasibility of a model which would permit continuous corrections by employing data easily obtained from the system, size-frequency measurements.[2] Although this model (Fig. 2) has time-varying numbers of postlarvae as the input and recruitment to the bay as the output it can correct the parameter estimates using size-frequency data. If successful, this approach promises to afford us a maximum of precision in predictive capabilities with a minimum of effort expended in monitoring the system.

LITERATURE CITED

BERMAN, M., WEISS, M. F. AND SHAHN, E. (1962). 'Some formal approaches to the analysis of kinetic data in terms of linear compartmental systems.' *Biophys. J.*, 2, pp. 289-316.

LANDAHL, H. D. (1955). 'A mathematical model for the temporal pattern of a population structure, with particular reference to the flour beetle.' *Bull. Math. Biophys.*, 17, pp. 63-77.

TAYLOR, N. W. (1967). 'A mathematical model for *Tribolium confusem* populations.' *Ecology*, 48, pp. 290-294.

---

[2] This possibility of a hybrid number-size frequency model was pointed out by Ian Somers.

FACTORS AFFECTING THE CATCHABILITY OF A PENAEID SHRIMP *PENAEUS ESCULENTUS*

BY T. WHITE[1]
Biologist, Environmental Resources of Australia
96 Marine Terrace, Fremantle, W.A.

ABSTRACT

Exmouth Gulf, on the central western coast of Western Australia, has an area of approximately 2 200 km². It supports a substantial prawn fishery based principally on tiger, western king and endeavour prawns.

Upwards of 20 trawlers operate in the area during the season, which extends from late February until November. Trawling is mainly carried out at night, because prawns, particularly tigers, remain buried in the seabed during hours of daylight and emerge only at night.

Catches decline to a minimum towards the end of July, then remain constant or even increase slightly towards the end of the season. This trend is apparently related to the annual water temperature cycle. There appears to be also a monthly cycle in the catches related to the moon phases.

The fishing gear is designed to capture the prawns as they swim about on the seabed. They are made to jump up into the path of the net by 'tickler' or drop chains.

Net and gear are designed so that there is a minimum of disturbance to the seabed itself.

Occasionally big catches of tiger prawns are made during the day in Exmouth Gulf, possibly because of the presence of large numbers of juvenile prawns.

Much work is currently being undertaken, especially in the United States, on the development of electronic fishing gear that will permit daylight fishing for prawns buried in the seabed.

INTRODUCTION

Exmouth Gulf is situated on the central Western coast of Western Australia, between latitudes 21° 50′ and 22° 30′ South, and longitudes 114° 05′ and 114° 40′ East. It is approximately 64 km long, and 48 km wide at the mouth. The Gulf is a shallow marine embayment of approximately 2 200 km² in total area, surrounded by tidal mud flats, and with a depth range from about 6 m in the southern end to 22 m at the mouth.

The Gulf supports a substantial prawn fishery, based principally on the tiger prawn, *P. esculentus*, the western king prawn, *P. latisulcatus* and the endeavour prawn, *Metapenaeus endeavouri.*

Approximately 20 trawlers operate in the area over a fishing season which extends from late February until November.

The following papers are a part of the work carried out in that fishery during 1969 to 1972, for a Doctor of Philosophy degree. The title of the doctoral thesis is 'Population Dynamics of the Tiger Prawn, *Penaeus esculentus* Haswell 1879, (Crustacea: Penaeidae) in the Exmouth Gulf Prawn Fishery, and implications for the management of the fishery', and will be submitted for examination in late 1973.

THE CATCHABILITY COEFFICIENT

Introduction

The total mortality experienced by an exploited fish stock is composed of two parts, that resulting from the fishing activities, and that resulting from all other causes, i.e. natural mortality. Using the notation of Cushing (1968) and Beverton and Holt (1957) this concept may be expressed as:

$$Z = F + M$$

where Z is the instantaneous total mortality coefficient
F is the instantaneous fishing mortality coefficient
M is the instantaneous natural mortality coefficient.

Estimation of these three parameters usually involves the mathematical manipulation of the statistic *catch per unit of effort*, Y/g, where Y is the catch in numbers or weight, and g is a measure of effort, expressed in hours spent fishing, days from port etc. (e.g. Ricker 1940, 1958; Beverton and Holt 1957; Paloheimo 1958, 1961; Lander 1962).

Two relationships are assumed however in the above calculations:

(a) That F is directly proportional to the

---

[1] In 1975 was at: P.A. Management Consultants Pty Ltd, 44 Ventnor Avenue, West Perth, W.A.

fishing intensity (f) which is defined as the fishing effort per unit area (g/A). The relationship may be expressed:

$$F = q \times f$$

where q is the coefficient of proportionality, or the 'catchability coefficient'.

(b) That the statistic *catch per unit of effort* (Y/g) is directly proportional to the stock density (D) on the area fished. The relationship may be expressed:

$$Y/g = q' \times D$$

where q' is the coefficient of proportionality.

Gulland (1955) has shown that q is equal to q' and so the dependence of catch per unit of effort on true density uses the same coefficient as the dependence of Fishing Mortality on fishing intensity, the catchability coefficient. (See also Garrod 1964.)

The catchability coefficient q, is formally defined by Ricker (1958) as 'the fraction of the whole stock under consideration which is caught by a defined unit of the fishing effort actually used'. When referring to separate, defined parts of the total area occupied by the whole stock, the term 'vulnerability' should be used (Ricker *op. cit.*). Due to either vertical or horizontal distribution changes, the stock within such defined parts may have varying degrees of 'accessibility' (Cushing 1968). It is obvious that there may be considerable overlap between the terms 'accessibility' and 'vulnerability' and Marr (1951) uses the more general term 'availability' to include the meanings of both.

Where attempts have been made to measure the mortality coefficients for exploited prawn populations (e.g. Costello and Allen 1966; Gotshall 1972; Kutkuhn 1966; Iversen 1962; Berry 1971), it has usually been assumed that the catchability coefficient remains constant during the fishing period over which the estimates were calculated, although some of these workers, e.g. Costello and Allen, do indicate awareness of potential seasonal fluctuations in the parameter.

From observations of the fishery at Exmouth Gulf it is apparent that changes in catchability do occur both in the short term and the long term.

Fishermen are well aware of a diurnal rhythm in the catchability of prawns which restricts their trawling activities to the hours of darkness. Many workers (Hughes 1968, 1969c; Williams 1955, 1958; Eldred 1958; Dall 1958; Racek 1959; Iversen and Idyll 1960; Fuss 1964; Fuss and Ogren 1966) have demonstrated from both laboratory and field observations that penaeids remain buried in the substrate during the hours of daylight and emerge only during the night when they would become vulnerable to the fishing gear. *P. esculentus* was observed in this study to follow this activity cycle while held in aquaria with about 10 cm of beach sand on the bottom, and under a natural day-night light cycle. Hughes (1968) has demonstrated the persistence of the rhythm in *P. duorarum* under conditions of total darkness for up to one week. He was able to change the phase of this rhythm in the laboratory, by altering the light cycle. Hughes (*op. cit.*, p. 56) concluded that 'a circadian rhythm in phase with the light-dark cycle is responsible for the pattern of occurrence above sand'. Similar findings to these were also reported by Wickham (1968). It is of interest that Fuss and Ogren (1966), while working with the same species as Hughes were not able to produce a persistence in the rhythm under conditions of total darkness, only while exposed to constant light.

A lunar rhythm in catchability has also been demonstrated in the laboratory by several workers (Aaron and Wisby 1964; Fuss 1964; Fuss and Ogren 1966; Racek 1959; Wheeler 1937), although only one instance is known where such a rhythm has been demonstrated in the commercial catches (Racek 1959). Sutcliffe (1956) has demonstrated a correlation between the catches of the crayfish *Panulirus argus* and the moon phases. The correlation was shown to be due to the influence of light, not tide, on the activity. In penaeids, activity in aquariums, measured as the percentage of animals above the substrate, is at a maximum during the period of the new moon, and at a minimum during the full moon phases. Racek was able to document this change in catchability in the commercial catches of both *Metapenaeus macleayii* and *Penaeus plebejus* in Eastern Australia, the catchability being at a maximum during the period of the new moon.

Penaeids are observed to bury immediately upon exposure to light during the dark phase of a normal day-night cycle (Hughes 1968). Many workers (e.g. Wheeler 1937) consider that the lunar rhythm in catchability is simply an extension of this behaviour. Fuss and Ogren (1966, p. 187) also consider that 'it would not seem unreasonable to assume that the nocturnal pink shrimp (*P. duorarum*) are affected by moonlight, if not moon phase *per se*'. In opposition to this idea Racek (*op. cit.*, p. 30) considers that 'it seems unlikely that the cause of periodicity in behaviour of the predominantly demersal penaeid prawn species is the direct inhibitary effect of light'. His evidence (p. 30) for this is that 'penaeid prawns were found to be subject to periodical fluctuations within lunar months on deeper grounds of the inner littoral area, where a direct effect of moonlight can be expected to be negligible. As there is also a pronounced lunar periodicity in adult moulting, breeding, as well as offshore spawning runs, the controlling factors are evidently more complex.' He considers (p. 30)

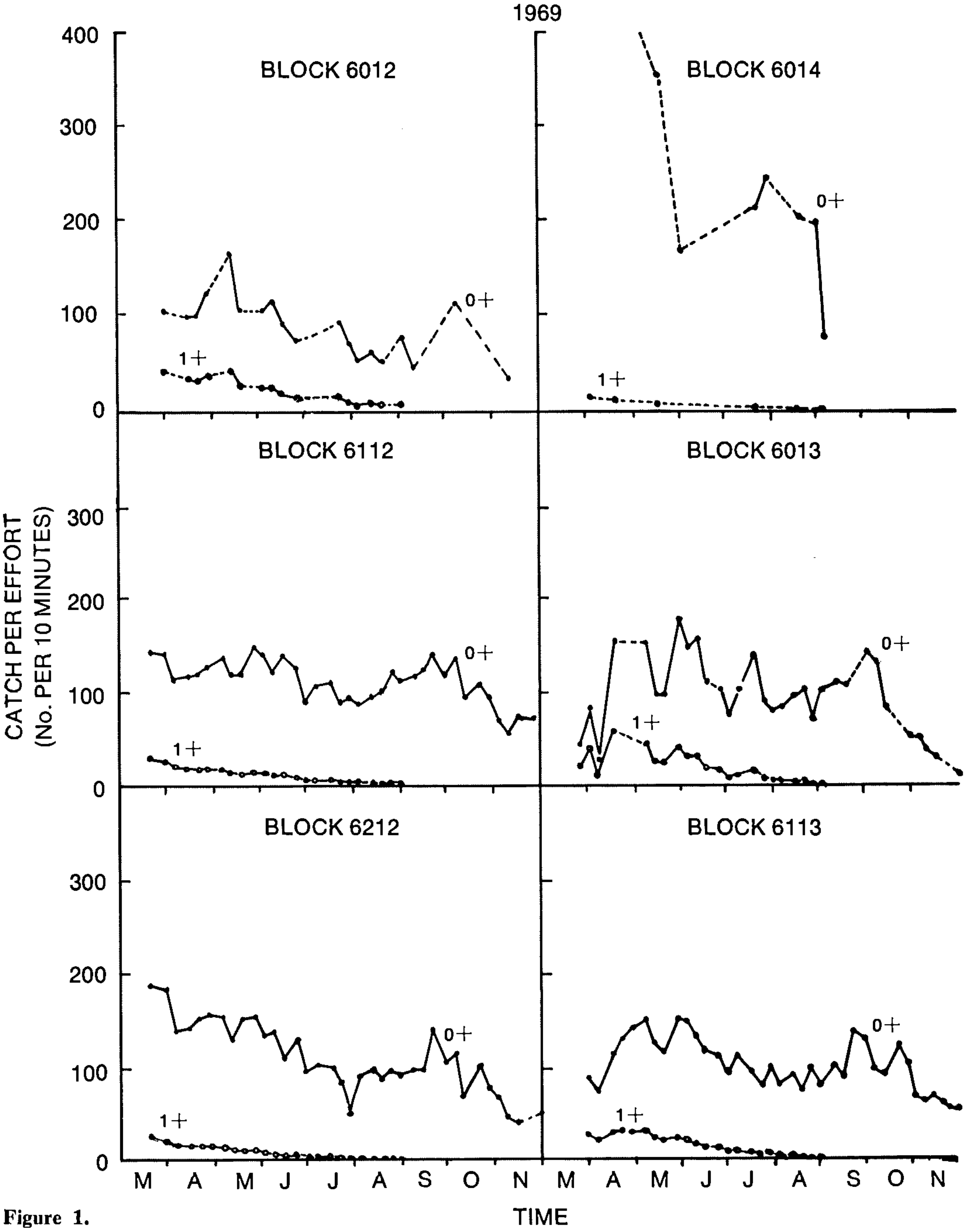


Figure 1.

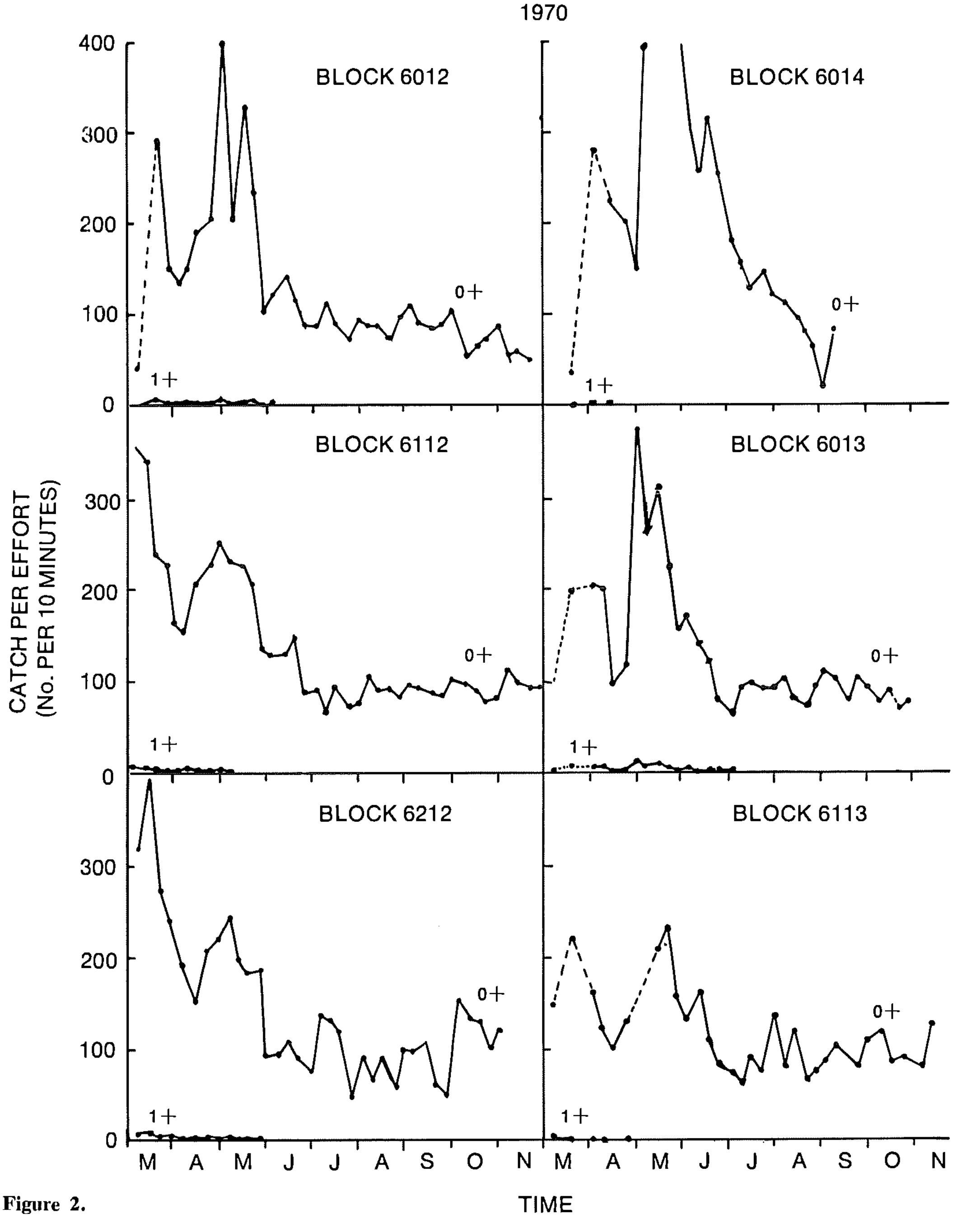


Figure 2.

The change in the catch per unit effort (in numbers of prawns caught per 10 minutes trawling time) for various Blocks in the Gulf during each of the three seasons 1969, 1970 and 1971 respectively. Values are given for both the O+ and 1+ age classes in the populations.

The points on the Figures represent mean weekly values. The dotted lines join points, between weeks in which no fishing was carried out in that particular Block.

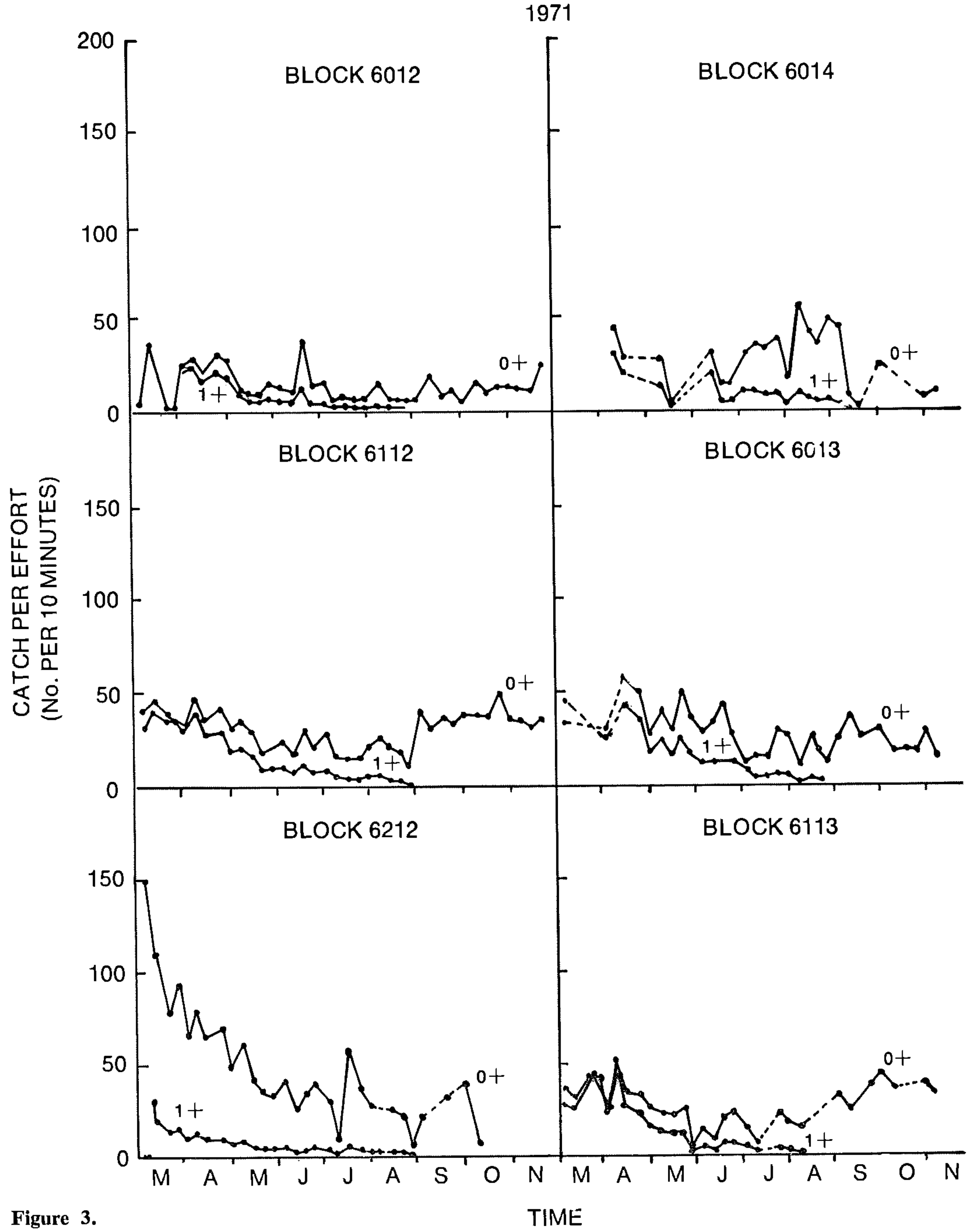


Figure 3.

Note the general trend in the catch per unit effort values in each of the three seasons. There was usually an initial decrease, followed by a small rise after about July-August. Note the similarity between the graphs for Blocks 6112 and 6212 of 1969 and 1970 on this Figure, and Figures 10, 11 and 12. They are in fact both drawn from the same data, the latter graphs using daily catch per unit effort values while the former were constructed using weekly averages of these.

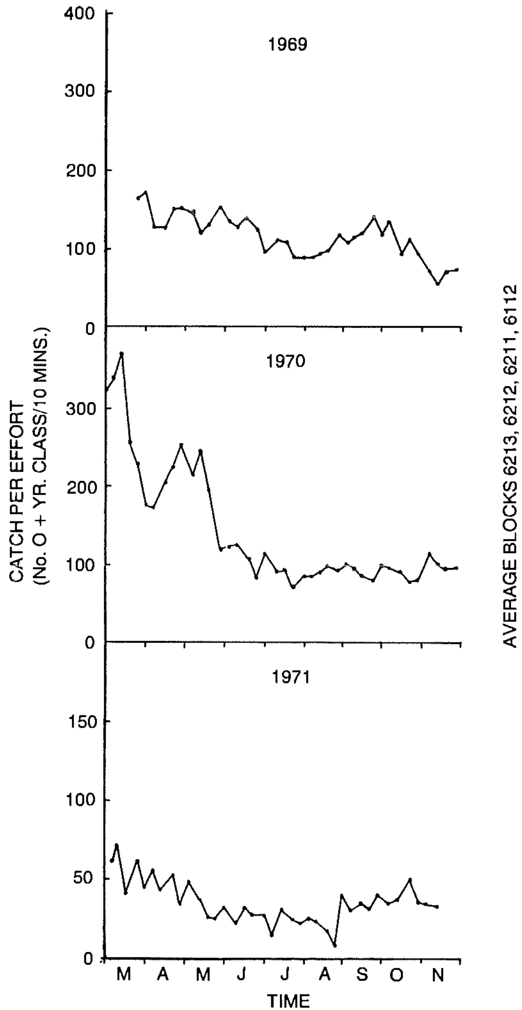


Figure 4.

rather that 'light may have a direct influence on the movement of prey, thus indirectly controlling the rhythm in the activity of prawns'. Clarke and Wertheim (1956) however have been able to obtain light intensity readings in the open ocean, during the full moon phases, at depths down to, and below those at which commercial penaeids are fished. These results would tend to counter Racek's arguments above.

In Exmouth Gulf, the catch per unit of effort is observed to decline to a minimum at about the end of July, and then remain fairly constant for the remainder of the season, or even to increase somewhat. (See Figs. 1, 2, 3 and 4.) Fuss and Ogren (1966) have demonstrated a seasonal change in activity (defined above) in the laboratory, which they relate to the environmental temperature cycle. It is possible that the seasonal cycle in the catch per unit of effort observed in the Exmouth Gulf fishery is similarly influenced by the seasonal change in water temperatures. Such a cycle in catchability has been demonstrated for a wide range of marine invertebrates, including the lobster (*Homarus americanus*) (McLeese & Wilder 1958; Dow 1961), and the sea scallop (*Placopecten magellanicus*) (Dow, 1962, 1964).

During the period of this investigation, studies were carried out on the moulting rhythm of *P. esculentus* in Exmouth Gulf. Although it is not intended here to discuss details of the method used, it was demonstrated that a pronounced cycle was evident in the moulting activity of the stock of *P. esculentus* in the Gulf. The percentage of recently moulted prawns (with one or two days) in the commercial catches fluctuated monthly, as illustrated in Figs. 5 and 6.

From the above discussion, it is apparent that at least four different changes in the catchability coefficient may occur in penaeid fisheries over a fishing season viz.:

(a) Diurnal—a circadian rhythm directly related to the light-dark cycle.
(b) Lunar—a rhythm possibly related to the light intensity as a result of the moon phases.
(c) Seasonal, or annual—a cycle possibly related to the annual cycle in water temperatures.
(d) Moulting—a cycle directly related to the lunar phase, which may produce an associated change in catchability.

The aim of this section is to establish if such rhythms exist in the Exmouth Gulf tiger prawn fishery, and to determine possible effects they may have on subsequent mortality estimates.

Although it is conceivable that other factors, such as weather, cloud cover, wind produced currents, predator/prey abundance, sediment, etc., may all affect catchability also, the study was limited to the four phenomena above, as no measurements were available of the other 'environmental' factors.

Methods

It was anticipated that the first three of the above rhythms in the catchability coefficient could be demonstrated in the fishery, using the catch-effort data for *P. esculentus* from the Research Log Books as follows:

1. *Diurnal rhythm*

In Research Log Books provided by the W.A.

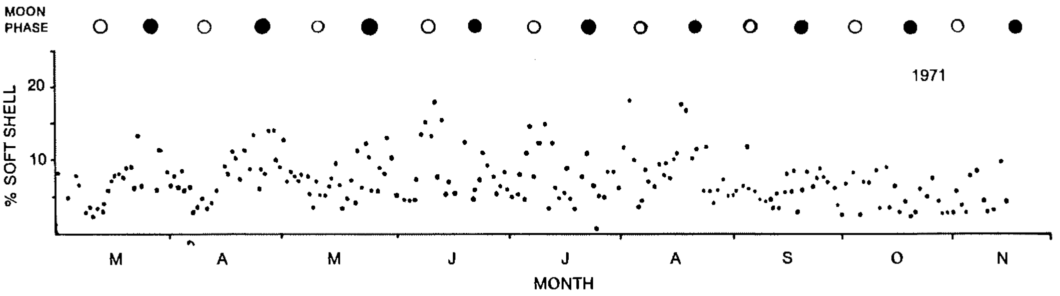
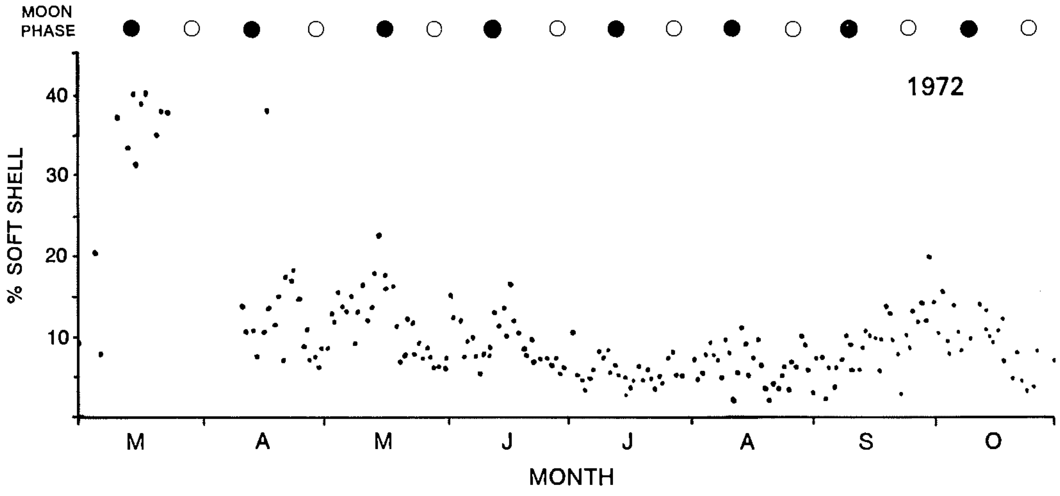


Figure 5.

The percentage of *P. esculentus* (sexes combined) in a 'soft shelled' or recently moulted condition during 1971 and 1972 respectively.

These values were obtained daily from the percentage of the commercial catch, landed at the processing factory, that was rejected during production by the processing staff. The criterion of softness was a subjective measurement of the part of the processors and hence liable to some week to week variation. The full moon is indicated by the open circles, the new moon by the closed circles.

Figure 6.



Fisheries Department the fishermen record the time at the commencement of each trawl to the nearest hour, and also the duration of each shot in minutes. The mid-point, calculated to the nearest hour, between the commencement of any shot, and its completion was denoted the shot 'time', i.e. if trawling commenced at 1800 hrs and the shot lasted for 120 minutes, then the shot 'time' was taken to be 1900 hrs.

Using the computer a three dimensional array was constructed of catch, versus duration of the shot, versus shot 'time'. Into the position of the array, appropriate to the calculated shot 'time', was placed the catch of *P. esculentus* (in lb) and duration (in minutes, corrected for the vessel relative fishing power), for all shots of all vessels for seven-day periods throughout the season. Details of the method used to calculate the *relative fishing power* factors are provided in the paper by Gullard (1956). From this array, the mean catch per effort (total catch/total effort) for each of the 24 possible shot 'times' was calculated for weekly intervals of the season.

2. *Lunar rhythm*

The method used was similar to that above, and employed the same data files. A similar three dimensional array was constructed, however, instead of shot 'time', Block was substituted for the third dimension. This array was

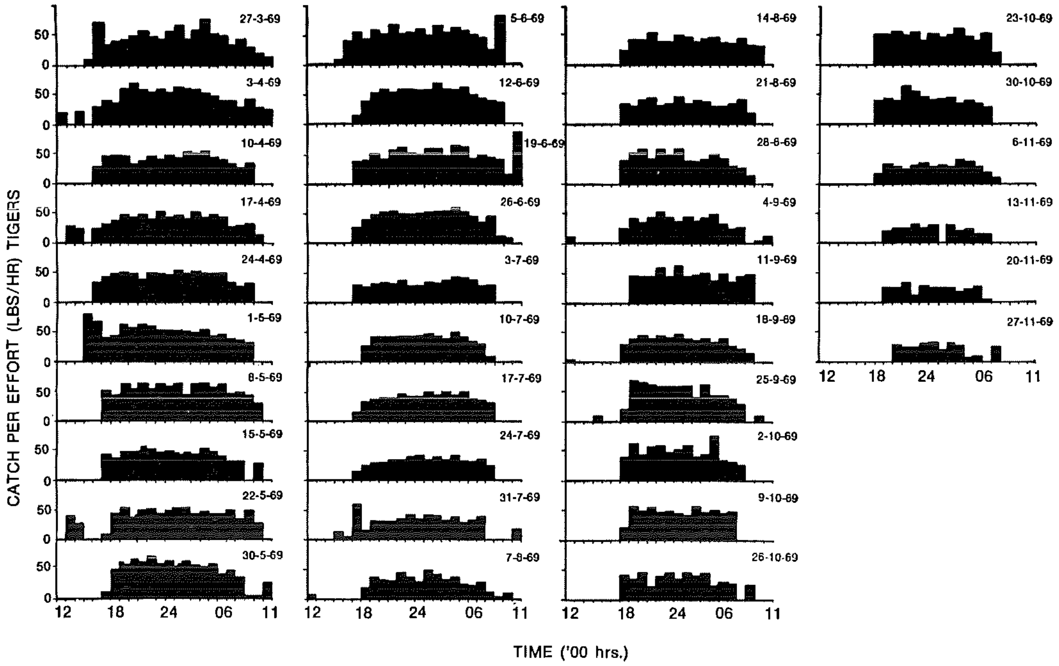


Figure 7.

Figures 7, 8 and 9.
Mean hourly catch rates (lb/hr) of *P. esculentus* for all Blocks combined, at weekly intervals during each of 1969, 1970 and 1971 respectively.

used to calculate a mean catch per effort figure for each Block of the Gulf, at daily (not weekly) intervals.

3. *Seasonal rhythm*

To demonstrate this cycle, it was first necessary to convert the catch per effort figures used in section 2 (Lunar Rhythm) from lb per hour into numbers of prawns of a single year class per unit effort.

From related work on the fishery, not discussed here, both the ratio of age classes and the change in the average weight of *P. esculentus* over the season were known. With this information, it was possible to convert the catch per unit effort values appropriately.

4. *Moulting rhythm*

As discussed above, the method involved basically the measurement of the percentage of recently moulted individuals of *P. esculentus* in the commercial landings on a daily basis throughout the season.

Results

1. *Diurnal rhythm*

The mean weekly values of the catch per corrected effort, per shot 'time', during the 24-hour day for the three years 1969, 1970 and 1971, are plotted in Figs. 7, 8 and 9. Although the absolute catch per effort values differ between years, in all three sets of data it is apparent that fishing is generally restricted to the hours of darkness, between 1800 and 0700 hrs. There is no significant increase or decrease (by visual observation of the results) in the catch per effort values between these two times.

The absence of data during the daylight hours is evident in most of the results. This is due to two factors:

(a) the catch rate during the daylight hours usually falls below a level that is considered economical to fish; and
(b) to a lesser extent, to the 'traditional' fishing pattern of the fleet.

The last shot of the night is usually pulled up between 0600 and 0800 hrs to allow the vessels time to return to the factory to unload, make repairs to gear and equipment, and to allow the crews to sleep. For similar reasons, the first shot of the evening is usually around 1700 or 1800 hrs. This does not imply that the vessels will not continue to fish during the day if the last shot is promising. Usually however, it is not.

A noticeable exception to this is apparent

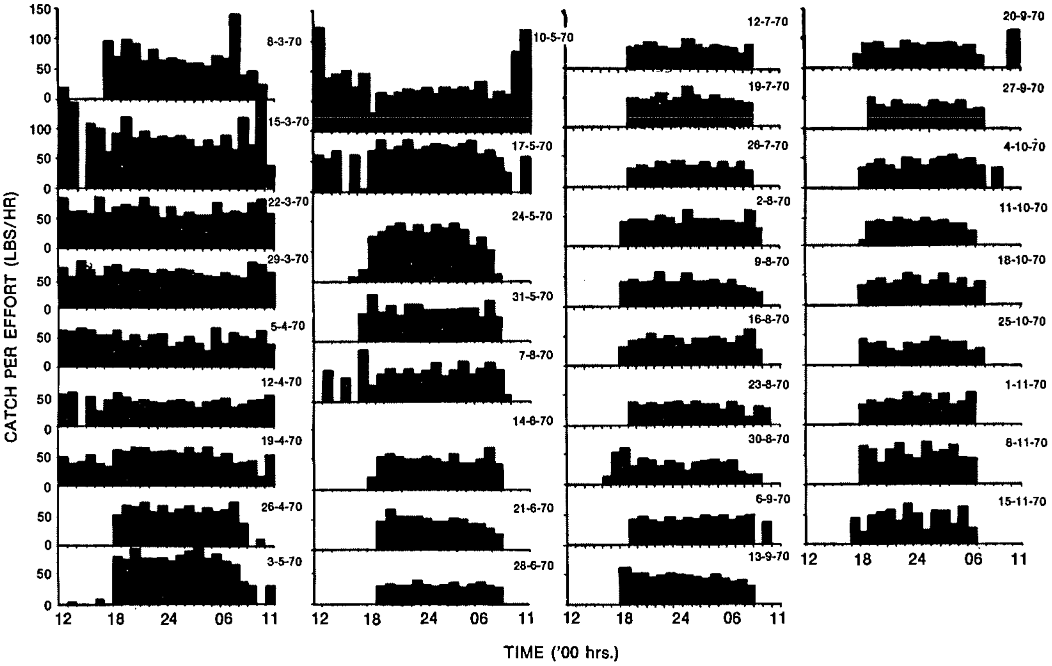


Figure 8.

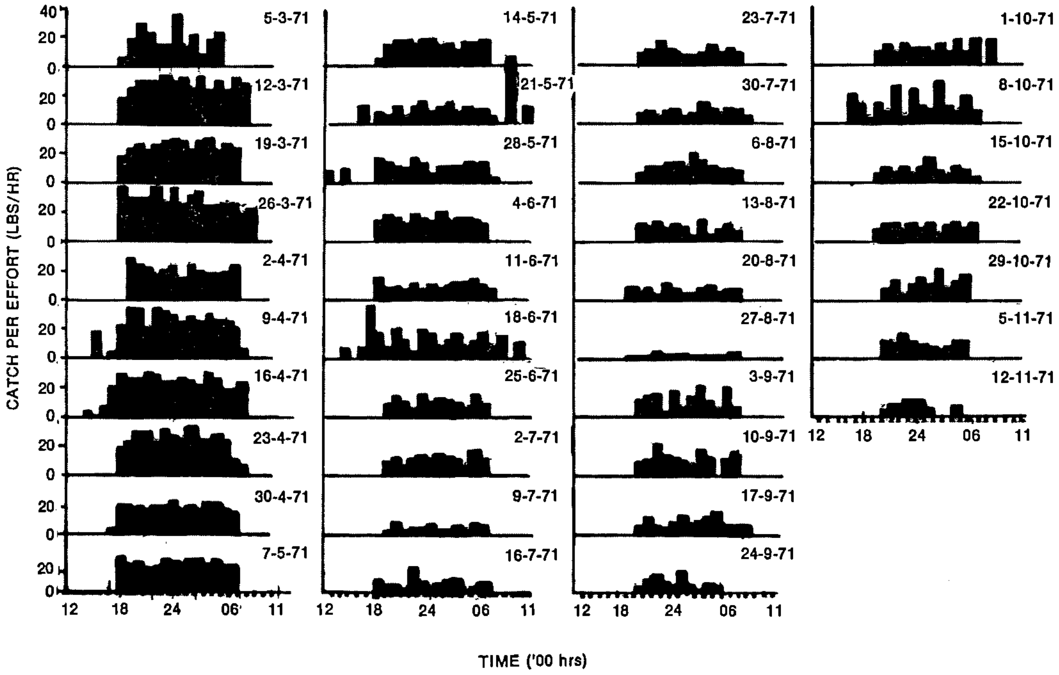


Figure 9.

during the first two or three months of the seasons, being most obvious in the data for 1970, and to a lesser extent, 1969. In the early months of these years, the catch per effort remained fairly high throughout the entire 24 hours of the day.

Occasionally also during the season, individual fishermen find an area on which the catches remain high during the daylight hours, for one or two days, then revert to the more typical situation. An example of this is seen in the 1970 data for the week ending on 10 May. These atypically high daylight catches were due to the efforts of one vessel in one area over a two-day period, and were not representative of the pattern in the Gulf as a whole.

2. *Lunar rhythm*

The daily mean catch per effort figures for all vessels fishing on Block 6112 are plotted in Figs. 10, 11, and 12, for the three seasons 1969, 1970 and 1971 respectively. This Block alone was selected to demonstrate the lunar rhythm as it was usually fished by two or more vessels on every night of the season and contained a high density of *P. esculentus* relative to the other Blocks. Both of these factors would tend to decrease the variance in the results. It was however possible to distinguish the cycle in all Blocks with more or less confidence, depending upon the conditions mentioned above. The cycle occurred simultaneously in all Blocks during the season. Some of the error in the daily catch per unit effort values plotted in Figs. 10, 11 and 12 may be due to the fact that occasionally only one vessel fished on a particular Block on a particular night, thus increasing the expected variance in the value plotted for that night.

The highest catch per effort values during any lunar month, presumably when the catchability was greatest, occurred just prior to the full moon phases, with the least occurring at the new moon phases. The cycle became less obvious in the Figures after about August, but was plainly evident in the early months of the seasons.

The catch per effort values plotted on Figs. 10, 11, and 12 include the data for both day and night fishing.

3. *Seasonal rhythm*

From an examination of Figs. 1, 2, 3, and 4, it is apparent that in each of the seasons, and generally speaking, in all Blocks, there was a decrease in the catch per effort from the beginning of the season until about the end of July or early August, when it either began to rise again or at least discontinue falling and remain steady.

4. *Moulting rhythm*

The data necessary to demonstrate this cycle are presented in Figs. 5 and 6.

Discussion

1. *Diurnal rhythm*

With the present-day designs of trawling gear, prawns must be above the substrate to be captured. Animals on the bottom are stimulated to jump up into the path of the net by the mechanical stimulation of the 'drop-chains', or 'ground-rope'. The net and gear are designed so that there is a minimum of disturbance to the sea-bed itself. This reduces the amount of 'trash' (sponges, rocks, crabs, algae, flatfish, etc.) trawled up. Consequently an absence of prawns in the nets indicates either an absence of prawns in the area, or that they are buried in the substrate. Because of the rapid appearance of prawns on the fishing grounds immediately following sunset, the second possibility is the most likely.

The nocturnal activity patterns of many commercial penaeid species have been observed and recorded by several workers (Williams 1958; Eldred 1958; Fuss 1964; Hughes 1968; Wathne 1963; Dall 1958; Hall 1962; Racek 1959, Fuss and Ogren 1966; and Fuss, Ogren and Kessler 1964), and the fishermen in Exmouth Gulf are well aware that the best catches are made during the night. A similar example is the North Sea trawl fishery for the macuran crustacean, *Nephrops norvegicus* where the best catches are made at night, due to the burrowing behaviour of the animals during the daylight hours (Simpson 1965). Actually the behaviour pattern is probably more complex than simply a circadian rhythm related to the day-night cycle, as the greatest

Figures 10, 11 and 12
Daily catch per unit effort values (in numbers of 0+ age class caught per 10 minutes trawling time) for Blocks 6212 and 6112 in each of the three seasons 1969, 1970 and 1971 (Blocks 6112 only in 1971).
The new and full moon phases are shown.
The heavy line drawn through the points illustrates the shape of the predicted mortality curve, using the formula:

$$N_t = N_o e^{-Zt}$$

The dotted line illustrates the effect upon the predicted mortality curve when compensation is made for temperature.
The open circles represent the full moon phases, and the closed circles the new moon phases.

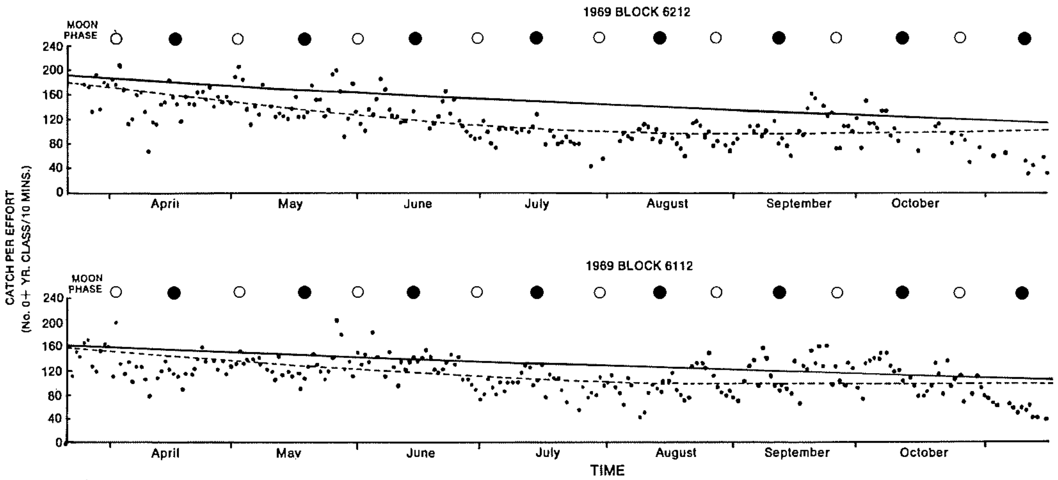


Figure 10.

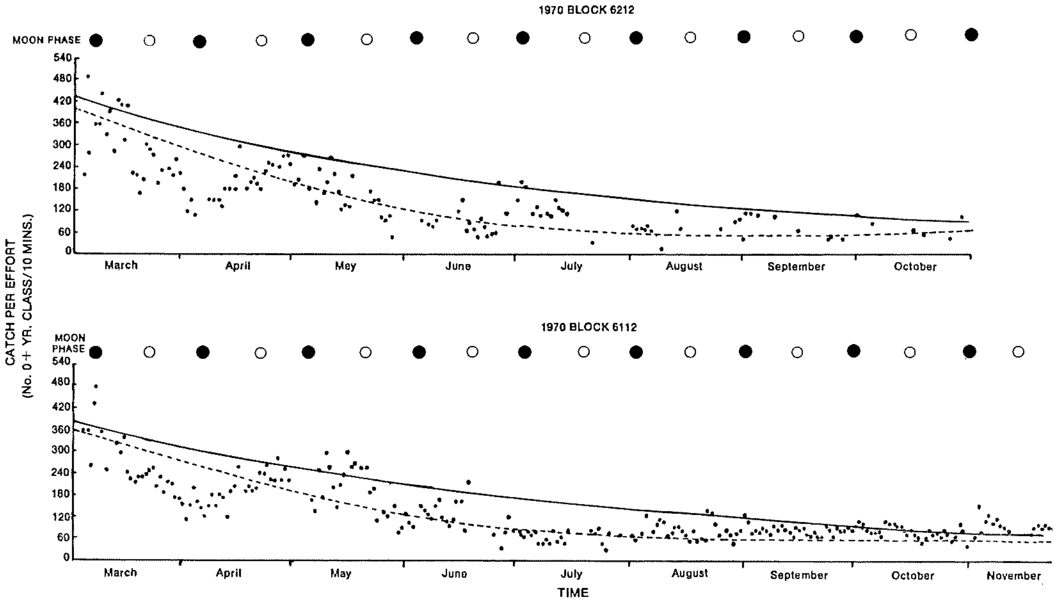


Figure 11.

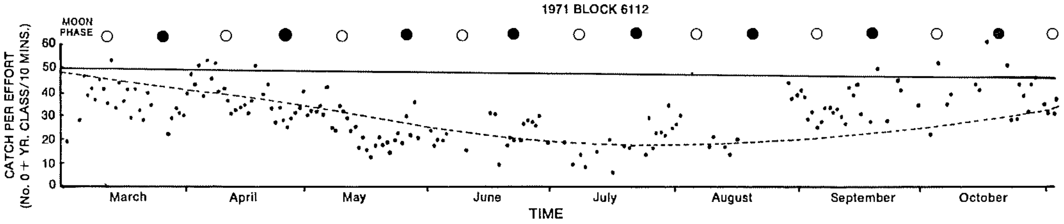


Figure 12.

catches are made just before daybreak, and at dusk in the latter species.

Hughes (1968) has shown a clear phase relationship between the time of activity of *P. duorarum* in the laboratory, and the day-night cycle. The most marked manifestation of this association was the close relationship that existed between the time of emergence from the substrate and the time of the light-dark transition of the day-night cycle. He found that the entire population emerged within only 20-30 minutes, at about the time of sunset. Hughes concluded that a circadian rhythm existed controlling this emergence, and was able to produce a shift in the phase of the rhythm, by altering the light-dark cycle by different amounts. Although no records were kept, similar observations were made with populations of *P .esculentus, P. latisulcatus,* and *Metapenaeus endeavouri* maintained in aquariums at Learmonth, and subject to the normal day-night cycle.

Shrimp remain active for variable periods above the substrate after emerging, Wathne (1963) found that *P. duorarum* remained active for 3½ to 10½ hours. He concluded that the period of activity was directly related to the light level on the bottom. During the full moon phase, prawns were active for only 1½ to 2 hours before re-burrowing, while during the dark phases they were active until dawn.

There is a considerable amount of literature on the effects of artificial light upon activity and burrowing behaviour in the laboratory. Eldred (1958), Fuss and Ogren (1966), and the author during this study, have all observed an immediate burrowing response by hard shelled prawns when exposed to artificial light, during the dark phase of the normal day-night cycle. This response is perhaps expected in view of the above results and discussion. Aaron and Wisby (1964) had contradictory results to these during an experiment designed specifically to test the 'photic behaviour' of *P. duorarum.* Fuss and Ogren have discussed these apparent discrepancies between the observations, and suggest that they may be due to size differences, stage of development and sexual maturity of the animals, or the intensity of light used. The effects of some of these variables are discussed by Pardi and Papi (1961). Nevertheless it appears probable that this photic response is initiated by a different mechanism than the circadian rhythm above.

Unusually high catches of several species of penaeids during the daylight have been reported by Dall (1958), Iversen and Van Meter (1964), Fuss (1964), and Hildebrand (1955). This is usually attributed to either decreased light intensity at the bottom on these days as a result of turbid water conditions in turn due to increased ground swell, tidal activity, or to cloudy overcast skies. Dall considers that it could be associated with the onset of sexual maturity. Investigations by Fuss and Ogren (1966) and Aaron and Wisby (1964) have shown that the burrowing response is correlated with the size of the prawn, smaller individuals having less response to light than larger ones.

High daylight catches of *P. esculentus,* equal to or even greater than the corresponding night-time catches are sometimes made in Exmouth Gulf, especially during the first month or two of the season. This is especially so at the area known as 'Tubridgie Point', which appears to be a major nursery area for *P. esculentus.* Other areas were high daylight catches are made are usually shallow (9-11 m), and contain high proportions of the new recruits (0+ year class). This situation was especially pronounced in the 1970 season, to a lesser extent in 1969 and almost non-existent in 1971. It is significant that these years reflect the trend in the degree, or success of recruitment into the fishery. The reason for these abnormal daylight catches may be due to prawn size, and/or the approach of sexual maturity as suggested above. These catches become less pronounced as the proportion of smaller prawns in the population decreases. It appears unlikely that they are due, as suggested by Iversen and Van Meter (1964) and Hildebrand (1955) to increased water turbidity, or overcast days, as the water in all of Exmouth Gulf is perpetually turbid.

This circadian rhythm in activity and hence catchability is of immense importance in the commercial penaeid fisheries, as it virtually limits fishing to only 12 of the 24 hours of the day, even though the vessels, crews etc. are available, and the weather may be favourable for a much greater proportion of the time. Much work is currently being undertaken, especially in the United States, on the development of 'electronic' fishing gear that will permit the daylight exploitation of these buried prawns (Anonymous 1965, 1969). Prawns are stimulated to emerge from the substrate by means of an electric 'pulse' through the groundrope. Daylight catches have been made by research vessels using such gear that equal night-time catches using conventional trawling gear, thus effectively doubling the total 24 hour

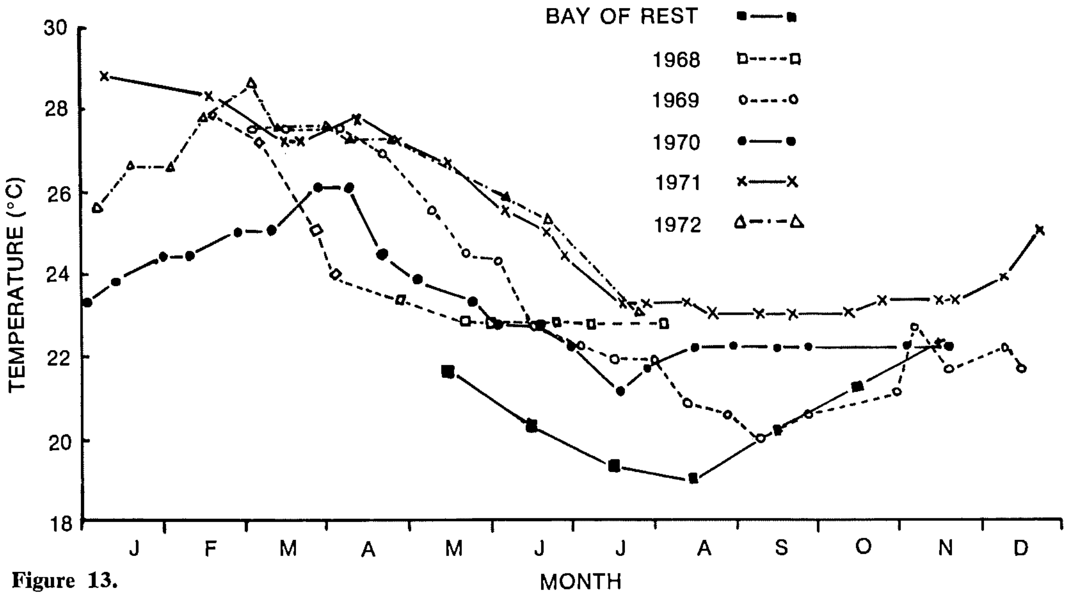


Figure 13.

Sea water temperatures off North West Cape. These were taken from the engineering log books of the State Shipping Service vessels. These boats record the intake water temperature of the vessel's cooling system at four-hourly intervals along the W.A. coastline. The water inlets are located approximately three metres below the water surface. While the sampling localities were always in the same vicinity, they were not always at identical places. Nevertheless temperatures are unlikely to be from distances greater than 32 km apart. The surface water temperatures recorded in 1962-64 in the Bay of Rest, located approximately 8 km south of Learmonth, by the staff of a pearl-culture operation are also plotted on this figure.

catch. (F.I.N.S. 1968; Fuss, Ogren and Kessler 1964; and Wathne 1963). Further refinement of this gear, and its commercial manufacture may have a significant effect upon prawn fisheries in the not too distant future.

2. *Lunar rhythm*

A pronounced lunar rhythm is present in the abundance (catch per unit effort) of *P. esculentus* in Exmouth Gulf. Apart from the suggestion that this may have been illustrated in their experimental population by Fuss and Ogren (1966), the only documented example of such a rhythm being demonstrated in a commercial penaeid fishery is a suggestion by Racek (1957), although he admits that his evidence is only brief. He found that commercial catches of both school and king prawns (*M. macleayii* and *P. plebejus*) were at a maximum 3-4 days before the new moon. Fuss and Ogren conclude that sufficient moonlight could penetrate to the sea-bed to influence activity, suggesting that there could be a decrease in catchability during the full moon phases.

The results obtained for *P. esculentus* in each of the three years are contradictory to these findings above, in that the minimum catches occurred at or near the new moon phases, and the peak catches 3-4 days prior to the full moon phases. The rhythm is apparently not affected by the water temperature, population density, age structure of the population, depth or tidal cycle, as it was present in the data for 1969, 1970 and 1971, and occurred synchronously on all Blocks. At this stage, it is impossible to determine whether the cycle is a result of lunar phase, or a secondary response due, as suggested by Racek to an associated fluctuation in the abundance of some prey species. Fluctuations in the commercial catches of some decapod crustaceans, e.g. *Panulirus argus* (Sutcliffe 1956) and *P. longipes cygnus* (pers. obs.) have been shown to be associated with the lunar cycles, with catches being at a minimum during the full moon phases. Nevertheless, the cycle is of considerable importance, not only because of its direct effect upon the commercial catches, but because of the complication it introduces into the calculations of mortality estimates.

3. *Seasonal rhythms*

Fuss and Ogren were able to demonstrate a seasonal cycle in activity in an experimental population of *P. duorarum* maintained in submerged cages on the sea-bed, adjacent to the commercial trawling grounds. They concluded that the duration of the activity was primarily controlled by photoperiods (as discussed previously), and the proportion of shrimp active at any time by the water temperatures. During the period of their experiments, water temperatures fluctuated from about 30°C. in the summer months to about 13°C. in the winter. Dall (1958, p. 112) has found a similar relationship for *M. mastersii*, stating that 'as the temperature rises in September, activity is resumed'. These results are not entirely unexpected, as various workers have shown relationships between temperature and such things as growth, metabolic rate, etc. in many species of penaeids. (Waterman 1960.) Fuss and Ogren were also able to demonstrate acclimation by the shrimp to the lower water temperatures. Following the initial decline in activity with decreasing water temperatures, the activity rose somewhat, even though the temperature remainder low or even decreased further.

Water temperatures for Exmouth Gulf for several years are plotted in Fig. 13. There is a close relationship between the cycle in water temperatures during the season, and the trend in the catch per effort in the fishery. Both the lowest temperatures and catches occur at about August, although water temperatures do not rise much between then and the end of the season, there may be some increase in the catch per effort (e.g. in 1969, 1970 and 1971—Figs. 1, 2 and 3) which was shown by other work to be independent of any new recruitment. This may have been due to the phenomenon of acclimation mentioned in the preceding paragraph, or perhaps it could have been behavioural, e.g. related to spawning.

Williams (1967) has been able to demonstrate a relationship between the summation of the coastal air temperatures (the trend in which, he considers to be reflected in the water temperatures), expressed as 'net heating degree days', and the total catches of three species of penaeids (*P. duorarum*, *P. aztecus* and *P. setiferus*), in the southern States of the U.S.A. Basically he associates good catches with warm years, and poor catches with cooler years. He suggests that this could be a direct result of changing catchabilities of the animals, related to the water temperature. He believes that this relationship may have some predictive value to the fishery, for management purposes. The same technique was applied to the Exmouth Gulf data, unfortunately without success, although this is not unexpected considering the small number of years for which reliable catch per effort data are available.

This cycle becomes important, when attempting to calculate mortality estimates for the fishery from the rate of decline in the catch per effort during the season. Unless the effects of temperature upon the catchability are removed, these estimates may be grossly over or underestimated, and more likely the former, as the trend in the temperature cycle during the fishing season is downwards.

4. *Moulting rhythm*

It is unlikely that the rhythm in the moulting activity of *P. esculentus* is directly responsible for the cycle in the catch per effort in the fishery which fluctuates with the lunar phases, as the percentage frequency of moulting prawns only ranges from about 4-10% between the full and new moon phases. However, as the two cycles are in phase with each other—the peak moulting frequency (during which time the catchability would be at a minimum) occurs during the same moon phase as does the lowest catch rates—the moulting cycle may to a small extent reinforce the other.

5. *General*

Hughes (1968) has also been able to demonstrate a feeding rhythm in *P. duorarum* which, in the natural situation, occurs synchronously with the diurnal activity rhythm. To demonstrate its presence, he produced a phase shift in the diurnal rhythm, causing the prawns to emerge to feed even in the presence of normally inhibiting light. He was able to show that deprivation of food did not lead to decreased activity but rather the contrary. Because this feeding rhythm is in phase with the diurnal rhythm it would be expected to have a minimal effect upon catchability, although Hughes concluded that because the first activity following emergence is feeding, the two rhythms may serve to reinforce each other in such a way that emergence of all individuals becomes more closely synchronised.

It is also theoretically possible that the fluctuation in the catch per unit effort during the season may have been caused by fluctuations in the amount of fishing effort expended, i.e. there may have been some sort of association between the two. For instance, increased catches may have resulted over a short time, with increasing effort, due say to increased activity of the prawns, caused by the increased disturbance by the fishing gear, or alternatively,

This Table illustrates the relationship between the weekly trend in the catch (in numbers) of the 0+ age group, and the total weekly corrected fishing effort for several Blocks of the Gulf in 1969, 1970 and 1971.
The analysis performed using a non-parametric RUN test. The catch per effort and effort data were examined on a weekly basis progressively throughout the season for each of the Blocks independently. Where the week-to-week trend in the catch per effort and effort were both tending in the same direction, either positive or negative or neutral, then the weekly change was scored as +ve. If they tended to different directions to one another, they were scored as — ve.
The number of runs of + ve and — ve weekly trends were scored and the significance (at the 95% confidence level) read from tables. Listed are the number of runs, number of both + ve, and — ve scores for several Blocks during the 1969, 1970 and 1971 seasons, together with the degrees of significance. The results would suggest that the change in the catch per effort fluctuates during the the season independently to the effort.
Table 1

		1969		
BLOCK	*RUNS*	*+ve*	*—ve*	*SIGNIFICANCE*
6212	16	25	9	N.S.
6112	14	24	11	N.S.
6013	12	14	16	N.S.
6113	16	19	15	N.S.
		1970		
6112	20	21	16	N.S.
6212	18	18	16	N.S.
6013	18	13	19	N.S.
6012	17	19	16	N.S.
6113	18	16	14	N.S.
		1971		
6112	13	23	14	N.S.
6212	11	20	8	N.S.
6012	19	13	23	N.S.
6013	12	19	11	N.S.

the catches may have decreased due simply to overfishing a small area with concentrated fishing effort over a short period.

To test the possibility of any association between the catch per unit effort, and the fishing effort, a non-parametric RUN test was applied which is described, together with the results in Table 1.

The simultaneous occurrence of all these rhythms discussed above presents a complex pattern in the catch per effort in the Exmouth Gulf fishery during the fishing season, making the interpretation of the population dynamics difficult.

A CATCHABILITY—CATCH PER EFFORT MODEL

Introduction

In the previous paper it was demonstrated that the catchability of *P. esculentus* changed both during the season, and within a month. It was considered that the long term change in catchability could be due to the water temperature cycle, and that the short term change could be due to the lunar cycle.

If in fact these two above were the major factors affecting the catchability, then it would be possible to compensate for, or reproduce their effect, by the use of a mathematical model and introducing appropriate 'correction' factors. Therefore an attempt was made to produce such a model which would faithfully reproduce the observed trend in the catch per unit effort pattern over the season, by introducing appropriate expressions to compensate for the two effects upon catchability, temperature and moon phase.

Materials and methods

If the catchability of *P. esculentus* remained constant throughout the fishing season, then the daily catch per unit effort would be expected to follow the well known exponential decline, given by the following formula:

$$\frac{dN}{dt} = -Z\,N \qquad (1.)$$

where Z is the instantaneous total mortality coefficient.

Z can be calculated by re-arranging (1.) to give: $N_t/N_0 = e^{-Z\,t}$ (2.)
or $N_t = N_0 e^{-Z\,t}$ (3.)
where N_0 is the catch per effort at the start of the season, and N_t is the catch per effort at some time nearer the end of the season. If temperature and the moon were having an effect upon the catchability, then N_0 and N_t should be measured on two occasions during the season when the water temperatures and lunar phases were similar.

The values of Z, calculated in this manner for Blocks 6112 and 6212 in 1969 and 1970, and for Block 6112 in 1971 were:

YEAR	*BLOCK*	*Z*
1969	6112	1.60×10^{-3}
1969	6212	2.11×10^{-3}
1970	6112	5.97×10^{-3}
1970	6212	6.48×10^{-3}
1971	6112	0.44×10^{-3}

These particular Blocks were selected to demonstrate the model, because they were fished regularly by several vessels on any particular night, thus reducing the amount of variance in the catch per effort data. On some of the other Blocks there were often extended periods during which no fishing was carried out.

1. *The effect of temperature changes upon the catchability*

It was assumed that the water temperature cycle in Exmouth Gulf followed a regular sine (cos) curve with the following formula:

$$\text{Temp.} = a \operatorname{Cos}((2\pi/b) \times \text{Time}) + c \qquad (4.)$$

where a is the amplitude of the cycle,
b is the period of the cycle
c is the mean temperature
time is the day of the year.

The maximum water temperature occurs in Exmouth Gulf at about the end of January, and the minimum at the end of June (see Fig. 13). Equation (4.) then becomes:

$$\text{Temp.} = a\operatorname{Cos}((2\pi/365)\times(\text{Time}-30))+c \qquad (5.)$$

It was considered that at the time of maximum temperature, the catchability was also at a maximum (1.0). The catchability was some amount less than this at the time of the lowest temperature. Equation (5.) could therefore be expressed in terms of catchability, instead of temperature *per se* viz.:

$$\text{Catchability}_{\text{temp.}} = a \operatorname{Cos}((2\pi/365) \times (\text{Time} - 30)) + c \qquad (6.)$$

where a is the amplitude of the catchability cycle
and c is the mean catchability.

If a and c could be determined, or in other words, the amount by which the catchability was reduecd from 1.0 at the time of the lowest temperature, then a curve of catch per effort could be produced by combining Equations (3.) and (6.), viz.:

$$N_t = (N_0e^{-Z\ Time}) \times (a \operatorname{Cos}((2\pi/365) \times (\text{time} - 30)) + c) \qquad (7.)$$

Unfortunately, there was no way to calculate exactly the effect of temperature upon the catchability of *P. esculentus* from the field data. At the time of the lowest temperature, the catchability could have theoretically been any value between 0 and 1.0, or in other words, c could have had any value between 0.5 and 1.0, and a, any value from 0.5 to 0. Using a BASIC computer program, written by myself for the purpose, daily catch per effort values were produced, using Equation (7.), while allowing c to vary throughout the permissible range above (0.5 to 1.0). N_0 and Z were selected from the data from a particular Block of the fishery. These calculations are not included here. The total sum of squares of the differences between the catch per effort values calculated in this manner, and those actually observed for the particular Block for each day of the season, were calculated. From the value of c that produced the least sum of squares, it was possible to hypothesise the effect of the minimum temperature upon the catchability.

2. *The effect of the lunar cycle upon the catchability*

Similarly, it was considered that the moon phase cycle produced a sinusoidal change in catchability during the lunar month, rising to a maximum at or near the full moon phases, and decreasing at or near the new moon phases. A similar function expressing this lunar catchability cycle was developed to that above, viz.:

$$\text{Catchability}_{\text{moon}} = a'\operatorname{Cos}((2\pi/29.5)\times(\text{Time}\pm \text{m}))+1.0 \qquad (8.)$$

In effect, this relationship assumes that the catchability fluctuates above and below (with an amplitude 'a') a mean value of 1.0. m is a factor which 'adjusts' the Time, which expressed as the day of the year, to the lunar cycle. Once again, the exact value of a' was unknown, and the model was applied with a range of values for this parameter from 0. to 1.0. The 'best' fit was determined by examining the sums of squares as above, between the observed and predicted values.

The lunar cycle function was 'superimposed' upon the temperature cycle to produce the 'complete' model viz:

$$N_t = N_0e^{-Z\ \text{Time}} \times c_{\text{temp.}} \times c_{\text{moon}} \qquad (9.)$$

This model was applied to the data for Blocks 6112 and 6212 in 1969 and 1970, and to Block 6112 only in 1971. The catch per effort data for the remaining Blocks was not sufficiently continuous to allow a fair appraisal of the model.

RESULTS

Using values of N_t and N_0, values of Z were calculated from the catch per effort data for the above Blocks. Using these values in Equation (3.) above, curves of the predicted catch per effort values were produced for each day of the season. These are illustrated, together with the observed daily catch per effort values, in Figs. 10, 11 and 12.

The 'temperature compensated' model (Equation (7.)) was then applied to the same set of data. The values of 'a' and 'b' used in the

Table 2
The upper values of each pair of values below are the total error sums of squares between the observed daily catch per effort values and those calculated from Equation (3.). The lower values are calculated after the application of the correction factors for temperature Equation (7.). Note that the sums of squares are cumulative each month.

1969

	BLOCK 6112	*BLOCK 6212*
Variable a of Eqn. (7.)	.1	.15
Variable c of Eqn. (7.)	.9	.85
Total sum of squares between the observed and predicted catch per effort values.		
	MONTH 3	
ss (Eqn. 3.)	6 460	16 786
ss (Eqn. 7.)	4 842	17 700
	MONTH 4	
ss (Eqn. 3.)	49 823	69 800
ss (Eqn. 7.)	31 840	44 856
	MONTH 5	
ss (Eqn. 3.)	74 972	110 524
ss (Eqn. 7.)	46 132	68 301
	MONTH 6	
ss (Eqn. 3.)	88 137	147 105
ss (Eqn. 7.)	60 168	84 309
	MONTH 7	
ss (Eqn. 3.)	139 928	237 963
ss (Eqn. 7.)	73 926	95 043
	MONTH 8	
ss (Eqn. 3.)	181 442	301 390
ss (Eqn. 7.)	90 209	101 847
	MONTH 9	
ss (Eqn. 3)	205 865	343 351
ss (Eqn. 7.)	116 214	121 005
	MONTH 10	
ss (Eqn. 3)	220 161	356 967
ss (Eqn. 7.)	135 149	129 224
Percentage reduction	38.6%	63.8%

1970

	BLOCK 6112	*BLOCK 6212*
Variable a of Eqn. (7.)	.25	.3
Variable c of Eqn. (7.)	.75	.7
Total sum of squares between the observed and predicted catch per effort values.		
	MONTH 3	
ss (Eqn. 3.)	209 808	324 159
ss (Eqn. 7.)	125 337	200 183
	MONTH 4	
ss (Eqn. 3.)	575 253	783 667
ss (Eqn. 7.)	303 241	387 642

(continued on page 132)

1970 (continued)

	BLOCK 6112	BLOCK 6212
Variable a of Eqn. (7.)	.25	.3
Variable c of Eqn. (7.)	.75	.7
Total sum of squares between the observed and predicted catch per effort values.		
	MONTH 5	
ss (Eqn. 3.)	655 959	1 016 350
ss (Eqn. 7.)	407 527	431 254
	MONTH 6	
ss (Eqn. 3.)	835 626	1 261 080
ss (Eqn. 7.)	442 203	456 145
	MONTH 7	
ss (Eqn. 3.)	1 046 020	1 335 280
ss (Eqn. 7.)	469 305	508 008
	MONTH 8	
ss (Eqn. 3.)	1 114 670	1 396 890
ss (Eqn. 7.)	496 882	515 404
	MONTH 9	
ss (Eqn. 3)	1 145 980	1 417 760
ss (Eqn. 7.)	519 818	530 764
	MONTH 10	
ss (Eqn. 3.)	1 152 670	1 426 360
ss (Eqn. 7.)	544 311	534 701
Percentage reduction	52.2%	62.5%

1971

	BLOCK 6112
Variable a of Eqn. (7.)	.3
Variable c of Eqn. (7.)	.7
	MONTH 3
ss (Eqn. 3.)	5 608
ss (Eqn. 7.)	3 243
	MONTH 4
ss (Eqn. 3.)	11 150
ss (Eqn. 7.)	5 155
	MONTH 5
ss (Eqn. 3.)	27 557
ss (Eqn. 7.)	7 047
	MONTH 6
ss (Eqn. 3.)	39 257
ss (Eqn. 7.)	7 704
	MONTH 7
ss (Eqn. 3.)	52 591
ss (Eqn. 7.)	8 327
	MONTH 8
ss (Eqn. 3.)	58 981
ss (Eqn. 7.)	8 878
	MONTH 9
ss (Eqn. 3.)	62 860
ss (Eqn. 7.)	13 749
	MONTH 10
ss (Eqn. 3.)	64 606
ss (Eqn. 7.)	16 953
Percentage reduction	73.8%

function to produce the prediction curves on these same Figures above, and the sums of squares between these 'corrected' catch per effort values and the observed data are given in Table 2. Note that these latter are presented as cumulative monthly totals over the fishing season.

The additions of the lunar compensating factor to this model however, did not have any effect, in that there was no further reduction in the total sum of squares between the 'corrected' catch per effort values and the observed data. These results are not presented in Table 2 for this reason.

In Table 2, two results are shown for each of the above Blocks; firstly, the total sum of squares between the observed data and that predicted from Equation (3.), with no compensating factor at all, and secondly, the sum of squares value for the same data after applying Equation (7.), to compensate for the temperature cycle.

DISCUSSION

It would be quite unreal to assume that temperature and the lunar cycle are the only two factors effecting the catchability of *P. esculentus* in Exmouth Gulf. Nevertheless, the results above do indicate that temperature, whether directly or indirectly has a major effect. This conclusion is based on the observation that one can significantly reduce the error sums of squares (by 39 and 64% in 1969, by 52 and 63% in 1970 and by 74% in 1971) by the incorporation of a 'compensatory' function into the mortality equation.

The best fits were obtained in the 1969 data by allowing the catchability in July to fall to about 70-80% of that in February; in 1970, by allowing it to fall to 40-50% and in 1971 to about 40%. The order of magnitude of these reductions in catchability with temperature are in agreement with those obtained by Fuss and Ogren (1966) in the laboratory. The reason for the different degree of reduction between the years is unknown, but could be due to a variety of reasons, including a sympathetic reduction in predator abundance or food supply, 'unseasonal' water movements, etc.

It is fairly apparent in Figs. 10, 11 and 12 that there is some lunar effect upon the catchability, although the model failed to demonstrate it. With the collection of more precise catch per effort data in the future, it may be possible to do so. Mr N. Campbell of the CSIRO Division of Mathematical Statistics, is at present examining the cycle in the data, using a more sophisticated mathematical technique.

LITERATURE CITED

AARON, R. L. AND WISBY, W. J. (1964). 'Effects of light and moon phase on the behaviour of pink shrimp.' *Proc. Gulf. Caribb. Fish. Inst.* 16th. Ann. Sess., pp. 121-130.

BERRY, R. J. (1971). 'Shrimp mortality rates derived from fishery statistics.' *Bureau Comm. Fish., Biol. Lab. Galveston Texas. Contrib.*, 282, pp. 66-78.

BEVERTON, J. H. AND HOLT, S. J. (1957). *On the dynamics of exploited fish populations.* Fishing Investigation Ser. II XIX. H.M. Secretaries Office, Ministry of Agriculture, Fisheries and Food, 533 pp.

CLARKE, G. L. AND WERTHEIM, G. K. (1956). 'Measurements of illumination at great depths in the Atlantic Ocean by means of a new bathyphotometer.' *Deep-Sea Res.* 3, pp. 189-205.

COSTELLO, T. J. AND ALLEN, D. M. (1966). 'Mortality rates in populations of pink shrimp, *Penaeus duorarum* on the Sanibel and Tortugas grounds.' *Fish. Bull.* Fish. Wildl. Serv. U.S., 66 (3), pp 491-502.

CUSHING, D. H. (1968). *Fisheries biology: A study of population dynamics.* Univ. Wisconsin press.

DALL, W. (1958). 'Observations on the biology of the greentail prawn, *Metapenaeus mastersii* (Haswell) (Crustacea, Decapoda: Penaeidae). *Aust. J. Mar, F.W. Res.*, 9, pp. 111-134.

DOW, R. L. (1961). 'Some factors influencing Maine lobster landings.' *Comm. Fish. Rev.*, 23 (9), pp. 1-11.

——. (1962). 'A method of predicting fluctuations in the sea scallop population of Maine.' *Comm. Fish. Rev.*, 24 (10), pp. 1-4.

——. (1964). 'A comparison among selected marine species of an association between sea water temperature and relative abundance.' *J. Cons. perm. int. Explor. Mer*, 28, pp. 425-431.

ELDRED, B. (1958). 'Observations on the structural development of the genitalia and the impregnation of the pink shrimp, *Penaeus duorarum* (Burkenroad).' *Tech. Ser. Fla. St. Bd. Conserv.*, 23, 26 pp.

(1969)—'Turning day into night. Electric net makes day shrimping possible.' *World Fishing March* 1969, 38-39.

F.I.N.S. (Fishing Industry News Service) (1968). Electric shrimp nets. *Fish. Indust. News Serv.* 1 (3).

FUSS, C. M. (1964). 'Observations on burrowing behaviour of the pink shrimp, *Penaeus duorarum* (Burkenroad).' *Bull. Mar. Sci. Gulf Caribb.* 14 (1), pp. 62-73.

FUSS, C. M., OGREN, L. H. AND KESSLER, D. W. (1964). 'Shrimp behaviour as related to gear research and development.' *Proc. Gulf Caribb. Fish. Inst.*, 16, p. 51.

——. (1965). 'Electric trawl ready for marketing.' *Fishing Gazette,* 82 (2), pp. 54, 76-77.

FUSS, C. M. AND OGREN, L. H. (1966). 'Factors affecting activity and burrowing habits of the pink shrimp, *Penaeus duorarum* (Burkenroad).' *Biol. Bull. mar. biol. lab. Woods Hole* 130 (2), pp. 170-191.

GARROD, D. J. (1964). 'Effective fishing effort and the catchability coefficient.' q. *Rapp. et Proces-verb. des Reun. Conseil Perm. Int. pour l'explor. de la Mer.* 155, pp. 66-70.

GOTSHALL, D. W. (1972). 'Population size, mortality rates, and growth rates of Northern Californian Ocean shrimp, *Pandalus jordani* (Rathbun), 1965 through 1968.' *Fish. Bull., California Dept of Fish and Game* 155, pp. 1-47.

GULLAND, J. A. (1955). *Estimation of growth and mortality in commercially exploited fish populations.* Fish. Invest. Ser., (2) 18 9. HMSO, London, 46 pp.

——. (1956). *On the fishing effort in English demersal fisheries.* Fish. Invest. Ser. (2) 20 (5), HMSO, London, 41 pp.

HALL, D. N. F. (1962). *Observations on the taxonomy and biology of some Indo-West Pacific Penaeidae.* Fish. Publ. Colonial. Off. Gt Brit. 17, 229 pp.

HILDEBRAND, H. H. (1955). 'A study of the fauna of the pink shrimp (*Penaeus duorarum* Burkenroad) grounds in the Gulf of Campeche.' *Publ. Inst. Mark. Sci. Univ. Texas* 4 (1), pp. 169-232, 1 fig.

HUGHES, D. A. (1968). 'Factors controlling emergence of pink shrimp (*Penaeus duorarum*) from the substrate.' *Biol. Bull. Mar. Biol. Lab. Woods Hole* 134, pp. 48-59, figs.

——. (1969c). 'Factors controlling the time of emergence of pink shrimp, *Penaeus duorarum.*' *F.A.O. Fish. Rept.* 57 (3) *Proc. World Sci. Conf. on the Biology and Culture of Shrimps and Prawns.* Mexico City, Mexico, June 1967, pp. 971-981, 2 figs., (French and Spanish summaries).

IVERSEN, E. S. AND IDYLL, C. P. (1960). 'Aspects of the biology of the Tortugas Pink Shrimp (*Penaeus duorarum*).' *Trans. Amer. Fish. Soc.* 88 (1959), pp. 130-132, 1 fig.

IVERSEN, E. S. (1962). 'Estimating a population of shrimp by the use of catch per effort and tagging data.' *Bull. Mar. Sci. Gulf and Caribb.* 12th. ann. sess. (1961), pp. 350-398, 8 figs., 17 tabs.

IVERSEN, E. S. AND VAN METER, N. N. (1964). 'A record of the microsporidium, *Thelokania duorara,* parasitising the shrimp *Penaeus brasiliensis.*' *Bull. Mar. Sci. Gulf and Caribb.* 14 (4), pp. 549-553.

KUTKUHN, J. H. (1966). 'Dynamics of a penaeid shrimp population and management implications.' *Fish Bull., U.S. Fish and Wildl. Serv.* 65, pp. 313-338, 15 figs. An abbreviated version of the same article appears in: *Rapp. et Proces-verb. des Reun.* 156 *Conseil. Perm. Int. pour l'explor. de la Mer.,* pp. 120-123.

LANDER, R. H. (1962). 'A method of estimating mortality rates from change in composition.' *J. Fish. Res. Bd Can.* 19, pp. 159-168.

MCLEESE, D. W. AND WILDER, D. G. (1958). 'The activity and catchability of the lobster (*Homarus americanas*) in relation to temperature.' *J. Fish. Res. Bd Can.,* 15, pp. 1345-1354.

MARR, J. C. (1951). 'The use of the terms abundance, availability and apparent abundance in fishery biology.' *Copeia,* pp 163-169.

PALOHEIMO, J. E. (1958). 'A method of estimating natural and fishing mortality.' *J. Fish. Res. Bd Can.,* 15, pp. 749-758.

——. (1961). 'Studies on estimation of mortalities 1. Comparison of a method described by Beverton and Holt and a new linear formula.' *J. Fish. Res. Bd Can.* 18, pp. 645-662.

PARDI, L. AND PAPI, F. (1961). 'Kinetic and tactic responses.' In *Physiology of Crustacea* 2. (T. H. Waterman ed.) Academic Press, N.Y.

RACEK, A. A. (1957). 'Penaeid prawn fisheries of Australia, with special reference to New South Wales.' *Res. Bull. St. Fish. N.S.W.,* 3, pp. 1-19.

——. (1959). 'Prawn investigations in Eastern Australia.' *Res. Bull. St. Fish. N.S.W.,* 6, pp. 1-57.

RICKER, W. E. (1940). 'Relation of "catch per effort" to abundance and rate of exploitation.' *J. Fish. Res. Bd Can.,* 5 (1), pp. 43-70.

——. (1958). 'Handbook of computations for biological statistics of fish populations.' *Bull. Fish. Res. Bd Can.,* 119, 300 pp.

SIMPSON, A. C. (1965). 'Variations in the catches of *Nephrops norvegicus* (L.) at different times of day and night.' *Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer.,* 156, pp. 186-189.

SUTCLIFFE, W. H. (Jnr. s) (1956). 'Effect of light intensity on the activity of the Bermuda spiny lobster, *Panulirus argus.*' *Ecol.,* 37, pp. 200-201.

——. (1969). 'Turning day into night. Electric net makes day shrimping possible.' *World Fishing,* March 1969, pp. 38-39.

WATERMAN, T. H. (1960). *The physiology of Crustacea.* vol. 1 (T. H. Waterman ed.) Academic Press, N.Y.

WATHNE, F. (1963). 'Promising leads in fishing gear development.' *Proc. Gulf Caribb. Fish Inst.,* 15th, pp. 5-9.

WHEELER, J. F. G. (1937). 'Further observations on lunar periodically.' *J. Linn. Soc. (Zool),* 40 (272), pp. 325-345.

WICKHAM, D. A. (1968). 'Observations on the activity patterns in juveniles of the pink shrimp *Penaeus duorarum.*' *Bull. Mar. Sci.,* 17 (4), pp. 769-786.

WILLIAMS, *A. B.* 'A contribution to the life histories of commercial shrimps (Penaeidae) in North

Carolina.' *Bull. Mar. Sci. Gulf and Caribb.*, 5 (2), pp. 116-146.

——. (1958). 'Substrates as a factor in shrimp distribution.' *Limnol. Oceanogr.*, **3** (3), pp. 283-290.

——. (1967). 'Penaeid shrimp catch and heat summation, an apparent relationship.' *F.A.O. Fish. Rep.* 57 (3). *Proc. World Sic. Conf. on the Biology and Culture of Shrimps and Prawns.* Mexico City, June 1967. pp. 643-656.

DISCUSSION

(This paper was presented by Dr D. Hancock but answers by Mr White were communicated to the Editor subsequently.)

Neal. He has used here quantity per hour, or quantity as a catch, as opposed to numbers, now do you think he is safe in using weight here rather than numbers?

Hancock. I am sure he could have made the conversion. He has very full information on size compositions. (Information in paper.)

White. In fact I used numbers, not weight, in all cases except to illustrate the pattern of catches during the 24 hour cycle (Figs. 7, 8 and 9). I was simply trying to show the *pattern* of catches on an hourly basis over 24 hours. I did not intend, or attempt to relate the absolute values between hours, weeks or years, but used the results to demonstrate the relationship between day and night catch rates (which I related to catchability), and the change in the *pattern* during and between years. At no time did I use the absolute values.

Lucas. It is a little bit unfortunate that Trevor White is not here, and this paper is taken out of a Ph.D. thesis so there is probably a lot more stuff around that I am not aware of, that he, if he were here, would have been able to tell us, but I could see two possible problems. One is the lack of discussion on the question of immigration or emigration, and the second problem is I think there is a bit of circular argument concerning the temperature effect on catchability. It seems that first of all it is assumed that there is a temperature effect on catchability and this is then used to obtain the solid lines in the Figs. 6.24, 6.25 which I do not really think represents a line of numbers of prawns remaining at any particular time. From that he is then able to say that there is a temperature effect because he can then draw a dotted line down below. So I really think that it is a circular type and argument assuming that there is a relationship between temperature and catchability and then after assuming that to prove that there is. Possibly there is other information available which could clarify this and I guess all we can say at the moment is bring this to Trevor's attention and then he may comment further on that.

White. Dr Lucas raised two points, the first being the 'lack of discussion on the question of immigration or emigration'. He is right, I have not really discussed this in detail in this paper, although I have done so in other parts of my thesis, which of course he was not to know. Naturally, I was aware of the possibility of movements in and out of the Blocks I chose influencing the results. But I did not consider this to be important for two reasons:

(a) I was not looking at absolute numbers or abundance in the catch rates, but a cycle or rhythm, so that it did not really disturb me if the catch rates were unnaturally high or low at any month, on the Block I chose because of immigration or emigration, so long as the rhythm was still apparent and reproducable.

(b) The same rhythm and curves were apparent on all Blocks in the Gulf synchronously, so that I could have in fact used any Block at all, or even combined Blocks to demonstrate the rhythm (which would have eliminated the 'problem' of immigration) but I deliberately selected one or two Blocks because of the reasons I gave in 'results', section 2, 'lunar rhythm' of the paper.

I only used the absolute values from any one Block to construct the model *based on* and used *only in relation to* that particular Block. They were not used to make predictions in other Blocks, and were not used in subsequent yield equation (in other parts of the thesis). The problem really arose later on, when I was trying to calculate mortality rates, but that's another story.

Dr Lucas' second question relates to the method which I used to demonstrate the effect of temperature upon catchability.

Perhaps, if I illustrate my 'line of reasoning' in the matter, it may clear things up a bit:

1. Assuming:
   (a) no migration, and
   (b) no change in catchability, then the numbers of prawns in the fishery should decline exponentially. The 'shape' of this curve can be constructed using the formula $N_t = N_o e^{-Zt}$. N_o and N_t can be calculated from the data, by selecting two catch rates during the season, with an interval 't' between

them. I 'arbitrarily' chose two points in time, during the season at the beginning (March), and at the end (September-October).

2. After inserting the values of N_0 and N_t into the formula and plotting the 'predicted' curve (the dark lines on Figs., 10, 11 and 12) it was apparent that the curve was not a good fit. The observed catch rates were much lower in the middle of the year than predicted.
3. I hypothesised that this decrease could have been due to decreased catchability, in turn due to the decrease in water temperature at this time.
4. To test the hypothesis I used the same values of N_0 and N_t as above, but 'superimposed' my hypothetical 'temperature catchability' model upon the equation, to produce the dotted line on the figures.
5. I then tested the 'goodness of fit' of the traditional model above, and the 'temperature compensated' model, with the observed data.

I hope that this clarifies the matter a little for Dr Lucas—I do not think that this sequence is a 'circular argument'.

Kirkegaard. Could Dr Hancock enlarge a little bit more on the methods used to determine the moulting rhythm? Again I am probably in the same situation as Dr Lucas was, commenting on something when a man is not here to explain, but he says that 'method involved basically the measurement of the percentage of recently moulted individuals in the commercial landings'. Now does this involve an assumption that these individuals do not alter their behaviour, but remain buried or otherwise move themselves out of what normally would be the catchable group during the period in which they are soft-shelled or even preceding that period. Was that an unfair question right now?

Hancock. Not really, I think as I know it, this was based on catch statistics and catch measurements. He does, as I mentioned later, point out that these are the numbers actually moulting in any sample or numbers of soft-shell that he sampled are not very high. I can only guess that he is using the fact that there are any there at all as an indication that this is a fraction of a lot that are not actually appearing in the catch and that you are just getting the surplus as an indicator or I do not know whether Jim Penn knows better or more about it than that from a factual point of view.

Penn. In the Exmouth Gulf it is a one-day-operation fishery, virtually all the catch is landed each morning and Trevor was able in fact, by looking at the seconds that came through the factory, which are predominantly moulted animals, to sample the entire catch, many thousands of pounds per day, and a proportion of that which amounted to perhaps a thousand pounds weight of animals per day as his numbers that are moulting. But, as I guess we both know, the period of time that they stay soft is quite short and probably only those which are in fact moulting as the net passes by are the ones he is going to catch and they probably buried after that. But I think that his moulting figures are possibly all right. The only problem he has got is in sorting out different areas and perhaps different size groups, if the fishing fleet moves from one area to another, he could very likely get a combination of effect with big animals during one part of the month being taken as small animals in another. I think he has looked into this but it is obviously not in this section of his thesis.

White. Mr Kirkegaard asked about my method of determining the moulting rhythm.

I apologise for not providing more detail in the paper—again I have done so in an earlier section of my thesis. Jim Penn answered Ian's query to some degree, but I will try and elaborate a bit.

Firstly the method:

The processing girls subjectively sort all of the 'soft' prawns from the commercial landings during factory processing. These are subsequently peeled and sold as prawn flesh. Admittedly, the criteria used to decide 'softness' are subjective, but the same criteria are used by the same girls every day. As Jim Penn pointed out, in Exmouth Gulf catches are unloaded daily by all boats, so I could obtain the total catch of each species for each night and the total weight of soft prawns in that catch. Then I had the proportion of soft prawn in the catch for each night, by species. I was not looking at the proportion in samples, but in total catch of the entire fleet. By plotting this proportion I tried to demonstrate the cycle. As Jim pointed out, the period of the moulting cycle when the prawns are 'soft' only lasts for a few hours, so that all soft prawns found in the night's catches were probably moulting that night. Now, I have no idea what proportion of these prawns actually undergoing ecdysis were caught on any particular night, but for the purpose of the exercise it is unimportant, as long as the ratio, whatever it is, is fairly constant. This is again, because I am only trying to demonstrate a cycle, and have not looked at absolute values.

I have discussed the effect of moulting upon catchability and feeding behaviour in a little more detail in another section of the thesis. I would refer Ian to a paper by Bursey and Lane (1971) in *Comp. Physiology and Biochemistry* 40A, pp. 155-162.

SESSION 3

THE CULTURE OF PENAEID PRAWNS

CHAIRMAN: DR D. A. HANCOCK

INTRODUCTORY SPEAKERS
R. A. NEAL B. WISELY

SHRIMP CULTURE IN THE UNITED STATES[1]

BY R. A. NEAL[2]

Investigation Chief, Aquaculture Research and Technology, Gulf Coastal Fisheries Center, Galveston Laboratory, 4700 Avenue U. Galveston, Texas 77550.

ABSTRACT

Early attempts to rear shrimp commercially in the United States were patterned after successful methods in use in the Orient. Economic, legal and social restrictions in the United States contributed to the failure of these methods. A review of recent research results is presented and typical commercial ventures of several types are examined.

INTRODUCTION

Shrimp culture activities in the United States have been characterised by three phases of development. I've assigned labels to these phases as follows:

1. Chickens in the woods
2. What's a shrimp?
3. Cats and rats.

I believe the reasons for these headings will be obvious.

CHICKENS IN THE WOODS

In the early 1960s, about the time of the price increases mentioned earlier, people suddenly became aware of shrimp culture in South-east Asia, and began thinking about shrimp farming in the United States. By the late 1960s larval culture techniques were available making the prospect of raising shrimp commercially even more attractive.

Now I want to draw a parallel with raising chickens. Any of you who have raised chickens realise that hatching and rearing chicks is not all there is to the chicken business. If you raise chicks then release them in the wild and plan to come back in 4 months for the harvest you'll have problems. Although you may harvest a few, most will have died.

This procedure which sounds foolish with chickens is about what people were planning to do with shrimp. The prospective shrimp farmers released postlarvae into natural ponds and came back 6 months later with the hope that by some magical process the ponds would be full of shrimp. Nothing magical occurred. They had the same kind of problems you might expect to have with chickens in the woods. The shrimp did disappear, but that wasn't the kind of magic the shrimp farmers had hoped for. Strangely enough, some people are still thinking along these lines today.

WHAT'S A SHRIMP?

Following the early failures shrimp culturists began to ask questions about shrimp—their habits, foods, requirements, and enemies, and realised we didn't have answers to many of the basic questions. In the late 1960s the research effort in the United States began in earnest. I would like to review the research accomplishments in the United States briefly with emphasis on developments during the last couple of years.

In the area of larval culture there are few new developments. The storage of algal foods by freezing has been useful in eliminating dependence on the timing of the algal cultures. The cells are separated from their culture media by simple centrifugation; concentrated cells are frozen in sea water and later thawed in distilled water.

After testing numerous food organisms we found that a combination of *Skeletonema* sp. and *Tetraselmis* sp. is most suitable. These two species not only provide the necessary nutritional requirements of the larval shrimp, but are relatively easy to culture, to concentrate and to store frozen.

We have long been dependent upon *Artemia* for food during the mysis and early postlarval stages. The possibility that a substitute for *Artemia* may be found has been improved by the availability of micro-encapsulated foods. Feeds coated with gelatin in particle sizes down to 50 microns are now available. Although we don't yet know what to put in these capsules,

---

[1] Contribution No. 387, National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Laboratory, Galveston, Texas 77550.

[2] National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Laboratory, Galveston, Texas 77550.

preliminary tests are underway with larval and postlarval shrimp.

Some nutritional problems have been solved but many remain. A suitable form for shrimp feeds is the small worm-shaped pellets produced by an extrusion process. The attractant in a shrimp feed is extremely important because the animals may stop eating a given diet after a few weeks if the attractant is unsatisfactory. Fish solubles, a by-product of the fish meal industry, is a suitable attractant. Considerable effort has also been spent in search of a binder which will hold food intact for long periods in the water and still be suitable from the nutritional viewpoint. An alginate binder is the best we have tested. The nature of the alginate binder requires that the feed be extruded in a wet state and dried following extrusion, an extra step in the manufacturing process which feed manufacturers dislike.

Until recently we have not had a control diet to use as a basis for nutritional comparisons. We do now have a standard diet (Zein-Eldin and Meyers, in press) which is fairly good from the nutritional standpoint, contains inexpensive ingredients (Table 1), and can be manufactured on a small scale.

It is becoming obvious that the environmental changes, which are normal during the life cycle of shrimp, must be duplicated, to varying degrees, to produce conditions for optimum growth of the shrimp. We must begin thinking beyond the tolerances of the animals and simple survival to optimum conditions for growth. Many details of the effects of metabolic wastes, light, and sea water chemistry must be examined as well as aspects of the shrimp's behaviour such as burrowing. At present very little data of this type are available.

Unfortunately, very little new work has been done in the area of pond culture methods. Most of the methods used in the United States have been used for some time in Asia. I found it very difficult to summarise the results obtained by the four main research groups working with pond culture of shrimp (University of Miami, State of Texas, State of Louisiana and Texas A&M University). Because of the different approaches, the different stocking densities and the different environmental conditions, research results frequently cannot be compared. Two general relationships could be recognised, however: a relationship between stocking density and size at harvest, and a relationship between stocking density and yield. If experiments of 90-120 days duration in static ponds are considered, the relationships can be approximated as follows:

1. Size at harvest ranges from about 120 mm in total length for densities below 20,000 per hectare to about 80 mm for densities over 250,000 per hectare.
2. Yield ranges from 100-200 kg/ha (heads-on) at stocking densities of 20,000-40,000 per hectare to 400-600 kg/ha at densities of 250,000-300,000 per hectare.

The problem of sexual maturation of females in captivity is receiving considerable attention from researchers. In addition to the reported successes in maturing female shrimp in Japan (for which little factual information

Table 1. Composition of standard diet in use at the Galveston Laboratory[a]

Component	Percentage	Source
Shrimp meal, sun-dried	31.5	Blum and Bergeron, Houma, Louisiana
Fish meal (menhaden)	8.0	
Soybean meal ('Promine-D')	3.0	Central Soya Company, Chicago, Illinois
Rice bran ('Protex-29')	49.0	Riviana Foods, Inc., Houston, Texas
Vitamin diet fortification mixture	2.0	Nutritional Biochemicals, Cleveland, Ohio
Fish solubles	2.0	
Lecithin ('Alolec')	1.0	American Lecithin Company, Long Island, New York
Kelgin (High velocity algin)	2.5	Kelco Company, San Diego, California
Sodium hexametaphosphate ('Calgon')	1.0	

[a] From Zein-Eldin and Meyers (In press).

is available), at least two research teams have induced maturation and spawning of captive, wild penaeid shrimp. A research team in Puerto Peñasco, Mexico composed of biologists from the University of Arizona and the University of Sonora, and a team of French scientists at the CNEXO facility in Tahiti have both accomplished maturation under similar conditions. Both groups were using a continuous exchange of high quality, oceanic water through their tanks and both had reduced light intensity by shading the tanks. The species matured successfully to date have been *Penaeus californiensis* (Mexico), *P. semisulcatus*, *P. merguensis* and *Metapenaeus monoceros* (all in Tahiti).

We have not yet matured species from the Gulf of Mexico even though environmental factors such as low light intensity and good water quality have been conducive to partial development of the ovaries. Eyestalk ablation can be used to induce vitellogenesis; however, normal spawning does not follow completion of vitellogenesis in ablated animals.

The final topic I want to mention in this section is intensive culture and the applications of engineering methods to high density culture. I am predicting this will be the most active area of development during the next few years even though efforts along these lines are just now beginning. The Japanese have not been interested in high-density culture until recently because more traditional methods were profitable in Japan.

The need for intensive culture arises with animals that require animal foods for part or all of their diet. Carnivores can graze on natural animal foods just as herbivores do; however, the density of carnivores which can be supported on natural foods is not nearly as attractive economically as is the density of herbivores. Therefore, we need to boost production per unit of area, and we do this by adding feeds and controlling the environment.

At the Galveston Laboratory we are just beginning to work in a closed system in a greenhouse which permits year-round production. By aerating the water heavily, encouraging algal growth and insuring adequate circulation of the water we have had surprisingly good results.

CATS AND RATS

The third phase of shrimp culture activity actually hasn't followed the second phase because the second is not complete. I might also label this phase the phase of 'Grand Plans'.

For illustration I want to tell you about my cat farm. I'm going to buy an old building in Galveston for $1,000. This building is going to be my cat farm where I will raise cats for their fur. Cat pelts are worth only about 40c each so I'll need lots of cats, in fact about 20,000 of them. Now if you know anything about cats you know that if you start with a few hundred you will soon have 20,000. The cats will be fed rats, and if you know anything about Galveston you know that won't be a problem. Rats need to eat too, of course, so I will feed the cat carcasses to the rats.

Since a cat is ready to pelt at 20 weeks of age, I will pelt 1,000 cats per week. The income will be $400 per week minus $100 which I will pay the cat skinner. This leaves a net income of $300 per week from my $1,000 investment.

I'm sure you've all talked with entrepreneurs who have similar plans for shrimp farming. Typically the plans include a scheme for selling shares in the company, and frequently the budding businessman has ignored advice from biologists.

Fortunately not all the 'Grand Plans' are this bad. In fact, some of the commercial trials have been very good efforts from which a great deal can be learned. I want to review several representative commercial efforts which I feel were good efforts, looking both at their successes and their shortcomings. These commercial firms (which will not be identified by name) worked in the following environments:

Company A—Natural marsh area
Company B—Natural bay plus ponds
Company C—Ponds
Company D—Outdoor raceways using waste heat.

Company A began using natural marsh areas in southern Louisiana which have little value except for wildlife and oil. The soils in this area are very loose with a high organic content. During oil drilling and exploration the oil companies dug many canals through the area. This company planned to use these waterways plus natural and artificial ponds to rear shrimp that entered the waters naturally as postlarvae. Considerable experimentation was conducted with levee construction, feeding methods, methods of harvesting and methods for control of predators.

Even though the natural environment supported shrimp, the biologists found the environment to be very unstable. Disturbances such as dike construction caused many problems. The dikes sloughed continuously and disturbances of the high organic soils created high oxygen demands in the ponds. Dike construction and maintenance proved to be prohibitively expensive partly because of damage by burrowing mammals. Harvesting a high proportion of the crop was virtually impossible because the water could not be completely drained from the enclosures. Commercial efforts were abandoned after a few years.

Company B transferred Japanese larval culture technology to the United States. Their larval culture procedures have been consistently successful. The grow-out procedures also were patterned after Japanese methods with the following exceptions:

1. The area of the culture enclosures ranged from a 120-hectare pond to a 1,000-hectare natural bay, while Japanese enclosures are much smaller.
2. A retaining net 5.6 km long was constructed across the mouth of the large bay area.
3. Much less tidal exchange occurs along the Gulf of Mexico than in the Inland Sea of Japan.
4. Predators have not been controlled as successfully as they have in Japan.
5. Only supplemental feeding was used.

Because the biologists have only limited control over these large bodies of water survival has been poor. Harvests have ranged from 75,000 kg to 225,000 kg during the period 1971-1973.

The pilot studies by Company C are typical of several which have taken place in Central America utilising artificial ponds. The company established its operations in Honduras to take advantage of low labour costs, low taxes, low land costs and freedom from regulations such as the pollution laws in effect in the United States. Two problems have hampered culture efforts in Central America. First the labourers, although inexpensive, are not always productive. Second, problems of obtaining equipment and maintenance services on the equipment have caused difficulties. Although reports of growth and survival of shrimp in Company C's ponds were good, this pilot operation was discontinued for undisclosed reasons.

The efforts of Company D represent the most progressive commercial effort in the United States to date. The company hired a competent, experienced staff and constructed a modern hatchery. Raceways were constructed near an electrical power plant to utilise waste heat during the cooler months.

The procedure used in the 0.2 hectare raceways was to stock at very high densities (up to 700,000 per hectare), use a rapid exchange of water, fertilise heavily and feed heavily. Even with the rapid exchange of water growth sometimes stopped at 60 or 70 mm total length, especially at the higher densities. Generally the operation appeared to be quite successful although figures on production and costs are not available.

A major problem associated with this trial was the rocky, porous nature of the soil. It was necessary to use butyl rubber liners in some raceways in order to hold the water. This type of liner is quite expensive ($3.00-$4.50 per m²). The only indication of the profitability of this operation has been the termination of commercial scale trials in the United States and the development of new facilities in Central America by Company D.

Although much more could be said about the commercial activities in the United States, let me say in summary that there are no outstanding successes yet and probably no profitable operations.

WHITE PRAWN (PENAEUS VANNAMI) CULTIVATION IN ECUADOR, SOUTH AMERICA

BY B. WISELY

N.S.W. State Fisheries, Brackish Water Fish Culture Research Station,
Salamander Bay, N.S.W. 2301.

When I was over in the States recently Dr Neal gave me a manuscript to read and this contained some rather appropriate concepts. He thinks in terms of two types of culture: intensive and extensive.

By intensive he means raceways, ponds, tanks, where you maintain a high density of prawns and you have control of just about all the variables; predators, temperature, salinity and so on. These are essentially man-made, artificial bodies of water and they contrast very sharply with the extensive bodies of water which are bays, sea arms or natural ponds with low prawn densities and very little control of variables such as predators and salinity.

These intensive and extensive methods of cultivation are the ends of a spectrum and I would like to talk about a prawn farming venture in Ecuador which comes somewhere in between. When you look at a map of South America, Ecuador is in the top left hand corner, down a little, between Columbia and Peru. Mike Harris, Jim Ryall and I went there primarily because we had heard that the people were catching wild, postlarval prawns and stocking ponds with them. This seemed rather unusual so we went to have a look at it.

The scientist in charge of this prawn farm is Dr Mario Cobo, a Spaniard who came into the scene only a few years ago. The ponds were put in by a group of banana growers, who thought they could put ponds into an area, let in the sea and postlarval prawns, block the sea off and harvest prawns. They ran into difficulties but when Mario came he started to think about things and made quite a few changes. I would emphasise that what he is doing is very much experimental. He has only been at it two or three years and he is learning all the time.

The farm is a considerable size—about 360 hectares of salt pan country converted into ponds—and with room around to double the capacity if need be. The smallest pond is about 36 hectares and instead of excavating to form the ponds, which would have been tremendously costly, they used bulldozers to form up walls or levees. Because the ponds are so large there is wave action and problems with levee erosion. They started putting in sticks, bits of bamboo and so forth against the levees but this was fairly costly and time consuming. Now, after each pond is harvested and drained, they bulldoze soil against the levee walls from the pond side to alter the slope from short and steep to very shallow and gradual. This helps quite a bit; the waves ride up over the walls rather than break and erode the levees.

One of the most interesting things about this venture is that they are indeed catching postlarvae. They do this between December and April in the wet season and even when we were there in October four men caught several thousand postlarvae in a few hours. These postlarvae coming from the sea swim up a canal to the farm. Incidentally the farm is just about on the Equator and the tidal amplitude is about 5.5 m. At the farm boundary the canal forks and runs about 1.6 km each way along the boundary and the men wade in these canals at low water and scoop up the postlarvae with dip nets. They pull larval crabs and fish from the catch and squash them between their fingers to stop them becoming predators later on.

During December nine men can catch 40,000 or so postlarvae per day. This sounds rather expensive but in fact it is not because the basic wage there is only about US$7.50 per week. The men worked well and seemed happy. This season Mario intends to put on more men in the wet season between December and April so he can stock more of the ponds.

We took samples from three ponds. The salinity in the first pond was about $20^0/_{00}$, in the second about $30^0/_{00}$ and in the last one about $40^0/_{00}$. The prawns in all three ponds were healthy. The main species cultivated is *Penaeus vannami*, which is a white prawn very much like *Penaeus merguensis*, our banana prawn. It is fast growing; the crop we saw being harvested after six months grow-out time had a count of 15-20 prawns to the pound and a weight of 20-40 g per prawn.

We also watched them harvesting. They use a dugout canoe to encircle prawns with a net that is about 46 m long, 100 meshes deep and 38 mm mesh. The day we were there they took something like 600 kg out and they caught maybe 100 kg in a haul. The catch was remarkably clean; there were a few fish and one or two crabs but nothing much else.

How does Mario control the situation? Firstly, let us take temperature. Because the farm is just about on the Equator they have no problems. In fact the surface water temperatures are around 30-32°C most of the year, sometimes dropping in winter to about 25°C. Secondly, salinity. They have two canals coming into the farm; the postlarvae swim up the seawater canal and there is also a freshwater canal coming from a nearby river. They can pump saltwater, freshwater or both into any pond using 37 kW diesel pumps. The pipelines are about 0.3 m across. They can pump in sea water and as it evaporates and becomes hyper-saline they can pump in freshwater to hold it right.

P. vannami is a resistant species which can apparently live equally well in saltwater of 20, 30 or $40^0/_{00}$ salinity and this helps considerably. Thirdly, predators. These are not a problem as the ponds can be drained and the predators removed.

As regards expenses, a considerable amount of money has to be spent in building up and maintaining the levees. Fortunately there are hundreds, possibly thousands, of banana plantations round about. The bulldozers used there are not working all the time on the plantations so in the offtime and at night they can be used on the prawn farm. There were two bulldozer drivers on the farm and they can keep a machine moving 24 hours a day if need be. This is good policy; if you have expensive machinery you should keep it working all the time.

The other main expense is pumping. I do not know the cost of pumping but there is continuous pumping going on all the time. There is a saltwater pump, a freshwater pump and two others that can be carted around to wherever they are needed.

The sequence is that during the summer wet season (December to April) all nine men go onto catching postlarvae. The women in the packing plant take time off during this period. In the early days Mario counted postlarvae and ended up with a unit called a handful; they know roughly how many thousand prawns are in a handful. Either Mario or the manager tally the handfuls of postlarvae caught by the men daily and work out the stocking densities. They allow for 50% mortality and this is a commonly used figure; we noticed that other prawn farms operated on it too.

The ponds are first stocked during the wet season when the salinity is fairly low but it soon starts to evaporate and after a month or two the salinity needs adjusting. Regular salinity readings are made during the grow-out period.

The most striking feature of the whole process is that no food is given to the prawns during the grow-out period. They have to forage for themselves in the ponds. Last year the yields were a little bit over 225 kg per hectare and you might have noticed Dr Neal's figures showing that you can expect yields around 340 kg per hectare from such a situation. If you are cropping 225 to 340 kg of prawns per hectare for nothing you are growing the right kind of prawn and this can add up to a substantial amount on a 360 hectare farm.

The packing and harvesting operations are a little primitive. They have six girls deheading in a big packing room. First thing each morning they go to vats containing the last of the previous day's catch stored in iced water. They start deheading these, putting them in 9 kg packets which are then frozen. Meantime the men are away harvesting and as soon as they have a catch of several hundred kg the manager brings it up to the packing room. By this time the girls have nearly finished the prawns left overnight in the iced vats and shortly afterwards they start on the freshly caught prawns. They are harvesting a suitable quantity each day rather than attempting to harvest the lot at once.

To harvest, they partially drain the ponds. The latter are 1-1.2 m deep on the seaward side and slope up to 0.3-0.6 m on the landward side. The prawns concentrate on the deeper side of the pond where they are netted and after harvesting the ponds are completely drained to kill predators.

Grow-out lasts for nine months of the year and there is not much taking place in the other three except catching the postlarvae. Mario plans next year to put on extra men and try to get enough postlarvae to get two crops per annum from some of the ponds. As I mentioned earlier they can harvest a crop after six months, mainly because they are growing in such high temperatures (30-32°C). If they could harvest two crops a year this would be much better, but they would have to hold the smaller prawns somewhere and this has difficulties. As Dr Neal mentioned, if you give the prawns a setback along the line they take quite a while to recover.

We also noticed that they feed waste bananas to the cows in this area, so if you chase a cow around the paddock for a while you can get a banana flavoured milkshake out of her.

To summarise, the favourable aspects of this prawn farming venture are the cheap salt pan land, the cheap labour, the very high temperatures suitable for rapid, continuous prawn growth, the use of levee ponds (instead of digout ponds) which are less expensive to construct and can be drained by gravity instead of pumps, and an appreciable supply of 'free' postlarvae. The main disadvantage is having to use pumps continuously to fill or adjust the salinities in ponds. At present the yields are low (about 220 kg per hectare) but undoubtedly this could be increased considerably if the natural food in the ponds was supplemented with food pellets and if a hatchery was added to provide extra post larvae. This scheme could turn into quite a profitable concern and it will be interesting to follow its development over the next few years.

DISCUSSION

Dredge. Has any consideration been given to siltation in these pools?

Wisely. I do not think the problem arises. The levees are much higher than the surrounding ground, which is well drained salt pan country, so silt cannot run into the ponds.

Temperley. If there is a 5.5 m tide variation, wouldn't those drains be running dry for almost all the time? That's a very small drain you showed us.

Wisely. The ponds are built just above the high tide mark but a long drain (maybe 3.2 km long) runs along the seaward side of the ponds so they can pump from drain to ponds to fill them. Postlarvae come up the small drain you mentioned and into the long one on the high tide. As the tide recedes the water level drops but maybe 0.6 m of water is trapped in the long drain because there is a small bar across it where it runs out into the little drain. The postlarvae are trapped in this shallow water with no way out until the next high tide. They have just migrated up from the sea and it is unlikely that they will return anyhow until they have grown up and are returning to the sea to spawn.

Melvin. You mentioned salinities of 20, 30 and 40 parts earlier in your talk. I am afraid I did not follow that particular point. Would you elaborate on that please?

Wisely. Sea water is normally around 33 parts sodium chloride per thousand parts of water. A salinity of $20^0/_{00}$ means it has been diluted by fresh water from rivers or rain. Postlarvae, migrating from the sea into rivers, estuaries, or creeks can certainly tolerate such low salinities and may in fact be using them as guides to reach their destination. The postlarvae migrate towards the coast during the wet season and the ponds at that time would have low salinities. As the ponds evaporate later in the season the salinity goes up to $30^0/_{00}$ (about that of the sea) and still later on reaches $40^0/_{00}$ which is decidedly salty. Fortunately *P. vannami*, the prawn under cultivation, tolerates a range of at least 20 to 40 parts per thousand so the pond salinities can be allowed to vary during the grow-out period. Precise control of the salinities of ponds of 36 hectares or more would be difficult.

Melvin. You mentioned earlier that there was a 360 hectare pond. I just drew from this that there were divisions in which there were variations in salinity. Three hundred and sixty hectares—is it not in fact divided into a series of ponds of varying salinities?

Wisely. It is divided into a series of ponds. The smallest of these is 37.6 hectares, to be exact.

Barber. I have two points. One comes from the experience the oyster farmers have had in respect to water quality and Dr Neal kept mentioning this water quality problem. In the past they have moved to different areas away from population density because of the water quality problem. I just wondered if this might arrive in prawn culturing, they get these ponds built and then later water quality problems arise. Number two is, as everybody looks at this prawn culturing problem financially, I just wondered if we look at it from an energetics aspect. That is, to contract the energy input into a prawn culture program with the energy output in prawns and to compare it to the energy input and the harvesting results of prawns from the natural areas like Moreton Bay. I wonder if we might be barking up the wrong tree and should perhaps give prawn culturing away but try to maintain our estuaries instead.

Wisely. Water quality does not seem to be much of a problem at present because this particular farm is 300 km from the city.

WORKSHOP

Hancock. We have only one source of Government sponsored research on prawns in Australia which is being done at the Brackish Water Fish Culture Station, NSW, so I thought it was appropriate if we started our session by asking Mr Ian Smith just to fill us in on just how far his experiments have got and we can bear this in mind when we're thinking about where we should go from there.

Smith. So far we've had two full seasons and one season with not much equipment and we're just about into our fourth. We're not as well set up as Galveston, which is obvious since the talk Dr Neal gave us this afternoon. We've drawn techniques from Galveston publications, and also from Japan, to endeavour to raise prawns at the Station.

Techniques; we're growing algae for the protozoeal stage of the life cycle, and the diatoms we've been using have been *Skeletonema* sp. We have had some problem with these so we've used the technique that Fujinaga originally used in Japan, where he promoted a plankton bloom of naturally occurring diatoms in estuarine water in tanks. At the moment we're attempting to isolate our own species of algae from the natural flora. This seems to be a more useful thing to do than to use species which have been isolated in other parts of the world and which don't live normally in the water that we have. We've been using brine shrimp for a large part of our nutrition. It's not cheap but it's convenient to use and it saves getting involved in other facets of nutrition.

We haven't gone much into the juvenile rearing. The initial work was on raising the larvae and I followed Racek's lead in attempting beginning work on *Penaeus bennettae* (the greasyback). This was because I assumed that the larvae would be more hardy because of their natural growth in the estuary as compared with the usual penaeids which spend their larval cycle at sea where the conditions are much more constant. In actual fact this doesn't now appear to be true, as *Penaeus* larvae generally seem to be quite hardy but working with *P. bennettae* was useful because we were able to obtain females of this species with the well developed ovaries in a spawning condition and this allowed us to carry out a lot more work than we would have been otherwise able to do by relying on fishermen and weather to get gravid females from the ocean.

The season before this we were able to grow the greasyback right through its larval cycle and on into juveniles. Some of the last years crop are in ponds now and the males at least have developed testes in a sexually mature condition. The females haven't as yet but they're not at a size at which I'd quite expect that to occur.

We've raised two other species, *Penaeus latisulcatus* and recently *P. plebejus*, to juveniles but we have that only on a small scale and needs repeating so that we can get a larger number of specimens to have a full larval life cycle and be able to describe it.

P. plebejus was raised on a spawning that we brought about on one specimen by removal of one eyestalk contrary to Ridge's experience. The people in Conway have been removing one eye-stalk which presumably has been lowering the level of the ovary development-hibiting hormone sufficiently to kick off ovary in development and also to not kill the animal next moult which if one removes both eyestalks is what generally happens.

That's as far as we've gone at the moment and I've also recently had a look at other laboratories and we'll be restructuring the program as a result of this. We'll probably be involving some form of intensive culture in our research in future. This has advantages for if we're able to produce waste heat or to control temperature in some way because the temperature of latitudes of our laboratory is not ideal for raising penaeids.

Young. I was just interested when you were talking about *P. plebejus.* Was it the female you had brought in from the field, and what was the background behind this spawning?

Smith. It was brought in from the field and we don't know its previous spawning history, whether or not it had spawned, it had an ovary which was developed and it had regressed in the laboratory and it was barely visible at all at the time that one eyestalk was removed. It took about two weeks after that to come back to a good ovary development, but not as large as I would have expected from one directly from the field in a spawning condition. It spawned about two weeks after the eyestalk was removed and it was a fertile spawning.

Young. Why I was wondering about this is because presumably it was carrying a spermatophore. I haven't done any culture work at all, but what I have done on a couple of occasions is bring in a dozen or so adult females with ovarian development and just put them in a bit of a shock condition and within about 48 hours about 50% were almost inevitably spawned.

Smith. This experience has been mentioned earlier by Dr Neal in his talk. That's a fairly normal method of making animals spawn—shock often makes animals spawn—it's used for instance in abalone spawning. They take the water out of the tank and let the sun sit on it for 20 minutes and then put the water back in and they all spawn.

Hancock. Could I ask you if you have any impressions as to whether any of the three species looks likely to be more useful as one of your hatchery species?

Smith. No, we don't know which is more suitable as yet. One needs to know growth rates and also which species are more suitable for the particular set of conditions that you choose to raise them under. This would vary I think from an extensive type of culture to an intensive type of culture. The people at Conway, in Britain, under John Forster, ran a series of tests on eight species and they've chosen *Penaeus monodon* as the species they feel was most suited of those eight for raising in tanks. They're of course, limited in Britain to an intensive situation because of laboratory costs and temperature control. That species is not indigenous to the area anyway. The smaller prawn would be going into a sexual development as it approached market size and if it follows normal growth curves then one would be starting to lose some of the return of your food at the top end of your growth curve so even if you wanted to market a prawn of the size of a school prawn or greasyback prawn then it would probably be better to use a *Penaeus* genus of a larger size and take that section of it's growth curve. So *Penaeus* species in general I think would be more suited than *Metapenaeus*.

Hancock. Another piece of research which has been drawn to my attention in Australia, is by David Moriarty of Queensland University who has been doing something on feeding of prawns. Would you like to say a few words on that now?

Moriarty. I've been interested in what prawns in estuarine areas feed on. Bill Dall said some time ago that he thought the unrecognisable substance that one finds in *Metapenaeus bennettae* for example was bacteria and I've taken this as a research project for a two year fellowship that I have in the Zoology Department at the University of Queensland, to see whether bacteria are important as food. The first thing to do was to see whether they could digest bacteria and, in other words, there's no point in looking to see if they're ingesting bacteria if they aren't of food value to the prawns.

So I've really just begun this work and I've got a few preliminary results which show that prawns can digest bacteria very readily. They assimilate something like 90% of the carbon of the bacterial cell or perhaps a bit more but it figures about 90-95%. So this means that bacteria, if they're ingested by the prawns, would certainly be a major source of nutrition, especially if they can digest all the bacterial cell. I've also looked at blue-green algae briefly and so far I've used just one filamentus type. I've got no idea what it is yet as I haven't had a chance to classify it. But the prawn, if it eats it in a way that gets most of the algae cells into the digestive gland, can digest something like 90-98% of the blue-green algae carbon. Although if the prawn ate the algae in large lumps some of them presumably would not be broken up enough by the gastric mill to get into the digestive gland and would just go straight through. So provided the prawn is given the algae in a way which it could break it up into very small cells, it could also digest the blue-green algae.

So this shows that at least these two common forms of micro-organism that one would get in an estuarine mangrove environment or a seagrass area are probably very important as food. I've only just started this, I hope to be able to say a bit more in a few months time about how they do it and then to look at whether bacteria are ingested in large numbers.

Dall. There's something that's coming out fairly clearly, this is that you just can't say that a penaeid prawn eats this or that, as the Japanese saw where they found that *P. japonicus* was largely carnivore. My own observation on *M. bennettae* which seemed to show that it's a browser and I think the people that have looked at *P. plebejus* seem to feel that it may feed on something like polychaetes. So, there's the ever present problem of resolving what the things do eat so I think we've got to keep this sort of thing in mind when considering the choice of species.

Hancock. I might just raise the point that Dr Neal made in his talk, and that was about this 'indefinable' something which is missing from dead material and it may well be that things like bacteria, algae and so on, combined with the dead pellet type food could produce that little something that could make the prawns grow properly. Now, what I've done is to suggest a list of topics which I've put up on the board here (see below). It's not intended to cover that subject completely, but it seemed to me when talking to Dr Wisely, that these were some of the things that cause problems when people are trying to set up in prawn culture.

PROBLEMS OF PRAWN CULTURE

1. **Choice of species:**
   Rapid growth rate
   High food conversion rate
   Egg brooding or free eggs
   Carnivore or herbivore
   Adaptability to different conditions including crowding
   Experience and success in other areas
   Market suitability
   Indigenous or imported
   Behaviour in relation to harvesting
2. **Cannibalism:**
   How to reduce or overcome?
3. **Disease and parasitic infestations:**
   Which are important?
   How to reduce or avoid
4. **Supply of gravid females and problem of breeding in captivity**
5. **Supply of cheap food**
6. **Possibility for artificial selection:**
   Genetic improvement
7. **Choice of site**
   Natural or artificial, i.e. in terms of food production with or without substratum
   Temperature
   Salinity
   In relation to predator control—
      connection with sea
      possibility for draining ponds
   Need to install pumps
   Water quality
8. **Extent of control and its cost**
   Hatchery rearing of young
   Control of water supply—
     recirculating or not
       Choice of intensive
       or extensive culture
   Supply of food
   Control of environment
   Sand substrate
   Drainable

METHODS OF CULTURE

Extensive culture
  e.g. Pond culture of Indonesia, salt evaporation ponds
  Natural bodies of water
  Low density culture
  Minimal control of:
    environment
    competition
    predation
    strains
  No control of supply of young—all from natural sources
  Natural feeding (with or without natural/artificial food)
  Low capital investment
  Low labour input
  Low and variable profitability

Intensive culture
  e.g. raceways, artificial ponds—Galveston, Hawaii, Japan
  Artificially created water bodies (semi-natural an advantage?)
  High density culture
  Full control—including possibility of artificial selection
  Fully controlled hatchery supply of young
  Artificial feeding (supplemented by naturally developed food)
  High capital investment
  Labour dependent
  Not yet profitable except in Japan

Intermediate system (1)—
  Nearer to extensive culture
  e.g. Mari-farms
  Natural body of water
  Medium density culture
  Poor control of environment, predators, disease
  Seeding with hatchery young

Supplementary feeding
Harvesting by conventional means (trawling)
High capital investment
Labour dependent (high wage)
No profitability yet

Intermediate System (2)—
Nearer to intensive culture
e.g. Ecuador (Mario Cobo)
Artificial/natural ponds—bulldozed earth pond, pumped water
Medium density culture
Good control of predators (draining ponds)
Poor control of environment, disease
Seeding with young from wild
No supplementary feeding
Controlled harvesting by nets, gradual draining and scooping.
Moderate capital investment
Labour dependent (low wage)
Profitability—not yet tested

If you think it a profitable use of our time, we can look at some of these topics and see if we can come up with any sort of answers to the problems raised.

Kirkegaard. Going back to the first part of number one—choice of species—already we seem to be committed to penaeids. I'm in a certain amount of ignorance on this but I see a lot of people do come to the Northern Territory who tell me about the millions of dollars that are to be made culturing penaeids, and tell me that we have lots of the right sort of coast, which I guess is very true. They seem pleased about our tidal regime, they seem pleased about our water temperatures; but from what I've been told of what's been accomplished in commercial trials in terms of yield ratio of food to finished prawn, the palaemonid seems to have it all over penaeid prawns. Now could someone enlighten me on this, e.g. do they in fact have a yield rate on a prepared food of something like 3.6-7 as has been quoted to me for a strain of *Macrobrachium rosenbergi.* I gather this is well in excess of anything that's been achieved with penaeids.

Wisely. We had a look at a system in Honolulu where Fujimuru is culturing *Macrobrachium.*

The pond is less than a half-hectare in size. It's been going for three years and every month he puts in, over the month, about a hundred kilograms of broiler starter pellets. They're a pretty well balanced diet because chicks double their weight in the first week or so and you have everything in the right proportion and they cost about 20-22 cents a kilogram.

The pond itself is an ecosystem. The water is dirty, it looks as though it's got a phytoplankton bloom there. There's certainly a lot of zooplankton there and there are a lot of mosquito fish. Fujimuru said that mosquito fish never get above a certain density. They just dive to the bottom, where presumably *Macrobrachium* eat them.

Once a month he puts a net in and takes out about 90 kg or so of *Macrobrachium.* These are large ones that are getting to the stage where they should go off to market. He also re-stocks when these things are running down a bit. He puts some more postlarvae in. When you work this out you're getting a one-to-one ratio which is impossible so he must be getting something on the side out of the ponds. This, I think, is the key to the whole business.

In a raceway if you're just feeding pellets you can only get what the pellets will give you. In a case like this where you're putting pellets into a pond, you're getting something extra and it might go this way for example, the food pellet could dissolve and produce phytoplankton which could turn into zooplankton or get eaten by mosquito larvae which get eaten by Mosquito fish which die and get eaten by *Macrobrachium.* Mosquito fish are pouring out excretion into the water which can produce more phytoplankton and so it goes on. It could be quite a complex thing.

If you do tank trials on this in a laboratory, the results you'd get would be applicable to closed systems like raceways but I don't think it would be applicable to systems where you're using a pond because you've got this ecological wheel turning along too.

This, of course, brings up the question of what sort of prawns do we want to culture. Do we want carnivores or herbivores? I come out on the side of herbivores because I think that sort of protein is cheaper. We've seen in Japan, that they're stuck with *P. japonicus.* I'm pretty sure this is a carnivore because in the ponds where they're growing, there was a layer of algae over the surface of the sand which was virtually undisturbed. If they had been herbivores they would have browsed it as other prawns would. So they're stuck with a carnivore and have to lay out about $6.60 in food per kg of prawn produced before they start. That's a pretty hefty feed bill. So one of the first things is, do we want a herbivore or carnivore and carnivores are pretty expensive because you're just converting one animal into another.

Neal. I think we have to be pretty careful here about talking about food conversion when in a pond situation where the animals are dependent part on natural foods. We may need another term here rather than food conversion as Dr Wisely pointed out. The system may be very complex and it's been our experience that you may have a very good system at a low density and then the system breaks down as the density increases in the ponds. I question the use of the words 'food conversion' for this kind of a system. I think that I might just mention that in our nutritional work we've worked entirely in aquaria where there's essentially no other food available to the shrimp and with our standard diet we get conversion rates with maybe 3-1 dry weight of the food to wet weight of the shrimp up to sizes of maybe 40 mm total length. Beyond that the food conversion is much poorer and in order to get a shrimp of up to 120 mm our average conversion rates with our standard diet are in the range of 10-1 to 12-1. I don't think that we can select a species on the basis of food conversion at this point simply because we know so little about what's happening in a semi-natural situation or about the requirements of the shrimp.

Hancock. With those remarks we cross one agenda item to another but they're both relevant to choice of site whether we're thinking in terms of an entirely artificial site or a semi-artificial natural sort of site and that's all very relevant to the choice of species that we're dealing with. I wonder if anybody out of their experiences are going to have a stab at listing in order the types of prawn which they believe are going to be the most successful for culture. The sort of things that I've listed that I would look at in choice of species were that they should have a rapid growth rate, they should have a high food conversion rate, and we heard something of the complications of that. We also need to consider whether we prefer a species which is brooding its eggs or one which has free eggs, the question of whether it's a carnivore or herbivore we've heard about, and clearly it should be quite adaptable to different conditions rather than depending on the sort of culture that you want to expose it to. I think also that we might base our suggestions on the success that people have had in other areas. Now would anybody be game to either comment on those or perhaps take a stab and say 'I think penaeids above all' or whatever you like.

Kirkegaard. Could I comment before I pass the microphone over, and carry on my earlier question a bit. My next question to the hopefuls who come to me, is to ask them to which market they're looking. I guess quite a few people here are familiar with the sea-grant studies on raising shrimp for the bait shrimp industry, as against raising (as the Japanese joint venture in the Territory has been interested in) live tigers. The specific market they have offers an extremely high price for a live tiger prawn and the economics of this are most certainly going to be different from the economics of producing bait shrimp for which we don't have a market, and which we would presumably sell in competition with trawlers.

Hancock. I think that maybe somebody would think that we ought to put 'which market' right at the top of my list.

Maguire. I would like to comment on the choice of species. Firstly, the responses of prawns to crowded conditions are important. Secondly, should it be an indigenous or imported species? Whilst the rearing of larvae doesn't appear to be a major problem at all, there can be a problem with obtaining a sufficient number of gravid females.

Temperley. I spoke at some length with Japanese importers a month or so ago in Tokyo and talked in detail about markets of cultured prawns and one point came through quite clearly that at present there is no market for *Macrobrachium* in Japan. In their opinion, and they're the biggest people in the game, there was also no foreseeable future mainly because of the traditional position of the penaeids. I think this is very relevant because although Fujimuru has a limited market in Hawaii, I doubt that that's a very big market. Perhaps Dr Neal can throw some light on this in the States, I think it would take a lot of promoting there, also in Europe there is a lot of doubt. I think that the market is a very important thing to be considered here because it's a trap to consider that all prawns are saleable in large quantities.

Ruello. I'd like to add to Mr Temperley's comments. CSIRO Division of Food Research has recently been testing a consumer acceptability of various species and they've found that the prawn eaters can quite distinctly tell the different species and I think that you've raised a very good point that the selling price of these prawns varies quite a lot. I think that Ian

Kirkegaard brought up the point that we're in fact competing with the traditional fishing industry. For instance here school prawns and greasyback prawns sometimes become unsaleable when the Bay season's on and we have to face up to it that we are competing with the traditional fishing industry.

Hancock. I think obviously that we have to strike a balance between providing for the market and the cost of producing the prawns. I suppose that if penaeids were absurdly difficult and costly to produce then one would have to look to a species which would have to be coaxed on to the market. I'm not sure that I take the point about *Macrobrachium* although it's a good one. There are others who think differently on the basis of market investigations but there would have to be a lot of promotion.

Neal. Just very briefly, I will comment on the market for *Macrobrachium* in the U.S. Essentially it's untested. There are several commercial firms that now feel they can market *Macrobrachium* in the U.S. and they're aiming at a market for the whole animal which differs from our penaeid prawn market which is just for the tails. There is something that concerns me a little bit here, with the *Macrobrachium* species, just speaking generally, the weight of the tail is about 35% of the total weight while with the penaeids it's roughly 60%. If you just had to market the tails this would be a definite disadvantage.

Hancock. I would prefer to divorce the more or less biological questions that I've listed from the market question, but of course at the end of the list it is cost of production which is going to govern success so it would be perhaps useful if we try to think of these partly separately, although we can't separate them completely. From a biological point of view is anybody in a position to say that penaeids are better than *Macrobrachium* in particular looking at our Australian situation. This is one of the reasons that we're wanting to debate it here.

Would it be too naive to think that in terms of the sort of price increases which Dr Neal told us yesterday, and the world demand for prawn material, prawn flesh, that the humble *Macrobrachium* would be ignored in all this? Certainly not at the moment, for we hear of yabbies being sold in Sweden, or at least, freshwater crayfish, for over $8.80 kg for the little ones. I've never eaten a yabbie, but I think we certainly have to balance the efficiency with which we culture these animals with the possible markets.

Young. Just one thing about the marketing. Two of the mixed species of bay prawns are alphaeid species, which of course aren't penaeids, and they are looked on as one of the tastiest forms of mixed bay prawns, so you can't say that just because they aren't penaeids they won't be saleable. You just need to convince the market.

Hancock. Would anybody like to comment on any of the other attributes? I think rapid growth rate is something which we certainly look for. High food conversion rate we would want, but we're not too sure that we're actually finding what it is in the semi-wild artificial conditions. What about species which brood their eggs or produce their eggs free? An interesting point out of this is one person who's trying to culture marron, which broods its eggs, took the eggs from the mother, which we thought was really working uphill. Any comments on that?

Temperley. I think that these are second order problems from what I can gather, the cost of producing postlarvae is a very minor cost in the overall cost of land and wholesaling of prawns, and I think it doesn't matter providing that we can solve the problems. The cost for postlarvae is something less than 22 cents/kg for the harvested form.

Smith. Nobody has actually cultured any species to a market, I believe. This is the first I've heard of *P. esculentus* in the Territory, we've grown three species, and I believe *latisulcatus* is being attempted in South Australia. There's another *P. esculentus* grower in AMATIL operations, but nothing has actually been done conclusively at all.

Hancock. I think what we have to recognise is that there is only one place where prawn culture has been economically viable and that is in Japan and that is with *Penaeus japonicus* in intensive prawn culture. We must separate the extensive culture from the intensive. We haven't really got around to discussing this, but I think anyone looking at future prawn culture in terms of anything economically viable is going towards intensive prawn culture. Would anybody disagree with that? There are these fringe areas where people are attempting to culture prawns in salt ponds, salt extraction works and so on. They all have a hint of mari-farms about them, but it may be possible for this to work by using employees who are working on another job in their spare time, and without too much labour intensity and cost, and ancillary to an already existing enterprise.

Dredge. It strikes me that the only place where these extensive prawn farms can have any chance of obtaining the land area, which is required for them to be viable, is a long way away from intensive culture areas, that is, they're not going to survive close to the city and therefore they're getting well away from marketing facilities. I think we're rather at a loss here without the services of an economist who can give us some advice as to cost structuring of such ventures as extensive prawn farming, but my impression is that salt marsh areas a long way from centres of production wouldn't support extensive prawn farming.

Olsen. I think that for the benefit of the people present, the South Australian proposal is one in which they're going to stock the ponds from *latisulcatus* taken not very far away from the areas of the proposed farm. I think the farm has a freehold property of about 200 hectares. At the present time as I understand there are three or four ponds that are being developed and in the first instance they're not expecting any return from this particular farm under three years. The person who is putting it in has a contract for the development from a Japanese consultative firm and they are supplying all the expertise. They have also designed and created the ponds. I think that it should be mentioned that this is expected to be in operation in the next three months.

Neal. I'd like to add one more factor here. We really haven't domesticated any of these species yet. Personally I hold very high hopes for genetic improvement of the animal and I think, looking at other domestic animals, we can really plan on improving the animals quite a bit once we're able to rear them and conduct selective breeding programs. I guess again I'm just postponing a decision, but I think there's a way each of these adapt to culture. The kind of improvements that we can generate from a species may be very important in selection of a species, but this will be at least several years off.

Hancock. We've heard that probably the supply of gravid females is not going to be an important part in the costing. In practical terms, is this going to be a problem? Is the species which you cannot get to breed in captivity going to be an insurmountable problem? We've heard encouraging things today about the fact that a number of species are being carried through to produce their own young. I guess we need to be convinced that they will continue to do that. Is there any reason to believe they won't and could somebody answer my first question—is there a real problem in not being able to spawn them in captivity? No takers on that one. Well, it will be a question, I guess, which would need to be worked out, perhaps we've 'exhausted' the choice of species subject. I suppose it comes back to the fact that you are still going to experiment with penaeids and *Macrobrachium*. I guess the opportunities for penaeids at this time would depend on prices and market.

Payne. Could I ask the Workshop just what species are being attempted, penaeids, metapenaeids, *Macrobrachium*, or whatever, may, or are being attempted in terms of cultivation in Australia today. This might solve the problem of what species are suitable. I think first of all we've got to get a list of what species have been tried or are being tried.

Hancock. This raises a point. I think there is a certain vacuum perhaps in our knowledge of exactly what is going on in Australia and possibly one of the things that could come out of this meeting is a recognition of this fact. The sort of information that one hears about things going on in the Northern Territory and Western Australia highlights the fact that we don't really have a catalogue of information on this. I would like to say there is a need for it. Would anyone like to answer Mr Payne's question about the species which are actually being cultivated?

Olsen. We do have a positive attempt at farming in the southern area of Australia and this is one that the people do believe is viable. As regards anecdotal evidence, there was a very extensive dredge and refill area on Port Adelaide about three years ago with the pumping of the water and sand from a particular area into an area which was being reclaimed. I think somewhere around a hundred acres. One section of this actually developed prawns of a large size up to a total length of say 200 mm and these were collected by people with scoops and taken away by the kerosene tin-full. So, as far as I know, this is the only anecdotal knowledge that I have of the development of these under artificial conditions. It was reported to us a little late, unfortunately, but the amount that came out would be somewhere of the order of a tonne from this drainage area.

Hancock. There are two points which I listed, cannibalism used to be the one that people seemed to worry about most, but we're getting encouraging information from a variety of sources that cannibalism isn't the bogey that it was once thought. So, I think that we can say that, with advancing technology, cannibalism can be taken care of, at least, with a number of species. Disease and parasitic infestations—I guess the answer to that is a question of understanding, and most culture processes usually recognise these and manage to do something about them.

Neal. I think that diseases are still problems. We know so little about diseases and I don't think we know really what we're getting into. It bothers me quite a bit the way different species are being moved around, some that look promising, like *P. monodon*. A number of foreign species have been introduced into the U.S. and we really don't know what kind of risks we're taking here as far as introducing diseases or running the risk of introduction of a new species and I think it's an area for caution. I do think that we can anticipate problems with disease, particularly as the animals are crowded, e.g. trout—this animal has gone a long way with aquaculture and I think they're still having disease problems. They've done a lot of work and usually they do come up with solutions, but we can expect problems in this area.

Hancock. Anybody else want to comment on cannibalism or any of the other biological factors we've been talking about up to this point?

Smith. As far as I can make out, the Japanese have had considerable experience with disease in hatcheries. They have about six diseases and one thing that did come out of it was that, in nearly all instances, stress seemed to be the key to the issue. If the situation wasn't very stressed then diseases weren't experienced. Of course, this then depends on one having a culture operation which is not too crowded for the animal's physiology.

Neal. The behaviour aspect is something we have done very little on. We know very little about the behaviour of prawns, most is based on the work the Japanese have done apparently rearing up to 2½ kg per sq m with *P. japonicus*. I think that their behavioural problems are probably not serious and our work with *P. aztecus*, would indicate the same that the animals can be crowded very severely without any major behavioural problems.

Olsen. One particular point I think we must recognise is that if this experiment is going on in South Australia, we are not going to get any results out of it under three years because the person who is doing it is doing it as a private person. He has bought the knowledge and I do not think that he is likely to make this available to industry for years, it will be three years at least, before he will know it was successful by virtue of the returns that he is going to get from that particular industry. Therefore I should like to make a particular point—that there should not be a dependence on private enterprise necessarily to carry out some of this work, that it should be institutions that make the results available. I make this particular point because I think that there is a tendency to think that because a particular organisation was doing it, that the information is going to be readily available.

Hancock. On that, I think that our basic system of working is that when Government organisations do undertake research and results are available to everybody. They do, wherever possible I am sure, want the advice and experience of industry, but that is treated with confidence whenever it is absolutely necessary. We do respect the fact that the free exchange is not always possible under these circumstances. Something more on choice of species before I round that one off?

Dall. While we are on the subject of industry, maybe we could have some indication of the magnitude of people in industry that are in fact interested.

Hancock. The level of industry interest—I wonder if I could couple that with our concluding question about what industry wants of the scientist and ask them also perhaps if they are prepared to think about what they are likely to tell us about who is involved and how advanced this has got in Australia as a whole? Summing up on choice of species, I think we should be encouraged by the biological aspect of the species we have in Australia and we have heard that there are 30 different species which we do not know whether they are going to be suitable or not, but certainly amongst those there are a number which are going to have market acceptability. I guess now we could go on to that and when we look at the choice of site, which I use in its broadest sense, and the technique which might be adopted, which I use in the sense of the sort of culture possibilities that I listed, that we should think in terms of species again, in terms of those situations, because there must be differences between species in terms of relationship, we have heard with artificial environments and semi-artificial and so on. Anybody like to start off with that one? Maybe we could start with a question that was put to me today—did I believe that prawn culture will only be successful in the tropics? Now that is a fairly sweeping one—I wonder if anyone would like to take that a little bit further.

Ryall. I think a lot of emphasis has been put on temperature. It is also important to have clean water.

Hancock. That is a good point. What about the difficulties in the tropics—are there such things that would counteract the advantages of high temperatures? Not all parts of the Australian continent would be suitable for tropical species of prawns or to encourage fast growth rate. What about other problems coming out of high temperature in terms of marketing, storage and things like that?

Kirkegaard. Land prices from what I can see are pretty steep along much of the coast of Queensland. Around Darwin for example land is virtually unobtainable. Across Arnhem Land there is the Aboriginal reserve. In Western Australia I am not sure about the land availability. If you must go into the tropic waters do not expect cheap land.

Shanahan. I would like to extend the tropics down to at least as far as the N.S.W. border. I have been measuring the temperatures in the surf. The lowest temperature we have recorded is 18°C and at present it is running at about 23°C.

Young. May I make a point here that the temperature you will get in the surf is going to be very different from the temperature you will get in ponds.

Shanahan. I agree, but this is a matter of technique whether you are going for tanks, raceways, the Shigueno circular tanks, or whether you put up earth ponds.

Hancock. A diversion for a moment—would everyone like to know something about the Shigueno method.

Shanahan. Well, I think most of the people involved with private industry and a couple involved with research institutes have seen them. He has very big circular concrete tanks. His research tanks were about 25 m in diameter and about 2 m deep. There are two commercial farms using 36 m diameter tanks. He uses a continuous flow-through system. One is in the Bay of Kagoshima and the other is near the ocean off the end of the Bay of Kagoshima. They use a substrate in the tanks. They are using sand, and the water drains through the sand back to the ocean. Shiginouye has achieved very high yields but from the Australian point of view it may not be economic because of his diet. When I was there last it was of the order of some 900 yen per kg.

Hancock. We have heard about the physical problems of working in remote areas. I wonder if there are any attractions there in terms of either water quality because the tropics are, even in Australia I guess, more remote from a central community and also the problem of disposing of waste water, because this could constrain your techniques if you are trying to set up in areas where there are very high standards of water discharge.

Payne. I was wondering if anyone had any information on the comparison between artificial food and the exploitation of naturally occurring food in the sea, e.g. by artificial fertilisation.

Hancock. How does the tropics compare with other areas in terms of food supply?

Payne. I think it has greater productivity from the work I have seen.

Neal. In the U.S. we have found we get pretty good growth up to about 75 mm in ponds at densities of 50-100 000 per hectare simply by fertilisation of the water. I might again just preface what I am going to say by the fact that most of the pond work in the U.S. has been done during the summer months when ambient temperatures would be in the neighbourhood of 26-32 degrees. Most commercial efforts and most of the research efforts has so far utilised semi-natural ponds, open ponds, in which they are feeding only a supplement to the diet. They are depending on natural food produced in the pond and they are supplementing maybe at the rate of 2.5% of the weight of prawns in the pond per day. Under these circumstances we have found that growth is very good in low densities but at higher densities growth is poor. I think this may partly reflect out the quality of the food we are putting in as a supplement as well as the dependence on natural food. Generally people have been unhappy with the kind of production they are getting from using this approach and, in almost every case I know of, they are working toward increasing the production per unit of area as opposed to increasing their acreage or trying to expand or increase the scale of the operation. I am not sure if that answers your question.

Smith. I believe these farms are using chicken pellets in some of their operations. The business of different foods, used by different operations are quite interesting. One of the big companies in the States, and who will be moving to North Brazil, is Ralson Purina, who are also stock and pet food suppliers of a very large size, have produced what they call a 'marine mix' which is selling at about 40-44 cents/kg. It contains about 20-25% protein. They are testing this. It binds together well so it does not disperse as much in the pond as a normal stock pellet would. Other people seem to be using things like chicken pellets, but in other words an existing stock food which is cheap but is not a diet prepared especially for prawn growing. No one seems to be suggesting that we can prepare a diet costing as much as the Japanese one does that could effectively be used in other countries not catering for that specialised market, but there is a lot of work on nutrition to be done to get a diet that is anything like optimum for the price.

Temperley. Does anyone know of the efficiency of conversion of these foods?

Smith: I have heard figures ranging from 2.5 to 10 and there seems to be this size variation. There is also one problem that comes up with Zein-Eldin's work in Galveston. She has found that on a standard diet that she is using, conversion was less in a flow-through system than in a recirculated system where organics were able to build up. This would suggest some intricacies of nutrition that we have not got anywhere near.

Neal. The growth is considerably better on natural foods, alive or fresh animal foods, than it is on any of the prepared foods that I am familiar with. I think that with our best diets, when there is essentially no other foods available, ten-to-one would be the kind of thing we would expect. It is very difficult to compare because I do not know whether the calculations were made on a dry weight basis or the percentage moisture here can change rate very drastically. So we should have some kind of a uniform way of talking about conversion rates. But, on ten-to-one I am talking about a food with only a small percentage of moisture, so it is essentially dry weight of food to wet weight of shrimp.

Hancock. We are coming up to an area of formidable evaluation of the efficiency of food and its costs when we hear of squid being used to grow prawns in Japan at $US3.30/kg.

From what we heard from Dr Neal on Friday, this is likely to be complicated by virtue of the fact that you do things with artificial diets but there is quite often that little extra something that seems to be provided by living things which could be bacteria as we heard from Dr Moriarty and so on. So, it is a pretty complex question which has got to be evaluated against cost. But I guess it is a lead into the question I have been wanting to ask about, looking at Table 1, (see page 141) considering all these things, are we in a position to make any judgement on whether any or all of these systems are suitable to Australia? I wonder whether this will be an appropriate time to ask anybody from the industry but please do not comment if you do not want to. How you would go about or how you have gone about selecting sites in Australia and which are the most likely sites to be available?

Dredge. I would like to comment on a point you raised about 5-10 minutes ago related to water quality and that industry should perhaps consider reasonable areas. I think that this is a pretty relevant point and also compounded by the fact that coastal land for development as Dr Wisely spoke of for semi-intensive farming. It is not going to be as easy to obtain these areas especially near populated areas. There is increased pressure on intertidal areas. I think it is going to be very difficult to obtain large areas of such land.

Hancock. A good point, Mike. I was not intending to suggest that industry should go to remote areas, but I wonder if they are finding any constraints on the more built-up areas with tightening controls. It is not that there are not tight controls on undeveloped areas.

Payne. I think that industry's problem is now pollution and the difficulty of finding suitable areas. Not only industrial pollution but other forms as well.

Hancock. There is a serious problem in Western Australia with raised salinities following land clearing which is likely to affect survival as well as aquaculture—in the freshwater environment.

Shanahan. I would say that on the eastern seaboard where we are likely to farm we are co-operating with the Fisheries Departments who may use their influence with the Lands Department to minimise these sorts of problems.

Hancock. Though Mr Shanahan has not had any problems yet with site selection, how would we see it maybe if there were more Mr Shanahan's coming along.

Temperley. When you look at the map and remove areas already in use there is not a lot of land left for large-scale operations. You have to face, not so much what you would like to have, but what you can have.

Hancock. Does this mean that you are having to modify your approach to the choice of method you are going to use and are you finding it more difficult for one approach than another one?

Temperley. It is a combination of both. I think that you have to adapt a technique for available sites rather than look for sites for a pre-determined technique.

Hancock. Would anyone else like to comment on that.

Shanahan. We have land on the Southport Spit and past south of the border with N.S.W. We are constructing a hatchery system based on the Galveston technique and we will be constructing circular concrete tanks based on the Shigueno techniques and using ocean waters.

Ryall. If you apply these same criteria and give up the Shigueno technique you might find sites very difficult.

Hancock. What are the constraints, Mr Ryall? What are the things that are making it difficult for you to find sites that are suitable?

Ryall. Water quality, as you go up the Queensland coast inshore waters generally get shallower nad a bit of breeze will disturb the water and bang goes your water quality.

Ruello. Would anyone like to comment on the effect of rainwater on the salinity of their water.

Shanahan. Yes, in certain restricted areas it has a considerable effect. In Southport after 76 mm of rain the Broadwater salinity dropped down to 17% the normal range was between 32-33% and we detected no change in the ocean salinity and the salinity began to increase some 3 or 4 days after the rain had ceased and it takes a week for it to get back to normal.

Hancock. These have been interesting comments on the availability of sites and I guess the gentlemen who have really been looking for somewhere to put a culture site really know the answers to this at this stage. I wonder if, looking at Table 1, whether anybody would care to say whether they believe that the pond culture, such as practised in Indonesia, or the casual rearing of prawns in salt evaporation ponds, or even going as far as the mari-farm idea, have any place in the Australian system?

Zed. I would like to propose the semi-intensive system. Because of the energy crisis that may be coming up the hot water produced by power stations may be used to increase the temperature and therefore the growth rate in some latitudes and at the same time to use fertiliser to increase the productivity of the ponds. This could be produced as organic nutrients from sewerage treatment works.

Ruello. Listening to that it seems important in this suggestion that you are getting this hot water for nothing.

Zed. At the moment this hot water is going to waste causing thermal pollution problems.

Smith. On that, the temperature that is actually achieved by being next door or borrowing power station water is not all that great. Ralson Purina are on the power station for this sort of a reason and they have access to the intake and outflow water from the cooling system of the power station and I think there is about 5° difference in the intake and outflow—and the power station economics would not enable them to control it too much.

So, your actual rise in temperature is not all that much when you get a little bit of surface evaporation. If you do not, you only get a few degrees above normal water temperatures. It may not be enough.

Zed. But even so, would not there be an improvement in the ambient temperature locally? It would be an improvement especially if control was good enough.

There are problems associated with power stations not continuously supplying the warm water. If an animal is adjusted to this warm water and it suddenly gets cold water again, you can have it killed. This sort of thing does occur.

Hancock. I think we should not get involved too much in thermal effluent discussion. It is certainly a very attractive idea but I guess it is going to have fairly limited application, although who knows later on.

Zed. There are some other problems associted with power stations and these are that they get fouling organisms in their inflow and outflow ducts and you get various chemicals around for four times a year.

Temperley. Mari-farms have a 138 hectare pond that they had connected to a power station but they disconnected it on the grounds that there was nothing in it. Do you know more about that, Dr Neal?

Neal. I do not specifically, but I know near Houston, Houston Lighting and Power, and Texas A. & M. were working together and in cold months when temperatures are critical, they found that the cooling in a 30 m pond was very rapid. There was little benefit from putting the heated water in. As a matter of fact, they developed a gradient from the warm water one end to cool on the other end and the shrimp migrated to a portion that was desirable which made them fairly crowded. The use of heated water may have more applications in a covered system.

Austin. Do they use chlorination in these power stations in America?

Neal. Yes they do.

Austin. How does it affect them? If chlorination is bad for encrustations it is probably bad for crustaceans too.

Hancock. Well, we recognise that there are more limitations than just the supply of hot water-chlorination, pollution and a number of other things also are important. I would like to phrase my question in a different way —people who have shown interest in prawn culture in Australia, would they go for anything less than the ones that I have listed under intensive culture and intermediate system (2), which is bulldozing actual ponds rather like the *Macrobrachium* style in Hawaii? Do you ever see any possibility or economic justification for extensive culture Indonesia type or Mari-farms type which involves trawlers to harvest? Certainly on the showing of Mari-farms, I think we are a long way from knowing that. Would anyone like to comment on that?

Temperley. Can I offer a third alternative, it could be a combination of the both. It seems more logical to go for in-depth cultivation for juveniles and even adolescents. Mari-farms have been in some trouble trying to keep them within 30 km of net. I think that somewhere there is room for both.

Hancock. Are you excluding problems of predation that they have there and harvesting and so on?

Temperley. I have the impression that predation is a minor problem and as far as trawling is concerned I do not think we should knock this. They have demonstrated that this is a fairly practical thing in a large-scale operation. They claim fairly high recoveries and reasonable costs. One of the features is that, provided you do not have high escape losses, they will come back to you.

Hancock. Not with a short-lived species like this, surely? I think that is probably a separate subject—about what size to harvest —because I think that Chris Lucas would like to get his teeth into a pond full of prawns and really get down to understanding their growth and mortality rates, cost and profit, and so on, and really say which is the best size to harvest. I think though, in the Mari-farms idea, you have got all the problems of the wild which we all recognise and it is not a pumped up pond, it is an open one to the environment except for that net. By the Mari-farms system I am talking about the one that is generally known with the open body of water. By pumped up ponds we are coming into the Ecuador system.

Smith. On predation, the use of rotenone is about the only commonly known treatment to get rid of fish predators. It will not get rid of crabs which can be a problem in some areas, but rotenone may not have acceptability for very much longer. Mari-farms were having trouble with Florida State authorities because they cannot of course keep the rotenone in their net operations and any pond operation generally has some flow-through of water. So, putting in slightly used rotenone into the sea is not going to be an acceptable operation and some other method of treatment of predators is necessary and filtration to remove predators on the way in is a very difficult process, especially if you are talking about large volumes of water and big pumps.

Hancock. I think we have gone a fair way with that. It looks as if we are hanging our hats on the more intensive types of culture. Anyone disagree with that?

Temperley. I will disagree with this on the grounds of cost. I think that there has not been much investigation of the capital cost of some of these systems.

Shanahan. I disagree I would go for capital intensive systems from the labour intensive systems.

Hancock. Well, we have just heard some healthy disagreement between our industry representatives on the merits and capital costs of intensive and less-intensive culture. So, at least that is a subject we are not going to answer this afternoon.

There were a couple of nitty-gritties that have been put before me. I do not know really whether anybody would like to answer them after our discussion and after all this investigation that has been going on, is anybody prepared to say that this is or is not the time to start commercial culture of prawns? I suppose really that it is a bit of a rhetorical one because it sounds as though people have already started.

Temperley. Industry does seem awfully coy on this subject. I can only say, speaking from my own experience, that we are still interested in culture, on the other hand it depends in the long run on which way it goes.

Hancock. I certainly accept your point of view on that. One would be sticking one's neck out in terms of what we said on Friday —that there is only one real profitable prawn culture system going on in the world today and that is in Japan, and that is profitable for a reason we know—the high price of prawns. But it is another thing to emulate that with a different species in a different place and we have heard of the problems in the other parts of the world in trying to do just that.

Smith. Any operation that does go on in Australia is essentially a new one because the conditions in Australia will not be the same as anywhere else. I think the only possible way to tackle it would be on a pilot scale initially—if people go in as Mari-farms did on a large scale, on a six months trial period, make extra assumptions, go in boots and all, they could follow with their $9 million as well as Mari-farms.

Temperley. There must be good reasons why Mari-farms are still going, they are very much alive notwithstanding $2 million loss in the first year, a million and a bit the next; goodness knows what they will lose this year because they just do not know what they have in their pond. I think their reason is that the price of the prawns that they are producing is escalating at a greater rate than their production costs increase and I think that this is a thing that everybody is watching.

Neal. We have had a number of groups in the U.S. that have sold stock and so forth, and probably Mari-farms is the most successful. I think as long as they can keep people interested enough, as long as the Securities and Exchange Commission will let them, I think that they can continue, partly on the excitement of shrimp culture and partly on the promise that they are producing shrimp. They produced 226 000 kg in a year, which is pretty impressive, but I think that the sale of stocks is the thing that is keeping them going now.

Hancock. I think I will just record these two questions which are of interest. One of the questions which we put earlier on—should we be putting all our eggs in the one basket on a single species; and the other one—should we really be looking at monoculture at all? Should we not be looking at a mixed culture of different species in the hope that you are going to get side profits from at least one of them?

I do not think it is appropriate to answer those now but they were put to me. Could we then go back to just the final question before we leave and this was taking up the point about really what is the amount of interest by industry in prawn culture. I think we have got probably representatives of three or four different companies here and we have heard of one in South Australia, we know of others.

I hope I have put it in motion that we might get some of this information coming in. So that, I think it helps to make a judgment if you see that several people are perhaps aiming at a particular method or a particular species because it helps one to make a judgment on where one should be putting the research effort.

We have appreciated very much the participation of industry because we realise your problems in baring your souls for us but I think it has been extremely helpful. Could we then ask a final question and that is—what would you like the biologist to be doing? We have heard that someone would like the biologist to be moving into your camp a little bit more. Where would you see that the major effort ought to be? Would you like to see a move from the recruitment area into more the sources of the food and the control of predators—in fact improvement in growth rates and improvements in survival rates?

Temperley. It is important to see work in the area of important environmental controls.

Hancock. So you would like to see some experimental work on the environmental variables related to the particular species in its particular site and method of culture which has been adopted.

Olsen. Again another point has been overlooked. We have talked about predators, we have not discussed competition.

Hancock. So predators and competitors we should be looking at too. It sounds as though industry knows it needs but it is not sure what they are at the moment and would like to see more background research going on.

Harrison. I found it rather interesting that no one raised the problem of government policy towards the development of aquaculture. Aquaculture, as I see it, is going to be a big user of land and water. In both cases it means that large areas of land or water must be set aside by government for the purpose of aquaculture and around these large areas of land even larger areas must be closed off or protected in some way so that other industries can not develop them. I think that although we were right at the beginning and we do not know whether aquaculture will develop or not. I think it is time that policy was decided by government and industry on this one.

Hancock. We did not actually get around to policy on this one. I suppose within the framework of recognising what sort of situations you want, and this came a little bit out of our discussions, then the Government will have a better idea of knowing what presumably the policy would be. I do not know whether we could go into any depth of this at the moment.

Olsen. I think that we should perhaps be looking at having reserves, either aquatic reserves or areas zoned so you have a barrier not only for the maintenance of the ecosystem but also perhaps where primary products can be developed.

Harrison. That raises another issue. We are setting aside fisheries habitat reserves, areas of high marine productivity on which our coastal fish resources depend. If aquaculture is going to base itself to some extent on natural production are natural fishing and aquaculture going to be in competition?

Hancock. I think that is probably a question to resolve each individual application on its merits. We have heard of salt extraction ponds which tend to use prawn culture as a justication for more salt ponds and for taking more nursery areas. I think you have to make a judgment on that.

Smith. Two of the most advanced research outfits on this type of work—the Galveston Laboratory in the States and at Conway in England, have both arrived at the conclusion that in the future the sorts of problems you have discussed here today will push prawn aquaculture to a very intensive and totally enclosed system where the water is reconditioned or, at the very best, is replaced at a very slow rate. It seems likely that we are going to have the same sorts of problems in Australia, and, at least, background research is necessary to decide whether or not this closed system can work. There is a lot of economics to be done on it initially, just to see if there are any real barriers to it taking place at all.

Neal. I would just maybe reiterate that very much the same kind of problems you are talking about, we are up square against—the cost of land is extremely high. I see these things coming in Australia and probably in a shorter time than you would anticipate, for these reasons, we are investigating the very intensive approach and closed systems. I was surprised that no one from industry mentioned the sexual maturation problem—I wonder if you are further along than you are telling us.

SESSION 4

THE COMMERCIAL FISHERY

CHAIRMAN: MR E. O. BURNS

AUTHORS

T. B. GORMAN	J. H. RUELLO
K. J. GRAHAM	A. K. SHARP
D. G. JAMES	F. MEANEY

W. MURRAY

DEEP WATER PRAWN SURVEY OFF NEW SOUTH WALES

T. B. S. GORMAN
Senior Biologist
and
K. J. GRAHAM
Biologist, N.S.W. State Fisheries
211 Kent Street, Sydney, N.S.W.

ABSTRACT

The upper slope zone of the New South Wales coast between the 180 and 730 metre isobaths was surveyed acoustically, and grounds suitable for trawling were defined. Trawling operations were then carried out to discover if prawns in commercial quantities were present on any of the grounds.

The most abundant species was the royal red prawn which was found in commercial quantities between 275 and 685 m. An indicated stock of about 450,000 kg of prawn was calculated for the Sydney-Port Stephens ground.

Problems of handling, processing and marketing the catch are discussed. An assessment is also made of the fish stocks in the area. These were estimated at 5.9 million kg of table fish.

INTRODUCTION

The presence of deep water prawns in the upper slope zone off the east coast of Australia was first noted by Schmitt (1926) when describing material gathered during the research cruises of F.I.S. *Endeavour* (1909-14). Two of the species *Aristeomorpha foliacea* (Risso) and *Hymenopenaeus* (= *Haliporus*) *sibogae* (*de* Man) were subsequently reported off the New South Wales coast in depths greater than 180 m (in an unpublished internal report on the deep-sea prawn survey by M.V. *Challenge*, 1957-60). As closely related species form the basis of two important fisheries overseas, it was thought that these New South Wales species could also occur in commercial quantities.

Additional evidence of deep water prawns was provided by fishermen from Eden, Wollongong and Sydney who supplied the Department with occasional specimens or descriptions of large red prawns. But despite the rapidly increasing demand for prawns and prawn meat no assessment of the commercial potential of these prawns had ever been undertaken by commercial fishing vessels.

An exploratory fishing survey was commenced with the New South Wales Fisheries Department's 26 m research vessel *Kapala* to determine the distribution and magnitude of deep water prawn stocks in New South Wales waters. The program was divided into two phases. Intitially, a series of reconnaissance cruises was conducted to survey the entire New South Wales coastline between the 180 and 730 m isobaths to delineate the extent of trawlable bottom, and to determine if there was any likelihood of prawns occurring in commercial quantities in these areas. The second phase consisted of a quantitative assessment of the stocks on the most promising fishing grounds discovered during the previous reconnaissance.

During both phases, some minor modifications were made to the trawl gear to improve operational efficiency.

In addition to prawn data, information was also gathered on incidental fish catches to make some assessment of latent fish stocks on the continental slope.

FISHING GEAR AND METHODS

The development of the fishing gear and fishing practices used during the two surveys has been detailed in F.R.V. *Kapala* Cruise Reports Nos. 1-4 and 8-14 inclusive.

The headrope lengths of the nets used during the survey were between 19.5 and 22.6 m. This size range was selected to relate the survey to existing prawn trawling methods, as nets of this size are suitable for the average New South Wales trawler.

The basic design of the nets was extremely simple, and took into account the possibility that the working life of the net could be very short. The design utilised standard bales of netting 100 meshes deep by 46 m long with the minimum of cutting and shaping. The original nets had to be modified for various reasons and the final design, which proved most satisfactory, is shown as Fig. 1.

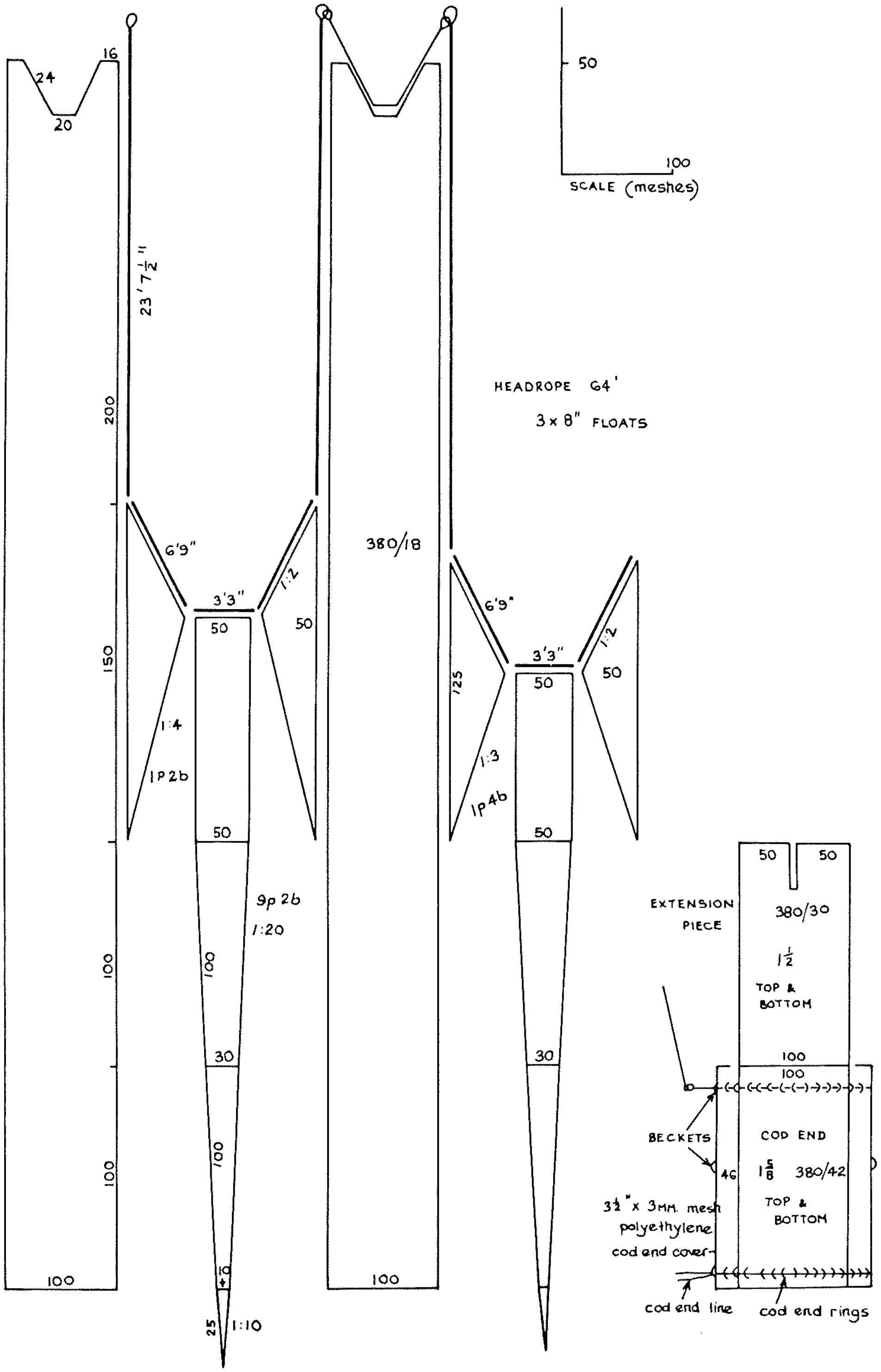


Fig. 1.—*Kapala* 6-seam prawn trawl

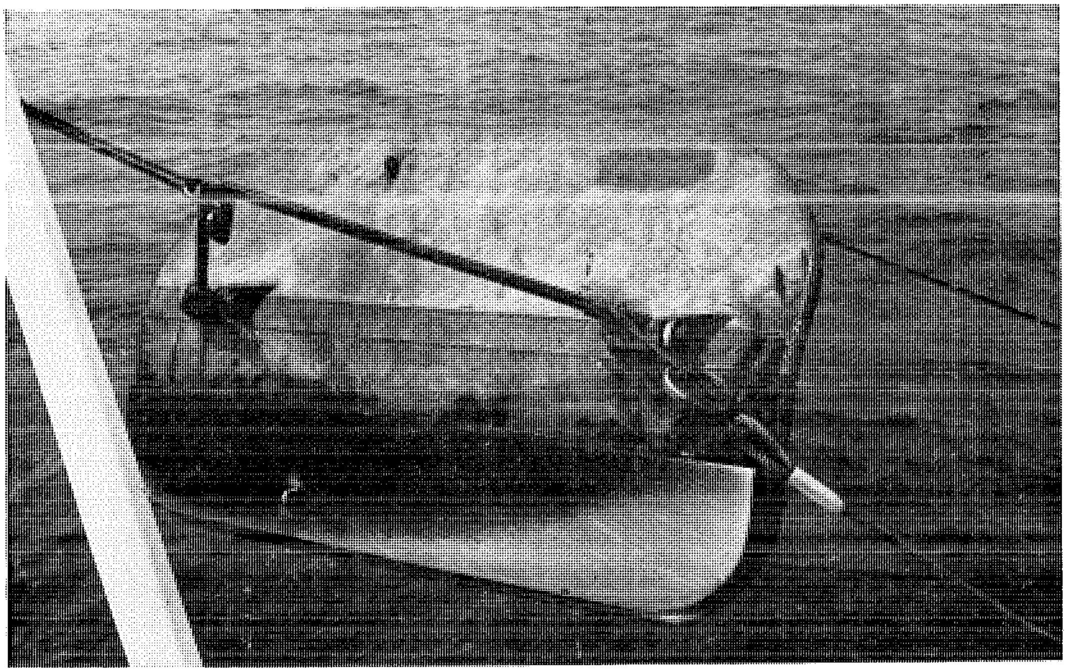


Fig. 2.—Vee-form otter door.

V-form, 1.8 m, steel otter boards (Fig. 2) were used primarily because they are less likely to bog down in soft mud than the conventional wooden ones. These doors have other advantages for exploratory work in that they can ride over rough ground without coming fast, and they are difficult to cross when the gear is being shot. In addition, they do not vary in density as do wooden doors, which can become waterlogged.

The doors were modified by increasing their weight from the standard 172 kg to 308 kg to reduce warp-length-to-depth ratios.

The wings of the net were connected to the trawl door back strops by a 13 m. bridle to make an 'isosceles crowsfoot'.

The bridles were attached by standard G-link and flat link arrangement and the net was shot away and retrieved by a net drum in the conventional manner.

Initially 1464 m warps of 14 mm diameter were utilised. In the final stages of the survey these were replaced by 12 mm diameter 1830 m warps to enable trawling at depths below 685 m. Two 'Olympic' trawl meters model F.M. 750 were used throughout the survey. They were always reliable, regardless of the length of warp paid out, and proved to be far superior to the conventional system of marking warps.

Dynamic warp-tension meters were fitted early in the survey and became indispensable during operations. These enabled us to reduce considerably the number of ineffective trawls caused by incorrect trawling speeds. Varying surface currents were encountered in the survey area for most of the time and by observing the warp tensions it was possible to adjust the surface speed of *Kapala* to obtain the correct ground speed for the trawls.

The normal operating warp load per warp varied between 1000 and 1150 kg regardless of depth. This gave the trawl net a ground speed of between 2½-3 knots. The shaft h.p. requirement for towing was more variable as it depended on the pitch setting of the propellor, but generally it was somewhere between 150 and 200 h.p. We have since fitted an electric/hydraulic pitch control system which will give full repeatability of pitch setting and allow greater precision in shaft horsepower measurements.

NOMENCLATURE

Uniformity in the use of common or vernacular names is obviously desirable, but unfortunately there has been some confusion in the past with both the royal red prawn, *Hymeno-*

penaeus sibogae (Fig. 3a) and the red prawn, *Aristeomorpha foliacea* (Fig. 3b).

Racek, for example, used the name 'royal red' in reference to *A. foliacea* in internal departmental reports. Subsequently Pike and Cooper (1969) referred to *H. sibogae* as the 'jack-knife prawn', and like Racek, used the name 'royal red' for *A. foliacea.*

However, Holthius and Rosa (1965) gave the name 'red prawn' to *A. foliacea,* and *H. robustus* was referred to as the 'royal red prawn'. The latter species is very closely related to *H. sibogae* and forms the basis of a substantial fishery in the northern Gulf of Mexico. The name 'royal red' was adopted by various authors of the U.S. Fish and Wildlife Service in the early 1950s to distinguish the species from the more lightly pigmented inshore prawns, and also from the many wine-coloured species commonly found in deep water.

From the marketing angle the vernacular name 'royal red' is definitely more appealing. Consequently, in the interests of marketing, and the desire for uniformity with an established fishery for a closely related species, the name *royal red prawn* was adopted for *H. sibogae,* and *red prawn* for *A. foliacea.*

The small carid prawn (*Plesionika martia*) was named 'golden prawn' by Pike and Cooper (1969). This name is not considered particularly appropriate as it bears little resemblance to the real colour of this species. In any case, there are several species of carids represented in our catches, so in this survey we simply referred to them collectively as *carid prawns* (Fig. 3c).

EXPLORATORY CRUISES

In the period April to July 1971, 10 cruises were made to establish the extent of trawlable deep water bottom off New South Wales. The sea bottom between the 180 and 730 m isobaths from south of Eden (approximately 38°00'S.) to Tweed Heads in the north (28°00'S.) was surveyed by echo-sounder and by trawl.

Before each trawl, the intended trawling area was surveyed by echo sounder to reduce the chances of gear damage. Unless otherwise stated each trawl was for two hours.

The New South Wales coast can be conveniently divided into three areas:

(1) South Coast—Sydney to the Victorian border

(2) North Coast—Port Stephens to the Queensland border

(3) Mid-Coast—Sydney to Port Stephens.

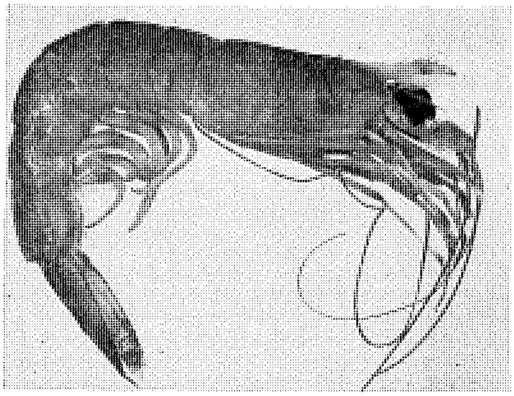


Fig. 3a.—Royal Red prawn *Hymenopenaeus sibogae.*

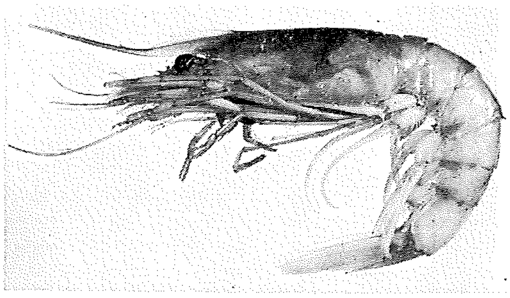


Fig. 3b.—Red prawn *Aristeomorpha foliacea.*

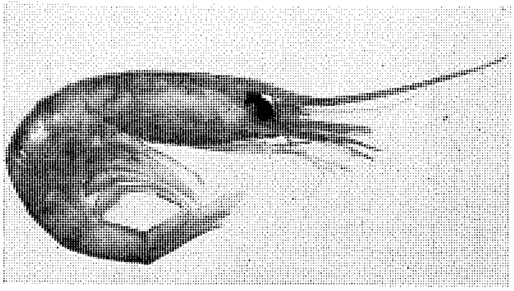


Fig. 3c.—Carid prawn *Plesionika sp.*

South Coast. As indicated on the chart (Fig. 4) trawlable bottom was almost entirely confined to the area between Sydney and Batemans Bay. South of this, only two very restricted areas appeared suitable for trawling. Underwater ravines, not shown on navigational charts, are also marked.

Fourteen trawls were made in this area but prawn catches were generally very low, with the largest catch being 20 kg of mostly red prawns in 365 m east of Kiama. Two trawls in

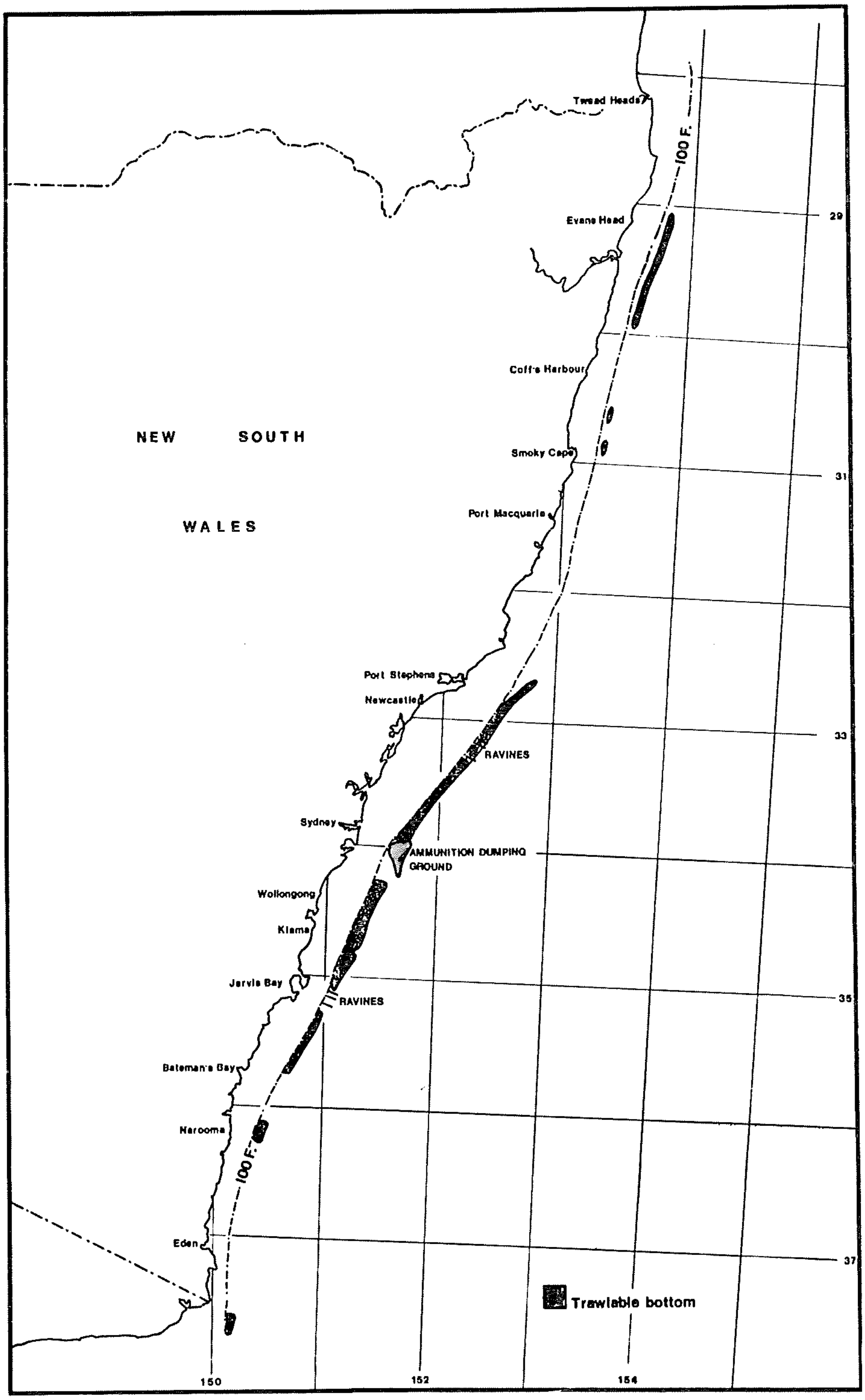


Fig. 4.—Chart of N.S.W. coast showing deep water trawling grounds.

the small area south of Eden caught only about 1.5 kg of small royal red prawns.

Fish catches were generally large, averaging about 450 kg per two-hour trawl.

Very heavy recordings of what appeared to be concentration of bottom fish were made adjacent to and on the trawl ground south of Eden. In addition, extensive midwater echoes were obtained from latitude 36°37′ to lat. 35°32′ which may indicate stocks of fish available to midwater trawling.

North Coast. In common with the south coast, most of the sea bottom between 180 and 550 m off the north coast was found to be unsuitable for trawling. Two small areas east of Smoky Cape appeared trawlable, although with high resolution echo sounding small ridges and troughs were detected. A third, more extensive trawling area was located between latitudes 29°13′S. and 29°57′S. from 320-36 m. This ground is approximately 80 km long, with an area of about 230 km^2

Three trawls were made in this area with mixed success. A daylight trawl in 220 m caught no prawns and a one-hour trawl at night in the same depth produced only about 0.25 kg of prawns, but included 63 kg of the sand lobster *Ibacus altricrenatus*. The third trawl yielded 14 kg of prawns in almost equal proportions of red and royal red prawns.

Fish catches were small, and comprised mainly red ocean perch and deep sea flathead.

Mid-Coast. It was quickly established that this zone included not only the largest trawlable area but was also a zone containing substantial stocks of prawns and fish. Apart from three ravines south-east of Newcastle, and rough ground east of Port Stephens, the entire sea bottom, deeper than 180 m appeared suitable for trawling.

Twenty trawls were carried out in this region. No prawns were caught in waters shallower than 230 m and the best catches were made around 360 m. Five consecutive 2-hour tows in the Newcastle-Port Stephens area yielded almost 270 kg of royal red prawns. Later in the year additional trawls were conducted in this area, with 180 kg of royal red prawns being caught in one of these trawls. Moderate to large fish catches were made at all depths. The trawl which contained 180 kg of prawns yielded 2 540 kg of fish, mainly sharks.

Discussion; Reconnaissance Results: About 5 200 km^2 of the New South Wales upper continental slope was surveyed acoustically and of this area about 2 300 km^2 was considered suitable for trawling. Almost all of this trawlable area lay between Port Stephens and Batemans Bay, and was only minimally restricted by rough bottom and ravines, and areas where ammunition had been dumped (Fig. 4).

The mid-coast area between Sydney and Port Stephens showed the most potential, and good catches of both prawns and fish were made. This is an area of about 960 km^2 lying between 32°45′S. and 34°00′S. The stock assessment phase of the program was carried out in this area. The South Coast to Batemans Bay contained a trawlable area of about 1 000 km^2 and although fish catches were promising, prawn catches were low. However, it should be pointed out that at this stage of the survey, the efficiency of trawling operations by *Kapala* was almost certainly lower than was attained later in the program. Consequently, the stock density of prawns in the south coast area may be higher than was indicated by this cursory survey.

The composition of prawns on the upper slope was different from what was expected. In internal reports it was indicated that the most likely commercial species would be the red prawn. However, it became increasingly obvious throughout the survey that the royal red prawn was the dominant species.

Good catches of fish were made at all stations, except the far north. From most depths small sharks and dogfish were the most abundant species of edible fish, while in some depths significant catches were made of red ocean perch (*Helicolenus papillosus*), ling (*Genypterus blacodes*), and mirror dory (*Zenopsis nebulosus*). Deepsea flathead (*Hoplichthys haswelli*) was also plentiful in most trawls and although it is a good table fish, the rows of spiny bucklers on the dorsal surface, which make filleting difficult, could make this species unacceptable for marketing. Another potentially marketable fish, probably for industrial processing was the cucumber fish (*Chlorophthalmus nigripinnis*) which was caught in good quantities between 360 and 460 m.

STOCK ASSESSMENT

Prawns. Before beginning this survey, the upper and lower limits of distribution of the prawns were not known. Similarly, there was no information on the optimum depths of the deepwater prawn stocks.

However, as the upper slope zone is narrow, with a fairly uniform slope, we adopted a simple survey method of trawling along particular isobaths at 45 m intervals within the southern and northern boundaries of the ground.

Trawling was conducted on a 24-hour basis, often under very adverse weather conditions, particularly during spring and early summer when the weather was very unsettled.

Radar fixes of the start and finish of each trawl were taken as accurately as possible. However, in some instances of extreme range or bad reception it was impossible to obtain more than approximate positions.

The estimated area covered by each trawl was calculated from the product of the trawling distance and half the headrope length of the net (underwater measurements of a half-scale model showed the opening coefficient of the net as 0.5).

The indicated stock densities of prawns for individual trawls were then calculated from the swept area and total prawn catch data. The weights of the edible fish species were recorded and the total trash fish estimated.

Results of prawn stock assessment

Distribution and abundance. The most abundant species was the royal red prawn. Their upper limit of distribution was 230 m, but they did not occur in commercial quantities above 275 m. Very small catches of royal red prawns were made at 825 m, which was about the maximum depth attainable by the gear on *Kapala* during the survey. Thus the lower limit of distribution was not defined.

In contrast to the results of the previous year, the catches of the red prawn were uniformly low and we did not locate the species anywhere in commercial quantities.

The carid prawns were more common in deeper water, and below 550 m they formed the greatest proportion of the prawn catch. However, considerably higher catches of these prawns could have been made if we had used 25 mm mesh cod ends rather than the standard 38 mm.

The best catches of royal reds were made north of the southernmost canyon. During the winter no prawns were caught during daylight but in late winter and early spring consistently good catches were made during both day and night, with the best catches at dawn and dusk.

Indicated stock size. Fig. 5 shows the mean indicated stock density of all prawns calculated as lbs/1000 yd^2 for each 25 fm isobath. Down to 300 fathoms (550 m) the density data refers almost exclusively to royal reds but below this depth it relates mainly to carids.

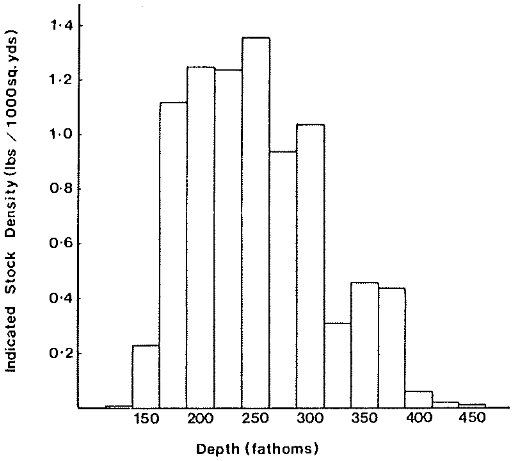


Fig. 5.—Mean indicated stock density of prawns on New South Wales continental slope.

The mean indicated stock density of prawns for the whole area was calculated as 0.61 lbs/1000 yd^2 (0.33 kg per 1000 m^2). As the total area was calculated to include about 960 km^2, the gross availability amounts to about 407 000 kg.

Discussion—Stock assessment. It is important to appreciate that the data on stock densities and gross availability represent minimum values. It is impossible to obtain absolute figures as this would require the assumption that every trawl was 100% efficient and that every prawn in the path of the net was caught.

It is also important to note that catches made during the survey were obtained without any attempt to adopt commercial fishing strategy, which would almost certainly have resulted in greater catch rates on certain cruises. However, on several occasions, catches of 450 kg or more of prawns were made in a 24-hour period. This compares very favourably with the average catches of inshore prawn trawlers in northern New South Wales of about 450 kg per week.

Gross availability of the prawn stocks has been estimated at about 400 000 kg for this ground. By eliminating all trawls which were only partially effective, especially those conducted over 730 m when the warp-load meters were not operating properly, this figure can be increased to the order of about 450 000 kg.

Therefore, our analysis roughly indicates a gross availability of between 400 000 and 450 000 kg of prawns on this trawling ground.

Bullis and Cummins (1962) reported that

Table 1. Comparative catch data of

Vessel	Challenge D.P.I.	Rama C.S.I.R.O.	Kapala N.S.W.
Date	1957-58	1963-64	1972
Area	East. Aust. Coast	Gulf of Carpentaria	Sydney-Port Stephens
Total Catch kg	745	1777	3420
Mean Catch per hour trawling kg/hr	1.6	3.0	26.7
Largest haul kg	54 (banana prawns)	272 (banana prawns)	274 (royal red)
Total hours	468.35	590.44	128
	—	—	

the indicated gross availability for *H. robustus* in the Gulf of Mexico was 349 000 kg for a total of 730 km^2. Using this figure for comparison, this amounts to approximately 480 kg/km^2 while the comparable New South Wales figure is 420 kg/km^2.

These results can also be compared with the *Challenge* and *Rama* surveys conducted by Department of Primary Industry and CSIRO respectively, both of which led to the development of extensive prawn fisheries in Australia.

The mean catch per hour as reported by Kesteven (1965) for these surveys is shown in Table 1, together with some equivalent figures for the *Kapala* survey. The *Kapala* result is based on effective trawls between 275 and 685 m which is believed to represent the commercially viable zone.

The very high catch rate by *Kapala* is probably due to two factors. First, the stock assessment was carried out in an area which had been previously surveyed and later selected because it showed the most potential. Secondly, the ground is a comparatively small area compared with the areas surveyed by both the *Challenge* and *Rama*. Nevertheless, the very high catch rate does indicate a high level of productivity.

The average annual catch of shallow water prawns in ocean waters in New South Wales is about 1.2 million kg. This bed, therefore, which is undoubtedly the largest single prawn bed in New South Wales, has the potential to increase the annual catch by more than 30 per cent.

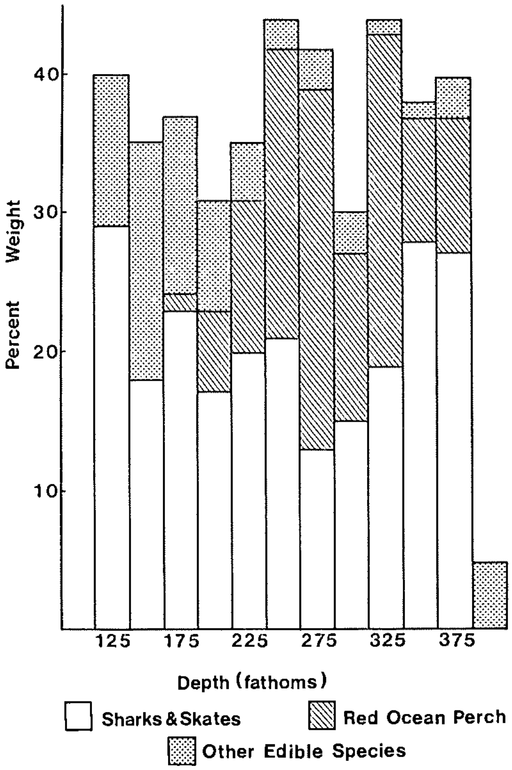


Fig. 6.—Composition of fish catches from New South Wales continental slope.

Fish results. In conjunction with the prawn assessment, a measure of the latent fish stocks on the upper slope was also made for this trawl ground. Fig. 6 shows the proportions of the edible species to the total fish catch.

An indicated stock density for table fish (including sharks) was calculated in the same manner as for the prawns. The mean indicated stock density for the whole ground was 1.76

kg per 1 000 m^2 which represents a gross availability of about 5.9 million kg.

Over the entire area assessed, a mean catch for all fish of 340 kg per hour was made, including about 130 kg of table fish. When only the area considered viable for prawn fishing is considered (between 275 and 685 m) these catch rates are slightly higher (374 kg per hour and 136 kg per hour respectively).

In depths to 550 m catches of over 900 kg were frequent, with one catch of 2 700 kg being taken from 365 m. Below 640 m, only small catches of fish were made.

At all depths, trash or industrial fish comprised the major proportion of the catch. The most numerous were two species of cucumber fish (Chlorophthalmidae), and several species of rat tails (Order Macruriformes). Samples supplied to a pet food manufacturer were reported on very favourably as suitable for industrial processing.

Of the table fish, sharks and skates comprised 15 to 25% of the total catch with two species, the endeavour dogfish (*Centrophorus scalpratus*) and the common or spined dogfish (*Squalus megalops*), forming most of the shark catch. Red ocean perch (*Helicolenus papillosus*) were abundant between the depths of 410 and 595 m. This fish has excellent eating qualities and is expected to market readily.

Several other table species were caught in smaller quantities. Good catches of nannygai (*Centroberyx affinis*) were made down to 320 m, while small quantities of other species such as New Zealand ling (*Genypterus blacodes*) and mirror dory (*Zenopsis nebulosus*) were caught at all depths.

At present about 3.62 million kg of fish are landed annually by trawl and Danish seine vessels, so exploitation of these deepwater fish stocks could significantly increase the New South Wales catch.

HANDLING AND PROCESSING OF PRAWNS

During the exploratory cruises the brine refrigeration system of *Kapala* was not operating and ice was used for preserving the catch of fish and prawns. The fish presented no problem as they were boxed in ice in the usual manner and discharged, usually within 5 days of capture.

On the other hand, prawns presented an immediate problem. They could not be held in ice in a whole state, even for a few hours, without developing black spot which soon enveloped the whole head and large sections of the tail.

Springer (1955) reported a similar problem with the Gulf of Mexico royal red prawn, noting that it was necessary to remove the heads immediately after capture to reduce black spot. We found that if the prawns were treated in this way the tails remained in reasonably good condition for several days, but after 5-7 days they had a marked iodoform flavour.

Royal reds are also very fragile compared with shallow water prawns and their tails are very easily damaged when packed in ice in standard plastic fish boxes.

While the method of heading prawns immediately after capture and preserving them in ice is normal practice in the Gulf of Mexico it differs so radically from the traditional system of handling shallow water prawns in New South Wales that we have some reservations about the method being accepted by New South Wales fishermen.

The red prawns smelt strongly iodoform, even when first caught, and while they were not perhaps as prone to black spot as the royal reds, this iodoform odour made them unacceptable to most people.

The carids were also less prone to black spot but the heads and tails separated easily during sorting of the catch. As with the royal reds they were acceptable if the tails only were preserved in ice, but with carids being so small manual tailing at sea does not appear to be practical.

Later, during the stock assessment segment of the program, the complete refrigeration system of *Kapala* came into operation. The whole prawns were packed into 13.5 kg onion bags and immersed in refrigerated sea water at −1-0°C for periods of up to 7 days. There was considerable loss of antennae and various other appendages, and commonly there was separation of heads and tails. There was also some colour loss from the rather thin shells of the tails, which, though obviously undesirable, is difficult to avoid.

MARKETING ASPECTS

The traditional consumer market in eastern Australia is catered for by freshly-boiled whole inshore prawns, which are supplied daily to State marketing centres. These prawns are firm shelled, with an attractive red colour when boiled. The prawns vary somewhat in quality and even the largest king prawns, which are more suitable for the preparation of prawn cutlets and similar products, are marketed in this manner.

The catering trade on the other hand, which requires prawn tail meat or whole green tails, relies largely on imports, although ever-increasing quantities of tails are being shipped south from northern Australia. Uncooked royal red tails are suited to this sector of the market. The tails peel very easily by hand or by machine, and the meat is an attractive light pink on the outside. Frozen tails can be prepared as crumbed cutlets or similar products but boiling is not recommended as the flavour and appearance is disappointing. When boiled, the attractive red pigment is bleached from the shell. This detracts from their appearance and brings out a distinct iodoform flavour in the meat.

These observations were confirmed by organoleptic tests conducted by the CSIRO Division of Food Research (Ruello and McBride, 1973), in which royal red prawns were compared with eastern king prawns for appearance, flavour and texture. In the freshly boiled form, eastern king prawns were significantly preferred for appearance, flavour and texture over the royal red. However, when presented to the 60 panellists as a prawn cutlet, the royal red prawn was acceptable and significantly preferred for flavour. The report concluded '. . . it appears that the royal red prawns would be very acceptable if presented to consumers in a processed form'.

Leading prawn processors in Sydney were supplied with refrigerated sea water preserved samples and without exception all reported most favourably. Japanese and South African importers have indicated that they would take unlimited quantities.

Some earlier catches by Sydney vessels were sent into the markets uncooked and preserved in ice in fish boxes. As these were quite black, they fetched a very low price. Nevertheless, as shown by our tests, it is easy with proper handling and preserving to produce high-grade royal red prawns for which a good domestic and possible export market exists.

The same comments above apply basically to the carid prawns and even though they are much smaller than the royal reds, they are about equal in size to the smaller categories of school prawns being marketed in ever-increasing quantities in New South Wales. In this regard they are also similar to the European deepwater prawn *Pandalus* sp. which is the object of an extensive fishery in the North Sea and North Atlantic.

The red prawns, however, present problems because of their marked iodoform smell and taste. Similar prawns caught in the Mediterranean are highly esteemed, but to our palates they are almost wholly unacceptable. There may be, however, an export market for this species to Mediterranean countries where the demand is greater than the supply.

COMMERCIAL POSSIBILITIES

There are at present two fisheries for royal red prawns, one in the Mozambique Channel off East Africa and the other off the south coast of the United States. In the Mozambique Channel, South African boats ranging in length from 23 to 30 m make voyages of up to 40 days. From trawls of about 4 hours duration, they can catch up to 100 kg of royal red prawns (*H. triathrus*), but more often catch between 20 to 40 kg (Anon, 1972). This catch rate is much lower than can be expected from the New South Wales fishery.

The United States royal red (*H. robustus*) fishery consists of three grounds in the Gulf of Mexico and off Florida. Boats are double-rigged and range from 17 to 26 m long, similar to many of the existing trawlers in New South Wales. In 1969 the catch amounted to 146 000 kg but only a fraction of the royal red prawn resources available are being utilised (Anon, 1971). In this fishery the distribution of prawns is seasonal with the prawns moving offshore to about 500 m in summer and inshore to about 365 m in winter.

The U.S. fishery has been slow to utilise the largely untapped resource of royal red prawns. Among the reasons are increased outfittings cost for deepwater trawling; initial problems of working in deep water; a reduced yield (55% *vs* 62%) from heads-off royal reds as compared to shallow water prawns; and the hesitancy of the processors in handling the species because of their susceptibility to breakage in existing automated plants. However, with the gradual increase in production some of the problems have been partially solved and it is estimated that up to 450 000 kg of royal red prawns could be harvested annually.

Similar problems to those being experienced in the U.S. fishery will probably face the development of the N.S.W. fishery. The commercial prospects for this fishery compare favourably with those overseas, and off Sydney and Newcastle in particular it would provide opportunity for winter fishing where no inshore prawn fishery exists. While the larger boats in service are suitable, their winches would need to be increased both in power and capacity. Some provision would also need to be made for the installation of a refrigerated sea water system.

With an apparently insatiable world market for prawn meat this fishery could develop into a significant part of the N.S.W. prawn industry. Also, the large fish catches associated with the prawns would provide an additional source of income whether presented as table fish or processed as industrial fish.

LITERATURE CITED

Anon (1972). 'Prawn fishery of the Mozambique Channel, *South African Shipping News and Fishing Industry Review,* 27 (12).

Anon (1971). "The Shrimp Industry. Three major fisheries in the United States,' *Fishing News International,* 10 (1).

Bullis, H. R. J. and Cummins, R. (1962). 'Another look at the Royal Red Shrimp Resource'. *Proc. Gulf Caribb. Fish. Inst.* 15th, pp. 9-13.

Holthius L. B., and Rosa H. jun (1965). 'List of species of shrimps and prawns of economic value'. *F.A.O. Fisheries Tech. Pap.* 52.

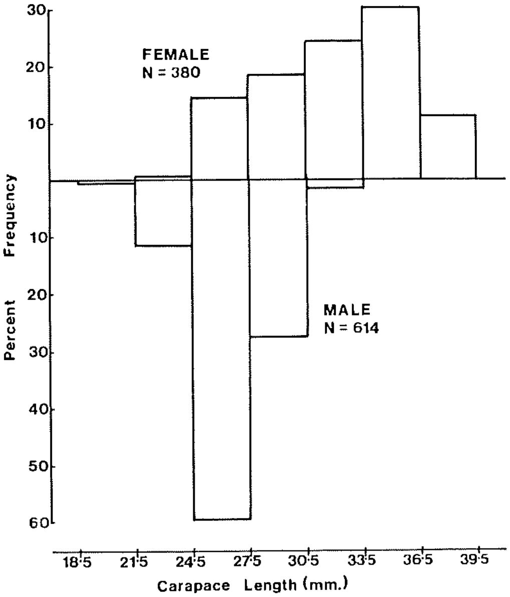
Kesteven, G. L. (1965). 'Tentative assessment of the results of the Gulf of Carpentaria Survey, to 23 June 1964. *Fish. Notes Qld,* 2 (1), Appendix.

Pike R. B. and Cooper R. D. (1969), *Prawn Fisheries Survey Report* (N.Z.) Fish Industry Board 1969.

Ruello J. H. and Mcbride R. L., (1973) 'Consumer acceptability of the royal red prawn, *Hymenopenaeus sibogae*'. *Fisherman,* 4 (9).

Schmitt, W. L. (1926). 'Report on the Crustacea Macrura (Families Peneidae, Campylonotidae, and Pandalidae) obtained by the F.I.S. *Endeavour* in Australian Seas.' *Biological Results of the Fishing Experiments carried on by the F.I.S.* Endeavour, *1909-14.* vol. V, 1926, pp. 309-380.

Springer, S. (1955). 'Exploitation of deepwater shrimp of the Gulf of Mexico'. Proc. *Gulf Caribb. Fish. Inst.,* 7th, pp. 67-71.



Appendix 1. Length frequency of *H. sibogae* on New South Wales continental slope.

DISCUSSION

Potter. You mentioned that you used a 19.5 m headrope net to make your results comparable to equipment being used by present New South Wales prawn trawlers, but you've used different types of otter boards and a much better winch, by the look of it. Would N.S.W. prawn trawlers be able to fish these stocks with the equipment they've got at present or would they need to re-equip with different otter boards and a better winch and so forth?

Graham. Some of the trawlers at present are working down to about 365 m fish trawling. Obviously there would have to be some modification to their gear for prawning and it probably would be an advantage for them to use the V-form boards as we do. Winches in most cases would have to be bigger and more powerful. There would definitely have to be some modifications, but probably not too extensive.

Walker. Would you consider perhaps that the development of this fishery might have to await the further exploration of the shallow water fisheries in the north of Australia before it becomes exceptionally attractive for people to go into the investment?

Gorman. What people fail to appreciate is that these prawn grounds are within 30-32 km of the most densely populated area of Australia. Furthermore, we've actually found that to trawl in deep water is just as easy as to trawl in shallow water. Going back to that point on the trawl boards, we obviously had to adopt a different door, and we believe we made the right choice. Steel doors are much more robust than wooden ones, they cannot become water logged and they are less likely to bog down because of the swivelling bracket arrangement. The cost of these doors is generally cheaper than the cost of the conventional wooden door. I might add a little more to what Ken has just said; the fishermen have actually started trawling in the upper levels of these fishing grounds using conventional trawl doors, and big nets, and have already established a fishery. We think that it will actually be a fishery for fish, with an important by-catch of prawns—quite an attractive by-catch of prawns. One other point I would like to make: Ken used the term refrigerated brine, in point of fact, it was just simply chilled sea water at about −1—0°C. It was not brine.

Hancock. It was interesting to see that you were getting the best catches at dusk and dawn. I wondered whether you have any ideas as to whether it is a burrowing one like the western king prawn or some other behavioural activity, which leads me to suggest that your terminology of mean stocks density is probably not the right one here because it is well known that prawn trawls are grossly inefficient, as a general factor and certainly to have this behavioural aspect to them has got to be more efficient.

Graham. We did not really do enough work to answer any questions on the biology of their behaviour. There was a lot of area to cover and in fact it would take several years to be able to predict whether or not you are going to get more in the morning and evening or at night or in the daytime. We did not have time—it was purely an exploratory fishing exercise looking for a new resource to see whether or not there is a viable fishery out there.

Gorman. The term 'stock density' is in actual fact 'indicated stock density' based on actual trawl catches. It is the basis of all our calculations and is different from the term 'stock density' used by Hancock.

Ruello. Could you tell me how you derived the length frequency. What I am interested in is—do you know what the age structure of these prawns is likely to be? Your samples are very big—are these a pooled sample from say different stations or are they just a lot from one particular cruise? What I am interested in is what is the age structure of these prawns?

Graham. I think those results are pooled from two cruises. They are more applicable to the marketing aspect and can be looked upon as typical size composition of catches from the grounds. They are not biological data to show age classes or such—the prawns were not measured for that purpose.

Gorman. The actual frequency distribution applies only to the prawn survey between Sydney and Newcastle and is pooled from a number of cruises. In fact, we did catch a much greater size range than shown but we had to go much further south to catch very small prawns. The interesting thing is that we have such a limited size range of prawns in this area. Essentially this was an exploratory fishing exercise and we are interested in getting information to industry that industry can use. As you must appreciate these surveys are done in two stages. The exploratory work first and once the fishery develops, you can become a little bit more sophisticated and collect more biological data, if you think it is necessary, and if you can afford it.

Neal. In the Gulf of Mexico we find that the fishermen are generally reluctant to get involved in the royal red fishery. I think primarily because they usually lose several days getting on to the concentration, getting on the stocks, partly because of apparently spotty distribution, partly because of the distance from shore and the depth. Would you see or anticipate similar problems here?

Graham. Our catch rates have fluctuated widely. Our latest catch was about 220 kg for two hours and our average catch for the whole assessment phase was about 22 kg an hour. Just recently we were out spot checking the grounds and we fished specifically in the most productive depths yet averaged only 18 kg per hour. This does indicate that a similar problem may be encountered on these grounds and the fishermen may require two or three trawls to find the best depths each trip. However, we do think that the combination of fish and prawns on these grounds will provide a valuable fishery.

SOME ASPECTS OF THE SHRIMP INDUSTRIES OF DENMARK AND GREENLAND

BY D. G. JAMES
Experimental Officer CSIRO, Division of Food Research,
Tasmanian Regional Laboratory, Stowell Avenue, Hobart, Tasmania

ABSTRACT

The deep sea or pink shrimp (Pandalus borealis) *is the main species caught in Denmark and Greenland. It is found continuously from the North Sea to Davis Strait and in Alaska. The annual catch, made by bottom trawling on muddy grounds at depths up to 500 m is about 15 000 tonnes. Conventional side trawlers ranging from 5 to 150 tonnes are used with hydraulic net drums and trawl winches driven from high powered low revving engines.*

The pink shrimp is fragile and small (100-200 per kg or 45-90 per lb). Since a great deal of effort is involved in handling and processing the catch efficient methods of handling have been sought. Some of these might usefully be employed in Australia, though there are great differences between our industry and that in the northern hemisphere.

In Denmark boats can be out in the Skaggerak for two days, or in the North Sea for 10 days and up to 480 km from the home port. The catch is iced in boxes, thus there is great variation in landed quality. In Greenland most vessels fish by day only and seldom stay out overnight. The catch is boxed without washing and is carried on deck. In winter temperatures are low and no ice is used, but insulated covers are put over the boxes to prevent partial freezing.

When the shrimp are landed at the factory an automatic machine tips the boxes and washes the shrimp before putting them in clean boxes or pumping to another part of the factory. The boxes are washed and returned to the vessel. The result is that the quality of landed shrimp in Greenland is better than it is in Denmark.

Processing plants are modern and efficient in both countries. Most of the production is frozen, but some factories produce canned or glass-packed shrimp as well. Until recently teams of women hand-peeled cooked shrimp, but machine peeling has now been introduced. The most popular machines are those made by the Laitram Corporation in the U.S.A., which peel with a system of rollers and water sprays after a cook of 2 minutes at 96°C. A short belt is used for final inspection and removal of pieces of shell.

INTRODUCTION

The main species of shrimp caught in Denmark and Greenland is the deep sea or pink shrimp, *Pandalus borealis*, which is found continuously from the North Sea to the Davis Strait and also in Alaska. (Smidt 1968) The combined annual shrimp catch from Denmark and Greenland is about 15 000 tonnes which is taken by bottom trawling, on muddy ground, at depths up to 500 m. The total catch includes a small quantity of brown shrimp, taken in shallow water on the Danish coast, which will not be considered here. It is a local delicacy usually marketed fresh, very shortly after catching.

The pink shrimp is cooked and peeled, before retailing as canned or frozen packs. (Aagaard 1968, Hansen 1968). A small quantity of fresh cooked shrimps or cooked peeled meat is also sold. The pink shrimp is very fragile and small, with a count per kilogram of 100 to 200 (45-90 per lb); the yield of peeled meat averages 25% and a great deal of effort is involved in handling and processing the catch. This has encouraged the search for efficient methods of mechanical handling; some of which may be usefully applied in the Australian prawn industry, although there are great differences between our industry and that in the northern hemisphere.

CATCHING

In both Denmark and Greenland the boats engaged in the fishery are much the same. They are conventional side trawlers ranging in size from 5 to 150 tonnes and of wooden or steel construction. Hydraulic net drums are now widely used and trawl winches are driven from the high powered, low revving main engines. The duration of each haul is about four hours and trawling speeds are very slow. A range of other species is taken as bi-catch and this often amounts to a considerable proportion of the total. The cod-end may either be split or the whole haul taken aboard at one hoist and the catch is either dropped on deck or into a tank. Sorting is carried out by hand. Although much effort has been spent in developing automatic sorting machines, the difficulties of removing small flat fish have not been overcome. If the haul is dropped into a tank and this is flushed with water, those fish having swim bladders rise to the surface and can be skimmed off. The larger fish are removed and boxed, while the small fish and other rubbish are either thrown back or made into silage, which will be considered later.

HANDLING

There are differences in handling practices after the catch has been sorted, so the two areas will be considered separately.

1. *Denmark*
   The length of trip for the Danish boats varies from two days in the Skagerrak to two weeks in the distant waters of the North Sea, up to 480 km from their home port.
   As a result there is great variation in the landed quality. The regulations stipulate that the catch must be chilled and either held in plastic boxes or in boxes made from new wood. In practice most of the fleet uses plastic boxes; although the initial investment is high they are durable and easy to clean. After sorting and washing, to remove the heavy dark-coloured mud which causes off-flavours and discoloration to develop in storage, measured amounts are tipped down a plastic tube. This empties into a box, on the floor of the fish room. The boxes have ice in the bottom and after the shrimp have been added they are top iced and stacked. The standard shrimp box is square and shallow so as not to crush the shrimp; it holds 20 kg. Despite the washing, I have found in experiments conducted on the North Sea, that there is almost a tenfold increase of bacterial count between the sea and the fish box. The deck equipment is difficult to clean and bacterial contamination builds up, but careful attention to hygiene can substantially reduce initial bacterial loads.
   After a two-week trip the oldest shrimp have been in ice for about ten days, and are approaching the limit of acceptability. However, as the grounds are becoming depleted it is necessary to stay at sea for this period to catch an economic quantity of around 200 boxes. As a result, the whole catch must be graded for quality on landing and the price varies depending on the expected yield. Peeling yields fall from about 30% when fresh to less than 20% in shrimp which have been held in ice for ten days. It has been found that it is necessary to hold fresh shrimp in ice for about 6-12 hours before cooking otherwise the texture is extremely tough (Hansen 1969). Apart from yield and texture, colour is an important marketing factor. The fresh pink colour of the meat fades in storage, ending up after ten days as a yellowish brown.
2. *Greenland*
   In Greenland trips are of much shorter duration; most vessels only fish during the daylight hours and seldom stay away overnight. The catch is boxed, without washing, and is carried on deck. During the winter, ambient and water temperatures are low and no ice is used but insulated covers are put over the boxes to prevent partial freezing. In the summer, when temperatures rise, ice is sometimes used. When the shrimp are landed at the factory an automatic machine tips the boxes and washes the shrimp before putting them in clean boxes or pumping to another part of the factory. The boxes are also washed and returned to the vessel. As a result the quality of landed shrimp in Greenland is generally better than it is in Denmark.

PROCESSING

In both Denmark and Greenland the processing plants are modern and efficient. Most of the production is frozen but several factories produce canned or glass packed shrimp as well. Until recently the meat was extracted by teams of women hand-peeling cooked shrimp. Following extensive development work, machine peeling has now been introduced; the most popular machines being those produced by the Laitram Corporation in the United States, these peel with a system of rollers and water sprays after a cook of 2 minutes at 96°C. Final inspection and removal of pieces of shell is done on a short inspection belt.

The amount of water used in washing and

peeling tends to leach out salt and some of the shrimp flavour. An attempt is made to replace this by dipping in a mixture of salt and citric acid. Unfortunately the low pH extracts the pink colour and artificial coloring is used for some markets.

Individually quick frozen (IQF) (Aagaard 1973) and vacuum packed frozen blocks of shrimp meat are produced (Hansen 1969). In both cases there is a pasteurisation step before freezing. The IQF lines have only been installed recently and the problem of pasteurisation has been solved by hot water pasteurisation on a moving belt, followed by transfer to another belt for cooling with U.V. sterilised water. (Anon 1972) After cooling the belt transfers to the flo-freeze tunnel with spray glazing at the discharge end, before packing into bags or cartons. The solid packs are prepared by weighing into polyethylene bags and vacuum sealing, before pasteurisation in boiling water and freezing in a plate freezer.

STORAGE EXPERIMENTS

Although chilled sea-water or brine storage is widely used in Australia, particularly in the prawn and tuna industries, its application in Europe is restricted to storage of fatty fish such as herring. A series of experiments was therefore conducted to determine whether chilled sea-water could be used:

(a) To extend storage life and simplify handling in the North Sea Fishery.
(b) To improve the quality of Greenland shrimp in short term storage.

Economics in the North Sea Fishery would be improved if the length of trip was extended and the number of crew reduced, whereas in Greenland, there are new shrimp grounds which can be exploited if storage methods are improved. New stocks of shrimp have been discovered in offshore waters in the Davis Strait. To fish these areas, handling methods must be improved because fishing trips will have to be extended to about five days from the present day trips. As new and larger vessels will have to be introduced, these investigations were timely, as designers of new vessels needed to know whether to incorporate tanks or fish rooms for ice storage. An additional possibility was the design of boats with a number of small removable tanks which could be used as storage containers in the factory, along the lines of the White Fish Authority experiments in the U.K. (Hewitt and McDonald 1972).

RESULTS

The results were in a sense disappointing, as neither method of storage showed a clear cut advantage. Although there were differences in appearance and other characteristics, the results of taste-panel testing showed that quality scores for both treatments fell only marginally for the first five days. Between five and eight days, which was the limit of acceptability, there was a rapid deterioration in quality with both treatments, the chilled sea-water samples being of lower quality. The tasters, who were accustomed to iced shrimp, commented on increasing off flavour in sea-water but preferred the colour and texture of these samples. Hydrogen sulphide developed in the sea-water after six days, which probably explains the off flavour. If shrimp were stored in a mixture of ice and sea-water, with a salinity of 1.5%, there was no off flavour and no hydrogen sulphide.

The bacterial count and the total volatile base (TVB) showed a predictable rate of increase, although the bacterial count when the samples became unacceptable was rather lower than expected. (Figs. 1 and 2.) In all experiments there was a tenfold difference in bacterial count between the treatments, with the chilled sea-water being lower. This can be accounted for partly by dilution and also because only anaerobes can grow in the water. Presumably

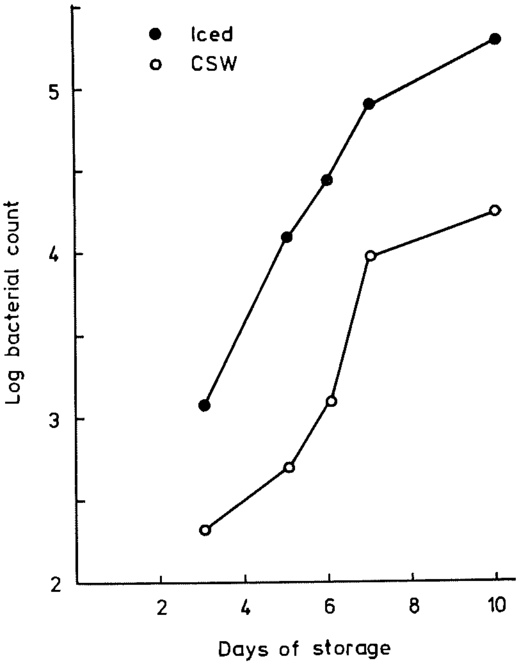


Figure 1. Bacterial growth during storage.

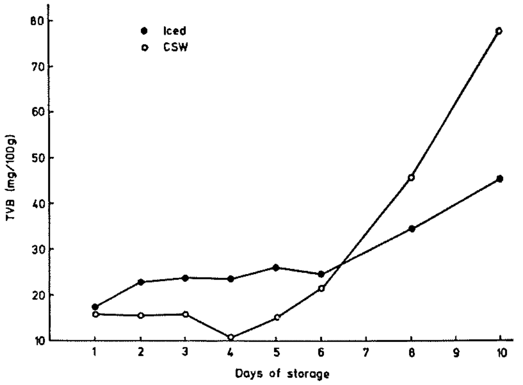


Figure 2. Changes in content of TVB shrimp muscle with storage.

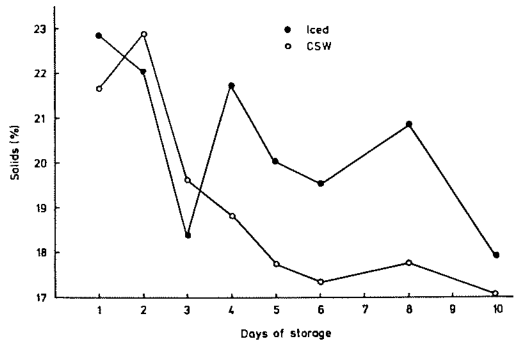


Figure 3. Changes of total solids of raw shrimp muscle with storage.

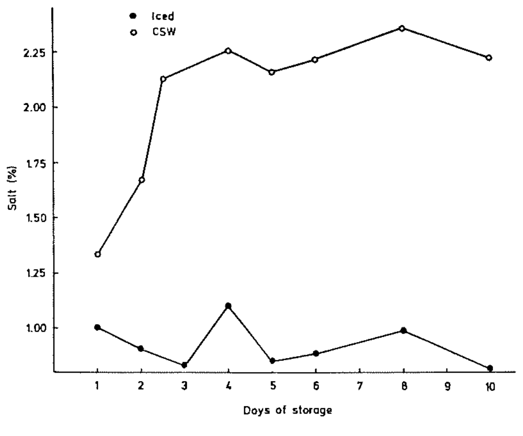


Figure 4. Changes of salt concentration of raw shrimp muscle during storage.

the spoilage association is a small population of hydrogen sulphide producing anaerobes.

The loss of solids (Fig. 3) in both treatments can be accounted for by uptake of water, as the solids of the tank water did not rise and the ice was not melting fast enough to leach out solids. In addition the cold sea water samples absorbed salt which would appear in the calculation of solids so their uptake of water is higher than the samples in the iced treatment (Fig. 4). Weighing before and after storage showed a gain in weight of 8 to 10% after four days in chilled sea-water.

In all these experiments the major consideration was the yield and quality of the cooked and peeled shrimp. This differs from the Australian industry, where the final pack is usually frozen green tails and the consumer has to stand the cooking loss. The figures for yield (Table 1) show that although iced storage maintained a relatively high yield throughout the storage period, the yield from the sea-water samples fell to an unacceptably low figure. As the solids of cooked shrimp were not markedly different the implication is that during cooking, water is lost from both samples, and in addition more water and progressively more solids are lost by the sea-water samples. When allowance is made for differences in salt content the sea-water samples showed a greater loss of solids and weight when they were cooked and peeled. Cooking losses are difficult to establish because of the variable amount of water which remains in the heads, so it is difficult to separate cooking loss from peeling loss. It may be that some meat is left in the shell, reducing the yield of the sea-water samples. These were more difficult to peel, both by hand and machine because of softening of the muscle and shell.

Table 1. Yield of peeled meat for days in storage

Days in storage	*Yield of peeled meat %*	
	Ice	*CSW*
1	26.5	24.3
2	26.3	24.7
3	27.4	22.1
4	25.4	19.7

These experiments showed that both treatments enabled first grade shrimp products to be produced from material up to five days old, but neither treatment offered an extension of storage life beyond nine or ten days. If appearance is to be the main criterion, then tank storage should be recommended, but the economic importance of higher yield probably over-rides eye appeal. Tank storage would not benefit the North Sea Fishery but it could be introduced in Greenland, particularly if new vessels were designed with removable tanks, holding about 500 kg, which could be unloaded from the boat and stored in the factory. However, as ice and boxes are available in Greenland, it may be better to extend the use of ice storage to cover longer fishing trips, rather than to introduce a new technology, requiring mechanical aptitude, to an undeveloped area.

LITERATURE CITED

AAGAARD, J. (1968). 'Frozen shrimp as an end-product', in *Dybhavsrejen*, Fiskeriministeriets Forsøgslaboratorium, Copenhagen.

AAGAARD, J. (1973). Paper presented at the FAO Technical Conference on Fishery Products, Tokyo, Dec. 1973.

FISKERIMINISTERIETS FORSØGSLABORATORIUM. *Annual Report, 1971* Copenhagen, 1972.

HANSEN, P. (1968). 'Canned Shrimp'. in *Dybhavsrejen*, Fiskeriministeriets Forsøgslaboratorium Copenhagen.

HANSEN, P. (1969). 'Handling and Processing of Prawns'. *Fd. Technol. Aust.*, 2, p. 62.

HEWITT, M. R. AND McDONALD, I. (1972). 'Containers for herring in chilled sea-water. *Fishing News Int.*, 11 (12), p. 67.

SMIDT, E. (1968). 'The deep-sea shrimp. Occurrence, biology, fishery', in *Dybhavsrejen*, Fiskeriministeriets Forsøgslaboratorium, Copenhagen.

DISCUSSION

Hillary. Just a few points of interest regarding the Laitram equipment. There are currently three installations in Australia, two on the east coast and one in South Australia, and they are processing most of our commercial species. One installation in Singapore processes down to 500 count, so it is versatile equipment. I believe that there are several installations in South America processing with salt water.

James. That is true, but the major problem with salt water is corrosion from the amount of spray that comes off the machine. We know the people in Singapore well and they asked for advice when they were faced with development problems, particularly excess saltiness and tough texture. For successful mechanical peeling there must be considerable difference in toughness between the shell and the meat in order to separate the shell.

Gorman. (I'd like to make one small point) The carid prawn that we are catching in deep water is very similar to those from Greenland and seem to be available in fair quantities. However, they have a much better flavour which is a good selling point. In my experience the Scandinavian prawns have very little taste.

James. I agree. When they are fresh the flavour is good but flavour and texture deteriorate during processing, particularly because of the amount of washing. A major commercial advantage in Australia is the good flavour and texture. I am trying to point out the comprehensive nature of the industry over there, which has been built up over a long period. They have evolved handling methods which suit their particular industry.

Pane. We are one of three processors on the east coast which have peeling machinery. It does work well as Mr Hillary has said, but not on all types of prawns. On the larger tiger and endeavour prawns it does not work at all and these have to be sorted after peeling. It does however, save time and money. From your pictures I saw that the trawlers had no sorting trays. Is this standard? In view of the temperature are the fish rooms insulated? It would seem a good idea to have an uninsulated fish room in a steel boat in −1°C water.

James. In Greenland they do not use sorting trays but sort off the deck. This surprised me and introduction of a sorting tray was one of my recommendations. In the North Sea fishing everything is sorted over the tray after the catch has been tipped in a flotation tank. The fish with swim bladders float and are skimmed off. This fish and other bi-catch is made into silage on board, by mincing and mixing with sulphuric acid, which is a very simple process. Development of sorting machinery is currently being undertaken. In answer to your second point, there is little insulation in Greenland but the fish is not carried in the hold. It is normally carried on deck, in boxes, which may be covered with an insulated canvas cover to prevent partial freezing. After freezing the yield is reduced so prevention of freezing is an advantage.

Moriarty. I was curious about the origin of the bacteria you were counting. Are these obtained from surface washing. I have no idea how food processors get the bacteria they are measuring.

James. It is important to have the simplest method when doing bacterial counts at sea in foul weather. We shook a weighed sample in a polyethylene bag with sterile Ringers and took out a sample for plating. This compares with results from maceration.

Smith. I am unfamiliar with total volatile base. Could you explain how you measured it and what it indicates?

James. It is an indication of spoilage when the total volatile base rises. Ammonia, di- and trimethylamine are volatile bases, produced during the spoilage of marine products. Many species have trimethylamine oxide in the muscle as an osmoregulatory compound. This compound is broken down by bacteria to form trimethylamine. Ammonia is formed from urea and arginine, also by bacterial action. You can follow the growth of bacteria by using total volatile base as a chemical index of bacterial numbers.

Macguire. You mentioned trimethylamine as a by product of spoilage. Does this apply to other species as well as shrimp? It is supposed to be a food attractant for crustaceans in general.

James. Yes, that would figure for any species feeding on dead fish. All decomposing fish would liberate tri- and dimethylamine.

A STATISTICAL STUDY OF VESSEL AND GEAR USAGE IN THE NEW SOUTH WALES PRAWN TRAWL FISHERY

BY T. B. S. GORMAN
Senior Biologist, New South Wales State Fisheries,
211 Kent Street, Sydney, N.S.W.

ABSTRACT

The fishing boats, gear and practices in the New South Wales prawn trawl fishery were studied. In the study basic data were obtained from questionnaire forms completed under the supervision of departmental inspectors and additional data were collected from field observations. The boats working in N.S.W. are characterised into estuarine, oceanic-estuarine, and oceanic. Compared with overseas vessels trawlers operating in N.S.W. are much smaller and average only half the horsepower. This reflects the different nature of the fishery. At least 14 different net designs were used in N.S.W., the most popular were Siebenhausen, Sad sack, Brooklyn, Sydney Harbour (Italian), and Dawn, made from 400/18 or 400/21 polythene. With regard to the relationships of 1. horsepower to overall length; 2. horsepower to otter trawl headrope length; 3. otter trawl headrope length to otter board area, it was found that considerable variation occurred about the mean of each relationship and that there were significant differences between N.S.W. and overseas practice.

INTRODUCTION

N.S.W. State Fisheries is engaged on a formal program of gear research and exploratory fishing with the basic objective of increasing efficiency and productivity within the fishing industry. A current phase of this study is a general evaluation of fishing boats, gear and practices in the New South Wales prawn trawl fishery with a view to determining what aspects, if any, require further investigation.

The relationship between trawlers and their gear in any one port has always been regarded by fishermen as rather critical, e.g. it is taken for granted by fishermen that trawl nets and trawl doors increase in size relative to the length and horsepower of the trawlers. Nevertheless, very little published information is available on the actual relationship between vessels and their gear, and even the most casual observer can hardly fail to notice considerable port-to-port variation, even when the boats fish the same grounds. This situation demonstrates the empirical manner in which trawlers and their gear have evolved. Obviously, the wastage and conservatism inherent in such empirical evolution can hardly be justified in this era of high capital costs.

To assist the introduction of a more systematic approach to trawling, data relating to existing practices in the New South Wales prawn-trawl fishery have been documented in this report in a manner that makes them readily comparable with data on similar fisheries in other Australian States and overseas. This report will also permit fishermen in New South Wales to compare their own practices with the data in the sample. This paper follows the format of Juhl (1961) who reported a similar study on shrimp trawlers in the Gulf of Mexico.

DEFINITION OF TERMS

Owing to the uncertainty surrounding the terms 'length', 'beam', 'draft' and 'horsepower', it is desirable to clarify these parameters used in the questionnaire issued for the purpose of obtaining information for this paper. The following definitions are based partly on those in common use and partly on proposals by Boden (1966).

Overall length. This is the length, in a straight line, of the main body of the hull, excluding protrusions at the stern and sponsons aft. Unlike water-line length, which varies with loading, overall length is a constant dimension and can be recorded with a fair degree of accuracy.

Beam. This is the breadth of the vessel from outside the planking, at a point where the breadth is greatest. As with overall length, this parameter is a constant one and can be recorded with accuracy.

Draft. Unlike overall length and beam, draft varies with loading and there is frequently confusion about draft marks. The keel is usually raked and the deepest part of the hull below the water line is well aft. In this paper, maximum draft is used.

Tonnage. Tonnage is the measurement of a vessel's weight, capacity or volume. However, very few fishermen or even fisheries administrators are aware of the distinctions between the four various types of tonnage measurements. Tonnage (often not defined) is sometimes used as a basis for restrictive fishery legislation, or occasionally as a parameter for research purposes.

(i) *Gross tonnage.* This is a measurement of volume and it should reflect the true nature of the shape of the vessel, above and below the waterline. To some extent it is arbitrary and subject to manipulation.

(ii) *Nett tonnage.* This is a somewhat arbitrary measure and it is meant to represent the space available for carrying the catch. Nett tonnage is usually calculated from gross tonnage by deducting the ship's machinery and crew space. Generally, it is more applicable to cargo vessels than to fishing vessels.

(iii) *Tons register.* This is the measurement of volume of the vessel in units of 100 cubic feet. Gross and nett tonnages are expressed in register tonnage.

Tons displacement. This is the weight of water displaced by a vessel and is equal to the ship's weight. It is a variable and depends on loading. The most meaningful measure of displacement is displacement loaded. Speed and power requirements are based on design displacement loaded, and a vessel's seaworthiness is frequently dependent on adequate displacement for a given length. Displacement is invariably expressed in long tons.

Horsepower. Engine manufacturers tend to overrate the horsepower ratings of their engines and frequently supply curves showing gross and intermittent ratings, rather than continuous ones. The most widely accepted rating of the high speed diesel engines commonly used in Australian trawlers is referred to as 'continuous' (implying 24 hours per day for 365 days per year) at a specified number of revolutions per minute, and this rating is used in this paper.

METHODS

The basic data were obtained from questionnaire forms completed under the supervision of Departmental inspectors; with the addition of supplementary data obtained in the field by the author.

Both estuarine and ocean-going trawlers are covered in the survey and the data are reported separately, but as a proportion of both groups work in both estuarine and oceanic waters, certain data have been unavoidably duplicated.

RESULTS

The maximum number of trawlers working in the estuaries in any one month during 1966-67 was 124 and the corresponding figure for ocean-going trawlers was 59: these figures do not represent the total number of trawlers, particularly ocean boats, operating in New South Wales in any one year because considerable interstate movement occurs. In the final analyses, forms were completed for 68 estuarine and 79 ocean-going trawlers; consequently the sample represents a high proportion of the total prawn trawling fleet.

Table 1 summarises the principal characteristics of the trawlers and their gear. During the preparation of these data it became apparent that it would be more satisfactory to divide the boats into three categories, rather than two, in order to obtain more realistic averages. These groupings are defined below.

Estuarine. The estuarine group consists of trawlers that fish in the sheltered waters of estuaries almost exclusively. Generally, these vessels are unsuited for working in open water, although in calm weather some do so.

Oceanic-Estuarine. The mixed oceanic-estuarine group contains the medium-sized trawlers that operate freely in either ocean or estuarine waters. Vessels in this group, however, do not normally undertake extended seaward or coastwise cruises in search of prawns.

Oceanic. This group comprises the larger vessels that normally operate exclusively in oceanic waters. It is this class of trawler that compares most directly with interstate and overseas vessels.

It should be understood that these are generalised and somewhat arbitrary categories, and the areas in which the vessels operate could change with new owners, prevailing economic conditions, and other factors.

Unlike the fishery in the Gulf of Mexico (Juhl, 1961), very few double-rigged vessels are used in the New South Wales fishery. This method has not been accepted by the great

Table 1. Summary of characteristics of N.S.W. prawn trawlers and their gear

	Estuarine trawlers			*Oceanic/estuarine trawlers*			*6" or 8" glass floats*		
Vessel	*Range*	*Mode*	*Mean*	*Range*	*Mode*	*Mean*	*Range*	*Mode*	*Mean*
Overall length (feet)	18.0 - 60.0	26.0	25.7	20.5 - 60.0	38.0	38.6	22.0 - 48.0	28.0	32.2
Beam (feet)	6.5 - 16.0	9.0	9.1	8.0 - 16.0	13.5	12.3	6.5 - 14.5	10.0	11.3
Draft (feet)	2.0 - 4.6	3.5	3.4	2.5 - 7.6		4.4	2.5 - 7.4	4.0	3.9
Fibreglass hull	0			1			0		
Wood hull	55			65			29		
Horsepower	7.0 - 72.0	21.0	32.2	13.0 - 150.0		89.9	10.0 - 144.0		55.2
Petrol engine	2			0			0		
Diesel engine	53			66			29		
Mesh size (inches)	1.5 - 1.8	1.5	1.5	1.5 - 3.3	1.5	1.7	1.5 - 2.0	1.5	1.6
Headrope length (fathoms)	3.5 - 9.0	6.5	5.9	4.0 - 22.0	12.0	12.0	3.0 - 16.0	6.0	8.0
Footrope length (fathoms)	4.0 - 8.0	6.5	6.0	5.0 - 24.0	11.0	12.5	3.0 - 16.0	6.0	8.3
Number of floats	30 - 40			1 - 3			1 - 3		
Type of floats	*3" plastic 'corks'*			*6" or 8" glass floats*			*Ocean trawlers*		
Weight of footrope (pounds)	2.0 - 28.0	7.0	7.8	10.0 - 90.0	20.0	40.7	4.5 - 60.0	20.0	27.9
Length doorleg	3.0 - 12.0	12.0	10.6	1.0 - 18.0	12.0	13.0	6.0 - 18.0	12.0	11.9
Ticklerchain	4			2			2		
Boards—height (feet)	1.6 - 3.5	2.0	2.2	1.7 - 4.0	3.0	2.7	1.8 - 3.0	2.6	2.4
Boards—length (feet)	1.8 - 5.0	2.0	3.6	3.5 - 8.0	6.0	5.9	3.0 - 7.0	5.0	4.8
Board—weight (pounds)	28.0 - 150.0	80.0	79.1	48.0 - 440.0	150.0	169.0	30.0 - 240.0	150.0	112.5
Total boats in sample	55			66			29		

Table 2. Summary of characteristics of single-rig Gulf of Mexico prawn trawlers and their gear (after Juhl 1961).

	Range	*Mode*	*Mean*
Length overall in feet	38 - 82	54 - 67	60.0
Beam in feet	12 - 24	18	17.5
Effective horsepower	80 - 585	165 - 170	184.0
Headrope, length in feet	40 - 99	40 - 60	71.0
Footrope, length in feet	50 - 110	70 - 93	79.0
Footrope, weight in lb.	10 - 100	30 - 50	46.0
Mesh size (synthetic)	1¾ - 2¼	2	—
Height of trawl doors in ft.	2.16 - 3.66	3.33	2.97
Length of trawl doors in ft.	5.5 - 11.0	8.0	7.82
No. of floats	0 - 11	3	3.6

majority of the trawlermen in this State despite the almost universal acceptance of double-rig trawling in similar fisheries elsewhere. The reasons for this are not clear, and very little objective data are available on the comparative merits of both systems in New South Wales. Considering its wide acceptance elsewhere it is hard to believe that it would not be an economically sound practice to adopt double-rig trawling on a much wider scale in this State.

The characteristics of the New South Wales single-rig trawlers may be compared directly with their counterparts in the Gulf of Mexico (Table 2).

Compared with fishing vessels overseas trawlers operating in New South Wales waters are considerably smaller and average only half the horsepower. This size variation reflects the main difference in the nature of the fisheries, in that New South Wales vessels return to port every day to unload and the time spent on the grounds rarely exceeds 12-14 hours daily, American vessels remain at sea for several days at a time. New South Wales trawl nets are much

Table 3. Otter Boards—Measured angle of attack for three trawlers

'Rodney J'		*'Big Weld'*		*'Mora'*	
Port	*Starboard*	*Port*	*Starboard*	*Port*	*Starboard*
26°	25°	40°	45°	15°	15°
20°	25°	40°	45°	15°	10°
20°	24°	30°	40°	25°	15°
20°	24°		40°	20°	20°
	23°		35°		10°
			38°		
			35°		
			35°		

larger for a given horsepower and they are made from netting of smaller mesh size. New South Wales trawl doors are larger than the American ones in the 10 to 120 hp range, but above 120 hp the American doors are larger.

The New South Wales trawl nets are different from those used by the Americans, and details of these have been published by Gorman (1966) and Lorimer and Innes (1969).

Questionnaire answers revealed that at least 14 different net designs were used in New South Wales, although most of these were simply variations of the more common types. The most popular were the *Siebenhausen*, *Sad Sack*, *Brooklyn*, *Sydney Harbour (Italian)* and *Dawn*, made from 400/18 or 400/21 polyethylene.

Unlike most trawl nets used overseas, these trawls have very little overhang and the difference between the footrope and headrope lengths rarely exceeds 0.9 to 1.2 m.

The numbers of floats and footrope weights are slightly greater in New South Wales nets, relative to headrope length, and tickler chains are rarely used.

New South Wales trawl doors differ in their proportions when compared with the American ones and there is considerable variation from normal American practice in regard to their usage on nets.

In New South Wales fishing practices the warp length to depth ratio is usually 3:1 or 4:1 in 55 m and over, but in shallow water it may be increased to 6:1 to 7:1.

Echo-sounders are fitted on all ocean-going trawlers but only rarely on estuarine boats in New South Wales.

Radio location aids are seldom used.

Answers to questions relating to tonnage in the questionnaire indicated clearly that very few fishermen knew what was meant by the terms, and furthermore that the terms are not ones in everyday use. Thus, no precise relationships could be calculated from their answers.

The figures in the Appendix illustrate the *vessel-to-vessel*, *vessel-to-gear*, and *gear-to-gear* relationships for the trawlers. As these data deal with individual values rather than means, it is convenient to consider only two classes of trawler, namely estuarine and oceanic. The data have been grouped accordingly and the intermediate group comprising oceanic/estuarine trawlers have been duplicated by being included in both sets of data. Each figure is largely self-explanatory but some brief comments have been included where necessary.

Lines of best fit have been calculated for each set of relationships, but at this stage they should not be regarded as the most efficient combination, but simply a mathematical average of generally accepted and successful operational practices. They also provide a ready means of comparison with similar data from interstate and overseas.

The comparative data on the figures are drawn from data published by Dickson (1958), Juhl (1961), Miyamato (1959) and Garner (1967).

ANGLE OF TRAWL DOOR SET

The angle of trawl door set was calculated according to the method described by Juhl, and this gave an absolute range of 19.5° to 85.5°, with a mean of 46°, for both New South Wales estuarine and oceanic trawlers.

However, as Juhl pointed out, this method does not give a true angle of attack. A more accurate and direct method is to trace the scratches on the shoe of the door onto a celluloid strip. The angle of attack can then be read directly from the strip using a protractor. Port and starboard replications for three trawlers were obtained in this way and the overall range was 10 to 45 degrees with significant differences of the angle of attack for three vessels (see Table 3).

CONCLUSIONS

The most generally accepted critical relationships in regard to prawn trawling vessels and their gear are:

1. *Vessel-to-vessel*—Horsepower to overall length.
2. *Vessel-to-gear*—Horsepower to otter trawl headrope length.
3. *Gear-to-gear*—Otter trawl headrope length to otter board area.

Any variation of these parameters from the accepted norm of a port is usually regarded as tantamount to heresy by local trawlermen. However, the data clearly show that there is considerable variation about the mean for each relationship and also significant differences in practice compared with overseas fisheries.

It would be economically sound, therefore, to determine optimum values for these variables, with the immediate objectives of reducing costs and possibly increasing catches by standardisation of both boats and gear.

In this respect it is of interest that until very recently no information was available on dynamic or static loads imposed by trawling gear, or the power required to tow gear of various sizes at optimum speeds. Information of this nature is also essential for the design of winches, deck gear (including gallows) and propellers.

Instruments to measure these forces are now being produced commercially for large trawlers but equipment for small vessels is not readily available. A program to study these parameters now being undertaken by the New South Wales Fisheries Department should be of immense practical assistance to the industry.

The advantages and disadvantages of double-rig trawling have been clearly demonstrated overseas and interstate. In general, it has been found that the advantages outweigh any disadvantages, and the method has been almost universally adopted outside New South Wales.

The question then arises as to whether this is due to unique conditions or simply conservatism on the part of New South Wales fishermen. The answer might be found in an objective study, which could be fully justified by the immediate benefits that would accrue to the industry if double-rig was proved successful.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of the Departmental inspectors who interviewed trawler owners and operators and otherwise assisted in assembling the data; Dr D. D. Francois and Margaret Francois who authorised the study and processed the data respectively; and Dr W. B. Malcolm, Dr A. Pollard, Mr R. Grainger and Mr A. J. Collins who edited the text and checked the data for accuracy.

LITERATURE CITED

Dickson, W. (1958). 'How to match trawl size to engine power on inshore vessels'. *World Fishing* 7 (7), pp. 47-49.

Miyamato, H. (1959). 'On the relation between otter trawl gear and towing power', in *Modern Fishing Gear of the World* (H. Kristjonsson, ed.) Fishing News (Books) Ltd., pp. 248-250.

Juhl, R. (1961). *A study of vessel and gear usage in the shrimp fishery of the south-eastern United States.* U.S. Dept. of Interior, Fish. and Wildlife Service.

Boden, C. (1966). Proposals regarding measurement of Australian fishing vessels. Technical meeting on fishing boats, Broadbeach, Queensland, Australia, Paper No. 2.

Gorman, T. B. (1966). 'Prawning in New South Wales'. Part 1. *World Fishing* 15 (10), pp. 58-60.

Gorman, T. B. (1966). 'Prawning in New South Wales'. Part 2. *World Fishing* 15 (10), pp. 44-46.

Garner, J. (1967). *Modern deep sea trawling gear.* Fishing News (Books) Ltd.

Lorimer, P. D. and Innes, W. J. (1969). 'Australian prawn trawling gear'. *Australian Fisheries Paper,* no. 6.

APPENDIX

1. OCEANIC PRAWN TRAWLERS—SAMPLE SIZE 79

Vessel to Vessel Relationships

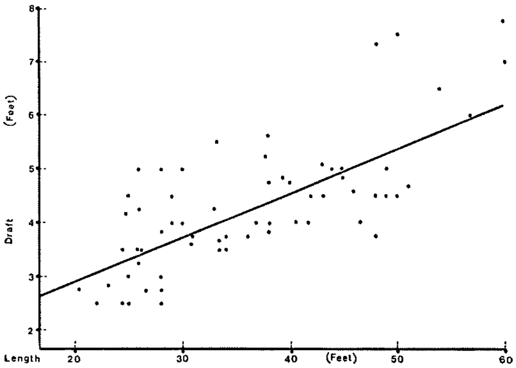


Figure 1. Draft to overall length.

Draft in inches = 14.92 + 0.0824 × length in inches.
Coefficient of correlation = 0.7332.
Standard error of regression coefficient = 0.00871.
Standard error of estimate = 9.004.

Trawlers operating from northern New South Wales rivers are restricted in draught and hull depth by the depth of water on the bars located at river mouths. This has, in return, restricted propeller diameters and kept propeller revolutions comparatively high; the reduction ratio between engine and propeller shaft seldom exceeds 2:1 or 2.5:1.

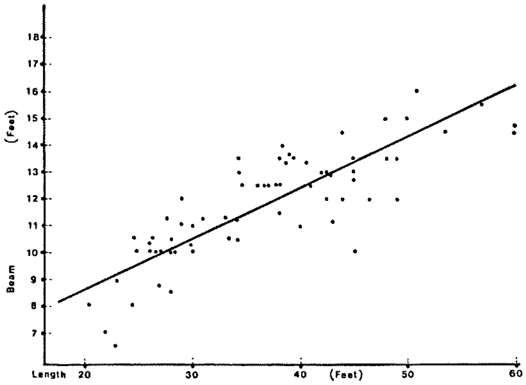


Figure 2. Beam to overall length.

Beam in inches = 58.58 + 0.1896 × length in inches.
Coefficient of correlation = 0.8865.
Standard error of regression coefficient = 0.01128.
Standard error of estimate = 11.658.

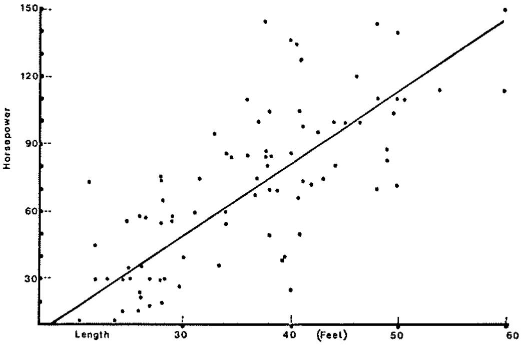


Figure 3. Continuous horsepower to overall length.

Horsepower = −51.54 + 0.2754 × length in inches.
Coefficient of correlation = 0.8123.
Standard error of regression coefficient = 0.02253.
Standard error of estimate = 23.2862

Juhl (1961) demonstrated the lack of standardisation in American shrimp trawlers. However, his data showed that many in the 40 to 70 ft class were fitted with engines of 120-190 hp, while the mean for all vessels was 184 hp. On this basis, American trawlers are fitted with more powerful engines than those in New South Wales.

Vessel to Gear Relationships

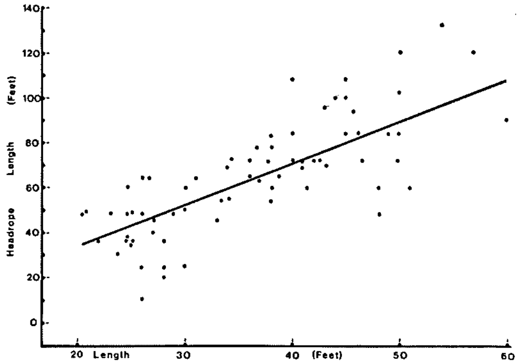


Figure 4. Otter trawl headrope length to overall vessel length.

Headrope length in feet = −3.407 + 0.1556 × vessel length in inches.
Coefficient of correlation = 0.7511.
Standard error of regression coefficient = 0.00559.
Standard error of estimate = 16.109.

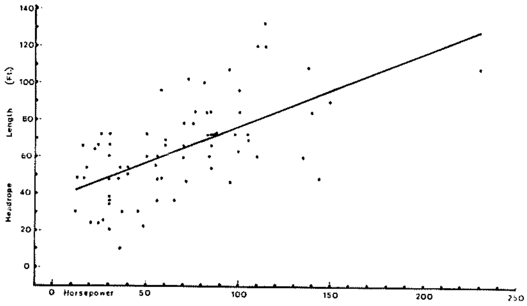


Figure 5. Otter trawl headrope length to horsepower.

Headrope length in feet = 37.73 + 0.3910 × horsepower.
Coefficient of correlation = 0.6398.
Standard error of regression coefficient = 0.0535.
Standard error of estimate = 18.75.

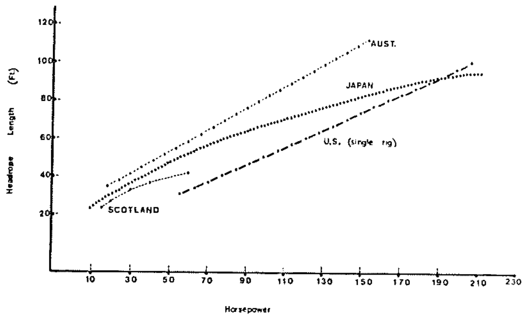


Figure 5a. Otter trawl headrope length to horsepower for Australian and overseas vessels.

Compared with single-rig American trawlers, Fig. 5(a), New South Wales vessels use, generally, much larger trawl nets, but the data are scattered and there is clearly wide variations among fishermen. The line for the American trawlers was computed from the relationships described in Figs. 5 and 7 of Juhl's paper.

The curve for Japanese trawlers is derived from the formula $L = \sqrt{43.6P} + 660$, given by Miyamato, where L = length of the headrope in feet and P = the horsepower of the engine. The curve for small Scottish fishing vessels was derived from data provided by Dickson and possibly applies to fish trawls rather than prawn trawls.

The interesting feature about this comparison is that Japanese data only barely approximate those describing Australian practice, but even this similarity is restricted to the lowest horsepower range, after which the Japanese curve drops away to intercept the American one at 190 hp.

This relationship is generally considered to be most critical but it is apparent from the data that wide variations do occur.

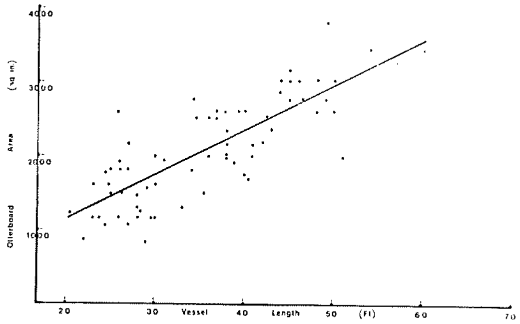


Figure 6. Otter board area to overall vessel length.

Otter board area in square inches = 93.64 + 5.0750 × vessel length in inches.
Coefficient of correlation = 0.8358.
Standard error of regression coefficient = 0.3799.
Standard error of estimate = 392.64.

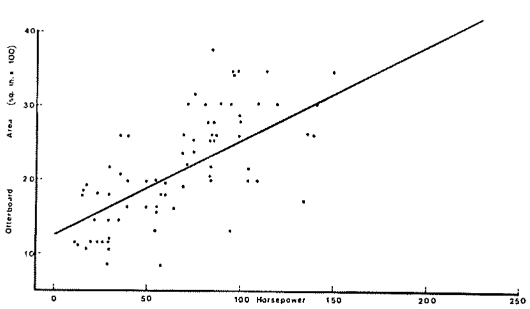


Figure 7. Otter board area to horsepower.

Otter board area in square inches = 1254.2 + 12.66 × horsepower.
Coefficient in correlation = 0.7068.
Standard error of regression coefficient = 1.444.
Standard error of estimate = 505.9.

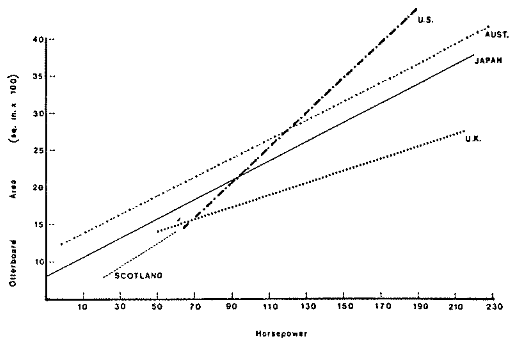


Figure 7a. Otter board area to horsepower for Australian and overseas vessels.

The comparative lines of best fit in Fig. 7(a) are particularly interesting, considering that the relation of door area to horsepower is generally regarded as the more critical of vessel-to-gear relationships. Nevertheless the differences demonstrated by this figure show clearly that there appears to be considerable latitude between countries.

American doors, in particular, are smaller than the New South Wales ones in the 10 to 120 hp range but above this figure they are significantly larger. However, American nets are considerably smaller than Australian ones for similar hp and generally their mesh is larger, i.e. 50 mm, rather than the 41 to 38 mm usually found in Australian trawls. Japanese doors, although slightly smaller, closely parallel Australian doors in area, while those of Scotland and the remainder of the United Kingdom are considerably smaller.

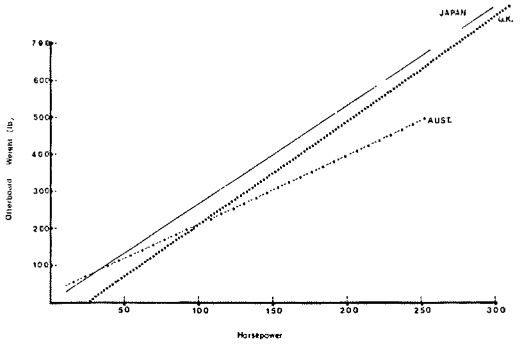


Figure 7b. Otter board weight to horsepower relationships for Australian and overseas vessels.

The line in Fig. 7(b) *Otter board weight to horsepower relationship,* was drawn from the combined data shown in Fig. 7 *Otter board area to horsepower,* and Fig. 10 *Otter board area to otter board weight.*

New South Wales trawl doors in the 100 to 250 hp range are considerably lighter than either Japanese or British ones.

Gear to Gear Relationships

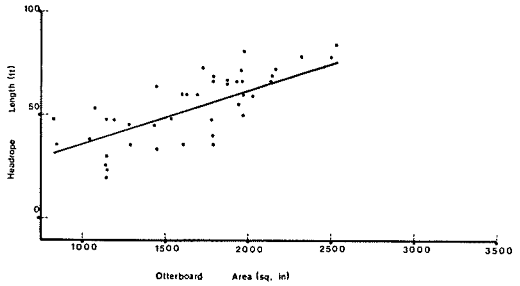


Figure 8. Otter trawl headrope length to otter board area.

Headrope length in feet = 10.35 + 0.0256 × otter board area in square inches.
Coefficient of correlation = 0.7487.
Standard error regression coefficient = 0.0026.
Standard error of estimate = 16.18.

Figure 8a. Otter trawl headrope length to otter board area of Australian to overseas vessels.

This is also regarded as a critical relationship and yet the data in Fig. 8(a) demonstrate that American trawlermen use a much smaller trawl door than their New South Wales counterparts. Scottish fishermen, on the other hand, use similar doors over the smaller range of door sizes.

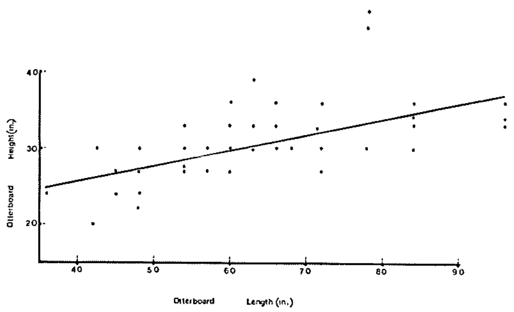


Figure 9. Otter board height to otter board length.

Otter board height in inches = 17.38 + 0.2054 × otter board length in inches.
Coefficient of correlation = 0.6825.
Standard error of regression coefficient = 0.0251.
Standard error of estimate = 3.381.
In Europe the standard rectangular door normally conforms to the accepted length-to-height ratio of 2:1. However, New South Wales prawn trawl doors clearly vary from this standard.

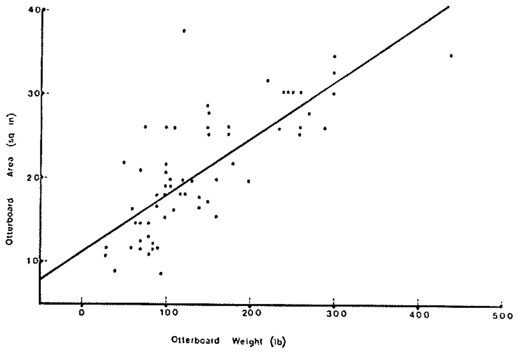


Figure 10. Otter board area to otter board weight.

Otter board area in square inches = 113.21 + 6.714 × otter board weight in lb.
Coefficient of correlation = 0.7789.
Standard error of regression coefficient = 0.616.
Standard error of estimate = 448.5.

2. ESTUARINE PRAWN TRAWLERS—SAMPLE SIZE 68

Prawn trawling is permitted in a number of estuaries. Prawn trawl nets used in these waters are restricted to a maximum headrope length of 6 fathoms (11 m) which places an artificial restraint on the other variables. Nevertheless, the data demonstrate that all the relationships vary significantly from those of the ocean-going trawlers. As noted elsewhere, the larger vessels in the estuarine category trawl in open waters and details of their gear are included.

These vessels appear to be somewhat unique, and as comparable data on similar fisheries have not been published no comparisons are possible.

As might be expected, the absolute values for the various relationships are somewhat lower than those for ocean-going trawlers of the same length.

Vessel to Vessel Relationships

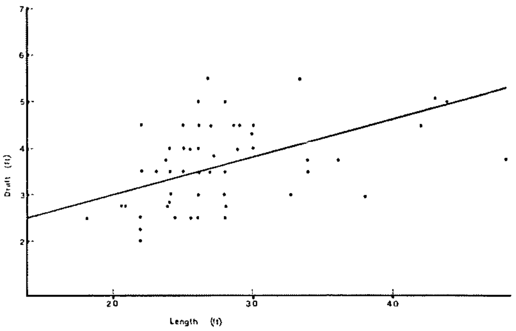


Figure 11. Draft to overall length.

Draft in inches = 16.68 + 0.0813 × length in inches.
Coefficient of correlation = 0.5327.
Standard error of regression coefficient = 0.0159.
Standard error of estimate = 9.46.

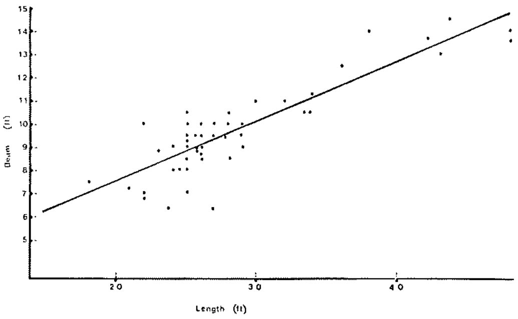


Figure 12. Beam to length.

Beam in inches = 29.76 + 0.2576 × length in inches.
Coefficient of correlation = 0.8684.
Standard error of regression coefficient = 0.0181.
Standard error of estimate = 10.78.

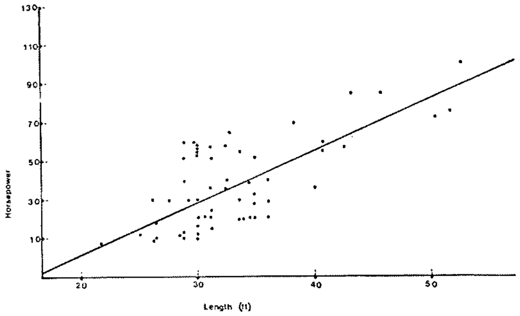


Figure 13. Continuous horsepower to overall length.

Horsepower = —50.86 + 0.2685 × length in inches.
Coefficient of correlation = 0.7525
Standard error of regression coefficient = 0.0289.
Standard error estimate = 17.22.

Vessel to Gear Relationships

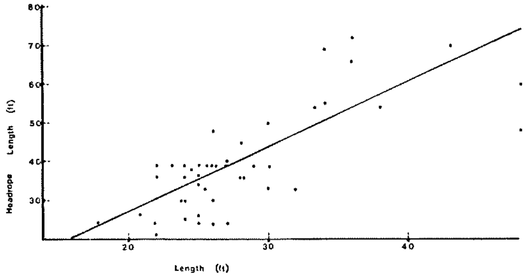


Figure 14. Otter trawl headrope length to overall vessel length.

Headrope length in feet = —6.89 + 0.1407 × vessel length in inches.
Coefficient of correlation = 0.7607.
Standard error of regression coefficient = 0.0148.
Standard error of estimate = 8.80.

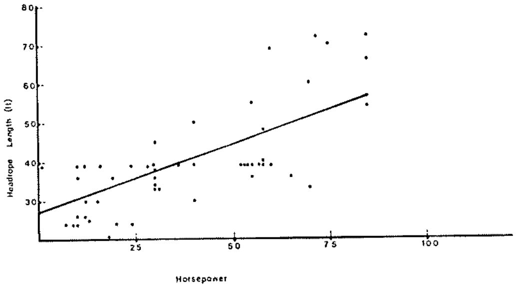


Figure 15. Otter trawl headrope length to horsepower.

Headrope length in feet = 26.70 + 0.3477 × horsepower.
Coefficient of correlation = 0.6707.
Standard error of regression coefficient = 0.04733.
Standard error of estimate = 10.06.

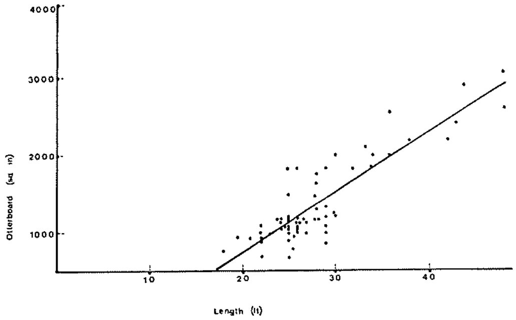


Figure 16. Otter board area to overall length.

Otter board area in square inches = —812.72 + 6.398 × vessel length in inches.
Coefficient of correlation = 0.8813.
Standard error of regression coefficient = 0.4224.
Standard error of estimate = 251.52.

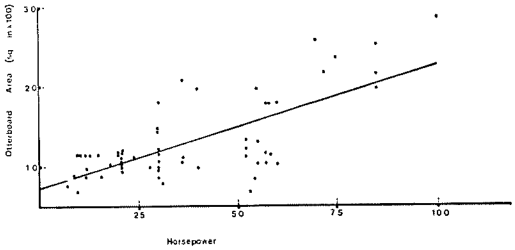


Figure 17. Otter board area to horsepower.

Otter board area in square inches = 728.77 + 15.449 × horsepower.
Coefficient of correlation = 0.7592.
Standard error of regression coefficient = 1.6301.
Standard error of estimate = 346.36.

Gear to Gear Relationships

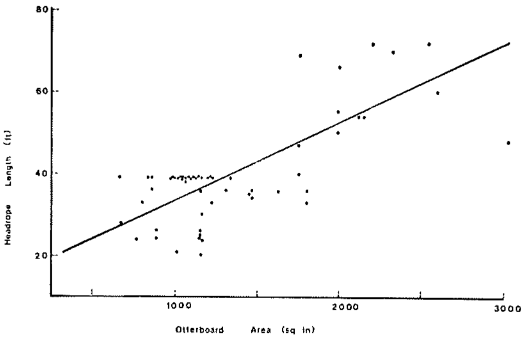


Figure 18. Otter trawl headrope length to otter board area.

Headrope length in feet = 15.05 + 0.0190 × otter board area in square inches.
Coefficient of correlation = 0.7438.
Standard error of regression coefficient = 0.0021.
Standard error of estimate = 9.063.

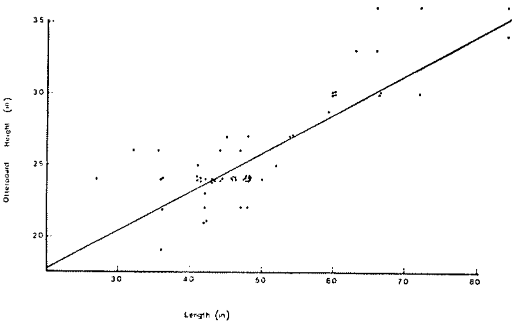


Figure 19. Otter board height to otter board length.

Otter board height in inches = 11.985 + 0.2797 × otter board length in inches.
Coefficient of correlation = 0.8254.
Standard error of regression coefficient = 0.0236.
Standard error of estimate = 2.26

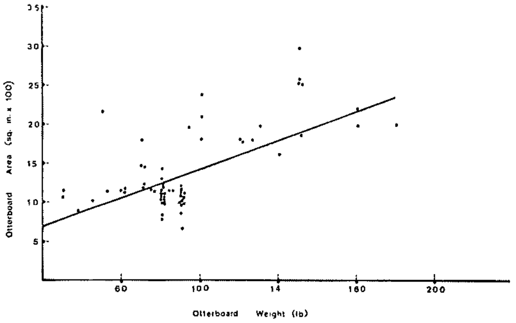


Figure 20. Otter board area to otter board weight.

Otter board area in square inches = 522.65 + 8.967 × otter board weight in lb.
Coefficient of correlation = 0.7211.
Standard error of regression coefficient = 1.06.
Standard error of estimate = 368.7.

DISCUSSION

Potter. I remember talking to some Tweed fishermen once and they told me that the reason that they didn't use twin-gear in New South Wales was that they had to prove or go through some computer programs to show that the vessel was stable when twin gear was being used. In this possibly the reason?

Gorman. No, this could not have been the case when this survey was done, there was no such legislation. Subsequently, in the last couple of years when boats started to be built for the Gulf there was a very real danger that some were marginally unstable, and when they were fitted with double-rigged gear the risk was considerably increased. Consequently, the Maritime Services Board, in its wisdom, decided to apply the IMCO stability requirements to fishing vessels. It's not very realistic in regard to the situation in Australia, but it still produces perfectly safe boats and it doesn't cost you any more to build stability into a vessel than to build lack of stability into one. There have been a few boats in the Clarence River fishery that have in fact adopted double-rig, inside the river.

Penn. I'm wondering whether in fact if you have looked at the efficiency of the boats in terms of any of these parameters. Our main concern in looking at these characteristics in the past in Western Australian fisheries has been to work out fishing power for the vessel as part of management. You don't seem to have done this. I was wondering if there was any reason why you haven't in fact looked at efficiency for any of these particular vessels and sorted out what makes a good otter board or not.

Gorman. The most important factor of the lot (in terms of efficiency) is the ability of the skipper. This is the most important one and it's the most difficult to measure.

In Europe, where vessels and gear tend to be more standardised, i.e. the side trawlers and even the newer stern-ramp trawlers, studies have shown that you get tremendous cruise-to-cruise variation depending on the skipper in charge so its a very difficult parameter to measure.

At this stage therefore we are looking solely at the physical characteristics of the boats and their gear, rather than their overall efficiency.

What I wish to emphasise is that the lines shown in the figures do not represent by any means the most efficient combination or best usage, they are simply a convenient way of describing a mean set of values, and which can be compared easily with similar data from elsewhere. There is obviously a best combination somewhere within the range of all those points and we are interested in finding out what this is. This will be our next step although it will be a pretty complicated process, and I am not sure that the answers we will get will be all that clear cut either.

However, in this day and age, when costs are so high, we cannot afford to let development occur empirically.

To give you an idea of spiralling inflation, the cost of a 24 m vessel in the last 12 months has risen by something like $100 000. You're now talking in terms of something between $300 000 to $400 000. So I think that people have to give more careful consideration to the way they outfit the boat.

We have described a clear case of inefficiency in small, high-revving propellors fitted to north coast trawlers, but there is a reason for this and they will probably disappear after the program for harbour improvement is completed.

Olsen. We've got an artificial limitation at the present time on the use of twin-rig trawling gear. This has been in effect for about four years. It's interesting that there's a factor of about 1.3 if you print the single-rig to a twin-rig for the same size, but we are re-examining this situation but it's interesting to note that it is the New South Wales ex-fishermen that have moved to South Australia who are keen on the twin-rig and that has more or less affected quite a number of the newer fishermen coming in and there is a very strong requirement for vessels to engage in double-rigging.

QUALITY CONTROL IN THE PRAWNING INDUSTRY

PART 1.

STORAGE OF PRAWNS IN REFRIGERATED SEA-WATER

BY J. H. RUELLO
Experimental Officer CSIRO, Division of Food Research,
P.O. Box 52, North Ryde, N.S.W. 2113.

ABSTRACT

Current research into quality control of prawn handling being undertaken at the CSIRO Division of Food Research at North Ryde, N.S.W. is directed towards improving the effectiveness of refrigerated sea-water (RSW) as a medium for storing prawns on board fishing vessels.

Using a laboratory scale RSW storage system it has been shown that eastern king prawns (Penaeus plebejus) can be held for up to six days at −1.5°C and still retain the excellent eating qualities characteristic of freshly caught prawns.

Modifications to existing handling methods, including mechanised treatment of prawns to prevent black spot, followed by containerisation of the catch to facilitate storage and unloading procedurres, are being studied for use under commercial fishing conditions.

Black spot will not develop in freshly caught prawns if they are treated with a solution such as sodium metabisulphite before they are stored in refrigerated sea water. The addition of sodium metabisulphite to refrigerated sea water is a less satisfactory method of treating black spot.

Dipping takes considerable labour, and a machine has been designed and is being built by the CSIRO Food Research Division which a deck-hand can use to treat an entire catch aboard a trawler.

INTRODUCTION

During the past five years the Australian prawning industry has expanded spectacularly and the technology for handling and storing prawns on board fishing vessels has undergone dramatic changes. Mechanically refrigerated sea-water (RSW) has replaced ice as the cooling and storage medium on most of the large prawning vessels.

The advantages of using RSW instead of ice are many and they are well documented (Roach, Harrison and Tarr, 1961; Nayar, Iyer, Appukuttan and Jacob, 1962). Not only are prawns cooled more rapidly when immersed in RSW but the tedious and sometimes difficult task of icing prawns at sea is eliminated. In addition, longer trips are possible as fishermen do not have to store large quantities of ice. It is also reported that prawns stored in RSW look more appetising and have a more acceptable flavour and texture than ice-stored prawns. The spoilage rate in RSW at −1°C is slower than in ice at 0°C as bacterial growth is reduced by half.

Prawns have a limited storage life in RSW as substantial physical and chemical changes can occur (Seagran, Collins and Iverson, 1960). Deterioration in raw whole prawns is mainly brought about by: (1) bacteriological spoilage; (2) enzymatic changes, principally the development of black spot; (3) uptake of the chemicals which are added to the RSW to extend storage life, particularly sodium chloride and sulphites; (4) textural changes and (5) physical damage (Campbell and Williams, 1952; Anon, 1959; Montgomery, Sidhu and Christie, 1970).

The handling and storage techniques which should be used by the fishing industry are those which will bring about minimal adverse changes to the prawns, and current research is directed towards improving RSW storage techniques. This research has been concentrated on: 1) finding economic ways of stopping black spot; (2) studying the uptake of salt; (3) evaluating methods for assessing quality; and (4) determining the importance of bacterial spoilage. The results of this research will form the basis of a series of recommendations to the fishing industry on ways of storing prawns in RSW so that the eating qualities of the stored prawns will not be noticeably different from those of the freshly caught prawns.

EXPERIMENTAL PROCEDURE

RSW storage equipment. A laboratory-scale

RSW system was built to simulate the commercial storage of prawns. It consists of three separate storage units in which whole prawns are immersed in sea-water which is recirculated through the prawns and a heat exchanger. A Colora[1] refrigeration unit was used to maintain the temperature of the RSW to within ±0.1°C of the desired temperature. The flow rate of the RSW was adjusted to 0.3 *l*/min which was adequate to maintain temperatures as low as −5°C.

Collection of prawns

Live eastern king prawns, *Penaeus plebejus*, trawled from Sydney Harbour, were collected at the Sydney Fish Centre at Pyrmont, packed in ice and transported to the laboratory. Before placing in the RSW, they were thoroughly washed in fresh water, drained and weighed.

Experimental method

Two of the three RSW storage units were used to hold prawns in sea-water to which different chemicals had been added. The remaining tank was used to store prawns in normal sea-water, thus acting as a control. During storage, samples of the RSW and prawns were taken for assessment of quality. On completion of each experiment the prawns were boiled for 1½ minutes in 3% brine. Before organoleptic assessment (by taste-testing) the texture of the shelled prawns was measured on a single puncture maturometer (Huntington and Rutledge, 1973).

The following tests were used to assess objectively the quality of the prawns:

(1) *pH*. The pH of homogenates of prawn flesh was determined according to the method described by Bethea and Ambrose (1962). The pH was measured with a Radiometer[1] pH meter with a scale expander using a glass electrode.

(2) *Sulphite content*. The method of Shipton (1954) was used to determine the sulphite content (as SO_2) of prawn flesh. The sulphite content (as SO_2) of the RSW was determined iodimetrically (Vogel, 1961).

(3) *Salt content*. Method 18.009 of the Association of Official Agricultural Chemists (1965) was used to measure the salt content.

(4) *Bacterial counts*. The prawns were homogenised in 1% peptone for one minute according to the method recommended by the National Health and Medical Research Council, Australia (1967). The total viable plate count/g was determined on dilutions of the homogenate after plating on standard methods agar followed by incubation for two days at 25°C. The total viable plate count/ml of the RSW was determined as follows: a sample was centrifuged, the resulting pellet dispersed in sterile saline and dilutions were plated on standard methods agar and incubated for two days at 25°C.

RESULTS AND DISCUSSION

Control of Black Spot

Black spot or melanosis, which is characterised by a blackening of the 'head', the abdominal shell segments and the tail fan, can be a problem in raw prawns. It is caused by certain enzymes in prawns which oxidise particular compounds to produce black melanin pigments. Black spot readily develops in dead prawns especially when they are held under dry refrigeration. Storage of dead prawns in RSW delays the development of black spot principally because the amount of oxygen available to the prawns' epidermis is reduced (Fieger, 1951). Nevertheless, unless special precautions are taken black spot will develop in prawns which are stored in RSW at or below 0°C for longer than two-three days depending on the condition of the prawns when caught.

Although prawns with black spot are not necessarily unfit to eat, their unattractive appearance makes them unacceptable to consumers. The presence of black spot often suggests that the prawns have been poorly handled and stored. The common methods of inhibiting black spot involve: (1) cooking; (2) use of sodium metabisulphite which not only stops black spot, but bleaches melanin pigments. (1) cooking; (2) reducing the pH of the storage medium; (4) removal of dissolved oxygen from RSW; and (5) freezing.

The following methods of stopping black spot were investigated:

Use of carbon dioxide and nitrogen gases

Bubbling of carbon dioxide (CO_2) or nitrogen gas (N_2) through the RSW should displace the dissolved oxygen and thus stop black spot. The experimental RSW equipment was modified so that CO_2 (or N_2) could be fed into the suction side of the recirculating pumps at the rate of 70 ml/minute. The addition of N_2 to the RSW only delayed the development of black spot by one day, and after seven days' storage at 0°C the prawns were extensively blackened. The prawns held in RSW to which CO_2 gas was added did not develop black spot after seven days. However this was not due to the displacement of dissolved oxygen, but to the pH effect of the carbonic acid formed when

---

[1] Registered trade name.

Table 1. pH of RSW used to store prawns

Days' storage	Untreated RSW 0°C	RSW treated with CO_2 0°C	RSW treated with N_2 0°C	Unbuffered RSW −1.5°C	Buffered RSW −1.5°C
0	7.9	7.9	7.9	7.8	6.2
1	7.6	5.8	7.9	7.5	6.3
2	7.5	5.9	8.0	7.8	6.2
3	7.6	5.9	8.0	7.7	6.5
4	7.6	6.0	8.1	7.7	6.4
5	7.8	6.0	8.1	7.6	6.6
6	7.9	5.9	8.2	7.6	6.8
7	8.0	5.9	8.2		

CO_2 dissolved in the RSW. The pH of the RSW to which CO_2 was added fell to 5.8 after one day, whereas the control and the RSW with N_2 added were slightly alkaline (Table 1).

Although the addition of CO_2 to the RSW was successful in stopping black spot, the prawns stored in this medium were unacceptably tough after boiling, whereas the texture of both the control and prawns stored in RSW to which N_2 was added was indistinguishable from freshly caught prawns. The acidic conditions also partly dissolved the shell, giving the prawns a 'soft shell' appearance.

These results suggest that the addition of CO_2 to the RSW is not a desirable method of extending storage life. However, CO_2 has been used successfully to extend the storage life of Pacific pink shrimp *Pandalus jordani* (Barnett and Steinberg, 1968). Storage life was extended because the carbonic acid inhibited bacterial growth.

Buffered sea-water

In order to take advantage of the pH effect to inhibit black spot and yet avoid the acidic conditions which apparently produced toughness, prawns were stored in RSW buffered with citric acid and sodium phosphate. The prawns were stored at −1.5°C for six days, and the pH of the RSW was adjusted daily to approximately 6.2 (Table 1). After six days all the prawns stored in unbuffered sea-water had black 'head' and 50% had abdominal black spot. Of those stored in buffered sea-water, two thirds had black 'head', but none had developed abdominal black spot. After cooking, the colour of the prawns stored in buffered sea-water was slightly duller than that of the control prawns, but the former were acceptable. Although the flavour of the control prawns was preferred to those stored in buffered sea-water, the firmer texture of the latter was preferred. This method of stopping black spot could have commercial application, as it is a simple procedure to add the chemicals to the recirculating RSW and to check the pH daily, and prawns stored in this medium showed no deterioration in flavour, texture and appearance (other than black 'head') after six days.

Use of sodium metabisulphite to control black spot

Of the many chemicals tested for their ability to stop black spot, sodium metabisulphite is probably the cheapest and the most effective (Faulkner, Watts and Humm, 1954; Establier, 1969). These authors recommend immersion of the prawns for between two and ten minutes into dilute solutions of sodium metabisulphite. These relatively long dips are impractical in some prawn fisheries where large quantities have to be treated quickly. The following investigations were aimed at finding the minimum immersion time which would prevent the development of black spot for at least eight days at −1.5°C. Experiments were also conducted to ascertain the suitability of adding the sodium metabisulphite directly to the RSW. As prawn flesh readily takes up sulphite, the success of these treatments depended on having a residual sulphite level of less than 10 mg/kg (wet weight), the Australian export limit.

As a dip

Immersion for 30 seconds in a 5 g/*l* solution of sodium metabisulphite provided complete protection against black spot during eight days' storage in RSW at −1.5°C. The residual sulphite levels in the flesh of these prawns are given in Table 2. Although the level of 15 mg/kg was obtained for these prawns when raw, this was reduced to between 0-10 mg/kg after cooking or washing for 30 minutes. Dipping for shorter durations in more concentrated solutions did not prevent the development of black 'head', although quite high uptake of sulphite occurred (Table 2).

Table 2. The sulphite content (mg/kg wet weight) of prawns dipped in sodium metabisulphite. *The prawns were stored for 8 days at —1.5°C in RSW. The 'washed' samples were immersed in running water for 30 minutes.*

Pre-storage dip		*Sulphite content in prawn flesh (mg/kg wet weight)*				*Appearance of prawn*	
		Raw		*Cooked*			
g/l Sodium metabisulphite	*Duration secs*	*Unwashed*	*Washed*	*Unwashed*	*Washed*	*Raw*	*Cooked*
12.5	15	0	0	3.5	0	100% black head	Colour dull extensively bleached
25	15	21.0	3.0	52.0	14.0	50% black head	Colour dull extensively bleached
50	15	76.4	44.0	105.0	57.0	10% black head	Colour dull very extensively bleached
5	30	15.0	0	0	8.5	No black head	Colour bright only minor bleaching
10	30	18.5	9.8	15.8	12.0	No black head	Colour bright only minor bleaching

Table 3. Data on prawns stored in RSW containing sodium metabisulphite

Days of storage at —1.5°C	*RSW*		*Sulphite in prawns mg/kg*		*Appearance of prawns*	
	Conc. Sulphite mg/l		*Raw washed 30 min*	*Cooked washed 30 min*	*Raw*	*Cooked*
	Initial	*Final*				
6	0	0	0	0	Extensively blackened in both the 'head' and abdominal regions	Colour bright; good appearance except for black spot
6	100	23	<16	0	100% black head 10% abdominal black spot, pigment discoloration	Colour dull; some bleaching
6	500	155	17.5	18	50% black head no abdonimal black spot pigment discoloration	Colour dull; some bleaching
3	1000	860	58	42	No black head pigment discoloration	Colour very dull; extensive bleaching
3	500	460	23	26	No black head pigment discoloration	Colour dull; extensive bleaching
3	1000	725	78	63	No black head pigment discoloration	Colour very dull; extensive bleaching

Added to RSW

The addition of sodium metabisulphite directly to the RSW is a simple way of preventing black spot, and therefore this method is commonly used on Australian prawning vessels. It can be seen from Table 3 that sulphite concentrations of 100 mg/*l* or less in the RSW were ineffective in preventing abdominal black spot or black 'head'. With concentrations of 500 mg/*l* no abdominal black spot developed but 50% of the prawns developed black 'head'. If the sulphite concentration in the RSW was maintained to approximately 500 mg/*l*, black 'head' did not develop. However, unacceptably high levels of sulphite were incorporated into the flesh when prawns were stored in RSW containing sulphite at a concentration of 500 mg/*l* or more (Table 3).

The RSW became acidic once sodium metabisulphite was added. However, if the

Table 4. pH of RSW containing sodium metasulphite

Days of storage	*RSW at −1.5°C*											
	Tank 1		*Tank 2*		*Tank 3*		*Tank 4*		*Tank 5*		*Tank 6*	
	SO_2 *mg/l*	*pH*	SO_2 *mg/l*	*pH*	SO_2 *mg/l*	*pH*	SO_2 *mg/l*	*pH*	SO_2 *mg/l*	*pH*	*mg/l* SO_2	*pH*
0	1000*	4.5	500*	4.5	1000	4.5	0	7.9	100	6.5	500	5.8
1	840	5.2	420	5.4	820	5.3	0	7.6	NA[x]	7.4	NA	7.1
2	900	5.4	470	5.5	760	5.4	0	7.5	NA	7.5	NA	7.4
3	860	5.9	460	5.8	725	5.8	0	7.4	NA	7.5	NA	7.5
6	—	—	—	—	—	—	0	7.4	23	7.6	155	7.7

* Sodium metabisulphite added daily to maintain original concentration.

[x] NA: data not available.

concentration of the sulphite was below 500 mg/*l* the pH of the RSW quickly rose (Table 4) but if it was maintained at this level or higher, the RSW remained acidic (Table 4). The texture of the prawns stored between pH 4.5 and 5.9 was slightly firmer than that of prawns stored in normal sea-water, and the firmer texture was preferred by most tasters. However, the degree of toughness which developed after the addition of CO_2 to the RSW did not develop in these prawns. Low pH does alter the texture of prawns, but storage at or below pH 4 is necessary to produce toughness (Ahmed, Koburger and Mendenhall, 1972).

The addition of sulphite to RSW is not always an effective way of stopping black spot as high sulphite uptake occurs when prawns are stored in RSW with a sulphite concentration greater than 100 mg/*l*, and black 'head' and some abdominal black spot develops if the initial sulphite concentration in the RSW is less than 100 mg/*l*.

Disadvantages

Although sodium metabisulphite is very successful in stopping black spot, it has three major disadvantages: (1) it bleaches the naturally occurring pigments; (2) since it removes black spot by bleaching the melanin pigments it may be used to disguise spoilage; and (3) it has undesirable effects when taken up by the flesh.

When sodium metabisulphite bleaches the natural pigments the appearance of the raw prawns may be enhanced; dead king prawns from Sydney Harbour usually have a green to grey colour when raw which turns slightly pink when bleached with sodium metabisulphite. However, the bleached areas appear as white patches once the prawns are cooked. All the prawns treated with sodium metabisulphite showed some degree of bleaching after cooking.

Sodium metabisulphite can be used to bleach black discolorations so that it is possible for spoiled prawns to pass as export quality. As soaking for several days in sulphite solutions at a concentration of at least 1 000 mg/*l* is necessary to remove completely any traces of melanin, high sulphite uptake will occur (Table 3) and will probably make these prawns inedible.

The relatively high sulphite levels, which occurred after some treatments, were reduced by an average of 50% (range of 20 to 80%) after 30 minutes washing in freshwater, but no significant reductions occurred after cooking (Tables 2 and 3). Washing removed almost all of the sulphite when the initial sulphite concentration in the flesh was low. Although the sulphite content of some foods may be reduced by prolonged boiling (Allen and Brook, 1970), the normal cooking times for prawns are too short to bring about a significant reduction (Fieger, Bailey and Novak, 1956). It is important to reduce the amount of sulphite in the prawns because it imparts an unpleasant metallic flavour note to food. Most people can detect this taint if the concentration exceeds 100 mg/*l* (Richardson, 1970). The detection threshold level of sulphite in prawns is not known, but Faulkner, Watts and Humm (1954) noted that the flavour of shrimp *Penaeus setiferus* containing 30 mg/kg of sulphite was indistinguishable from that of control shrimp.

There is no evidence that sulphite has any harmful effects when ingested in low doses other than its ability to destroy thiamine (a member of the vitamin B group) (Allen and Brook, 1970; Til, Feron and de Groot, 1972). Since the *per capita* consumption of prawns is very low this property of sulphite should not cause any concern in the prawning industry.

Commercial use

These experiments strongly indicate that the most effective way to use sodium metabisulphite is as a dip, as this gives complete protection against black spot as well as avoiding high sulphite levels in unprocessed prawns. The dipping techniques described by earlier workers are not adaptable to the banana prawn fishery where very large catches may be taken in a short span of time. My colleague, Dr Sharp, has designed a dipping machine which should be suitable for this fishery, and is described in Part 2.

When fishermen add sodium metabisulphite directly to the RSW they frequently add too little and black spot develops or else they add too much and high sulphite uptake occurs. The addition of sodium metabisulphite to RSW is only suitable for tanks equipped with recirculating RSW which should ensure equal distribution of the chemical. Local concentrations of sulphite occur in tanks without recirculating RSW and this could lead to a very high sulphite uptake by some prawns. Chemically impregnated test papers are now available which can be used to estimate sulphite concentrations in the RSW as low as 10 mg/*l*. If a sulphite concentration of the RSW is *maintained* at 100 mg/*l*, it is most probable that abdominal black spot will be prevented and sulphite uptake will be negligible; however, black 'head' will develop.

Storage in 'super-cooled' brines

When prawns are stored in normal sea-water chilled to 0° or −1.5°C for more than three days their eating qualities and their physical appearance deteriorate. In addition to the development of black spot, the flesh softens and the 'head' partially separates from the abdomen giving the prawns an 'old' look. However, when *Penaeus plebejus* is held in a partially frozen state at −4°C in 'super-cooled' brines its appearance after seven days closely resembles that of freshly caught prawns. However, as we will see, the use of 'super-cooled' brines raises certain difficulties.

The simplest way of producing a 'super-cooled' brine is to increase the salinity of the sea-water by adding sodium chloride. A salinity greater than 7.5% is required to depress the freezing point of sea-water to −4°C. Although the appearance of prawns stored at −4°C in a strong brine (>7.5% salinity) is excellent and black spot is inhibited without the use of chemicals, the prawn's quality may be impaired by it high salt content. When the salt content of prawn flesh exceeds 2.5% (wet weight) the prawns are unacceptably salty to most tasters, and when it exceeds 5% the prawns are extremely tough and rubbery (Montgomery, Sidhu and Christie, 1970).

Prawns stored in normal sea-water chilled to 0° or −1.5°C did not develop salt contents greater than 1.9% (Table 5). These results confirmed Collins, Seagran and Iverson's (1960) findings that rapid salt uptake occurred during the first three days of storage of Alaskan pink shrimp (*Pandalus* sp) in RSW, and that an equilibrium was reached when the shrimp had a salt content of 1.8 per cent. Seagran, Collins and Iverson 1960) found that the salt

Table 5. Salt content (% wet weight) in prawns stored in RSW

RSW % salinity	3.5	3.5	6.0	7.0	7.0	7.0	7.0
PRAWN: Brine ratio	1:1	1:1	1:1	1:1	1:1.5	1:3	1:6
RSW Temp. °C	0	−1.5	−1 ± 3	−4 ± 0.5	−4 ± 0.5	−4 ± 0.5	−4 ± 0.5
Days' storage	% Salt (wet weight) in prawn flesh						
0	0.3	0.4	0.4	0.5	0.4	0.4	0.4
1	0.8	0.7	0.7	0.9	0.7	0.9	0.9
2	1.3	1.2	1.9	1.3	1.3	1.3	1.3
3	1.3	1.6	2.5	1.6	1.8	1.9	1.8
4	1.5	1.7	2.7	1.8	2.0	2.4	1.9
5	1.7	1.7	2.7	2.4	2.3	2.5	2.4
6	1.9	1.5	3.0	2.5	2.4	2.7	2.5
7	1.9	1.8	3.0	2.6	2.5	2.8	2.6
8	1.8	1.8	—	2.7	2.6	2.8	2.6

content of the prawns increased from 1.8% to 2.0% if the brine:prawn ratio was altered from 1:1 to 2:1. When these shrimp were stored in a 6% salt solution at −1°C the prawns had a salt content of 3% after about three-and-a-half days.

When king prawns were stored in sea-water of 7.5% salinity at −4°C the salt uptake increased very rapidly for the first five days and an equilibrium was reached when the prawns had a salt content between 2.6 and 2.8% (Table 5). No significant change in salt content occurred if the prawn:brine ratio was altered (Table 5). Apparently salt uptake was retarded when the prawns were partially frozen, as very high uptake occurred when the temperature rose above the freezing point of the prawn, about −2°C Tables 5 and 6). When this occurred the salt content of the prawns was the same as that of those stored in brine (>7.5% salinity) at −1.5°C for the same length of time (Tables 5 and 6). The appearance of these prawns did not differ from that of prawns stored in normal sea-water at −1.5°C, although Seagran, Collins and Iverson (1960) noted that shrimp stored in brines containing 6% salt at −1°C or 0°C were firmer and of better quality than the control prawns.

Table 6. Removal of salt from prawn flesh

Storage brine % salinity	% NaCl in flesh after 8 days' storage at			
	−1.5°C		−1 ± 3°C	
	Un-washed	Washed 10 min	Un-washed	Washed 30 min
3.5	1.5	1.4	—	—
7.75	4.0	3.7	4.5	3.8
8.25	—	—	4.1	3.4
10.0	4.5	4.0	4.4	4.2

If the temperature was maintained at −4 ± 0.5°C the salt content of the prawns after eight days' storage was between 2.6 and 2.8%. Unless these prawns were thoroughly washed before cooking they were unacceptably salty to most tasters, and their texture was very firm but not tough. Although partial freezing produces toughness in cod (Love, 1969) prawns held under dry refrigeration at −5°C showed no textural changes after eight days, and after 16 days the flesh had become soft. It was most probable that the increased firmness which developed in prawns stored in 'super-cooled' brines at −4 ± 0.5°C was caused by the uptake of salt. Increasing toughness developed in prawns when the salt content exceeded 2.6% and the prawns were unacceptably tough when their salt content was greater than 4 per cent.

It was difficult to reduce the salt content of prawns when it was initially greater than 4 per cent. Table 6 shows that immersion in running fresh water for ten minutes did not markedly reduce the salt content and washing for 30 minutes did not bring about large reductions. Collins (1960) found that washing during machine peeling reduced the salt content of Alaskan pink shrimp by 50%, from 1.4% to 0.7 per cent. Montgomery, Sidhu and Christie (1970) found that the salt content of frozen tiger prawns (*Penaeus esculentus*) was reduced by 30-36% after washing for 1 hour.

Although the storage life of prawns was extended if they were held in brine at −4 ± 0.5°C this method cannot be recommended; few vessels can maintain a RSW temperature of −4 ± 0.5°C and consequently prawns stored for more than three or four days would have salt contents exceeding 4 per cent. With a salt content as high as this the prawns would be unacceptably salty and tough. In order to avoid high salt uptake it is possible to depress the freezing point of sea-water by adding calcium chloride. However, Higman and Idyll (1952) noted that shrimp *Penaeus duorarum* stored in 3% calcium chloride at 3.5°C became noticeably bitter on the seventh day, whereas shrimp held in 3% sodium chloride at 3.5°C were still acceptable after 26 days.

Quality assessment

At present, odour and visual observations are the criteria for evaluating the quality of raw prawns destined for export. These evaluations frequently lack uniformity and are often of little value as it is possible for spoiled prawns, or prawns with high salt and sulphite contents to appear excellent. The salt and sulphite contents are best estimated chemically and simplified tests utilising chemically impregnated strips are available. There are various chemical tests which processors could use to determine the suitability of the prawns for processing. These depend on the estimation of one or more of the degradation products brought about by bacterial activity, such as total volatile bases (TVB) and trimethylamine (TMA), and the estimation of total bacterial counts. These tests are useful in establishing that the prawns have spoiled, but they do not indicate when loss of prime quality has occurred.

The pH of homogenates of prawn flesh is generally considered to be a reliable index of quality of ice-stored shrimp (Bailey, Fieger and

Top Left:
Common and easily recognisable defects—freezer burn in prawn (right) and excessive bleaching with sodium metabisulphite in prawn (centre)—contrast with a freshly-caught prawn (left).

Bottom Left:
Other physical defects which exclude prawns from export include physical damage (right) and soft shell (centre), and are obvious when compared with a freshly-caught prawn (left).

Top Right:
Only black head distinguishes prawn (right) stored for six days in buffered sea water at 0°C from a freshly-caught prawn (left).

Bottom Right:
Prawn (upper) stored in brine at −4°C for seven days cannot readily be distinguished from a freshly-caught prawn (centre). Both contrast sharply with prawn (lower) stored in normal sea water at —1.5°, which shows black spot and a partially-detached head.

Novak, 1956, Bethea and Ambrose, 1962). It was noted by these authors that the changes in the pH of homogenates of *Penaeus aztecus* stored on ice were gradual, and were related to organoleptic changes. The pH of homogenates of freshly killed *Penaeus plebejus* varied between 6.8 and 6.9. During storage in RSW at 0°, −1.5° or −4°C the pH gradually increased (Table 7). At the fourth of fifth day of storage the pH rose to 7.4 or 7.5 and remained at this level for the next three days if the temperature of the RSW did not rise above 0°C.

Table 7. The pH of homogenates of prawn flesh

Days of storage	*RSW −4°C*	*RSW −1.5°C*	*RSW 0°C*
0	6.8	6.9	6.9
1	6.9	7.1	7.1
2	7.2	7.1	7.2
3	7.2	7.3	7.3
4	7.3	7.3	7.5
5	7.5	7.5	7.5
6	7.4	7.4	7.5
7	7.5	7.5	7.5
8	7.5	7.6	7.5

During the first six days of storage in RSW the pH changes could not be correlated with visual or organoleptic changes as the flavour and texture of these prawns when boiled were similar to that of freshly caught prawns. However on the seventh day an unpleasant taste could be detected, but the prawns were still acceptable to most tasters. On the eighth day bitter off-flavours were present which made the prawns unacceptable. If the RSW temperature rose above 0°C for a couple of days deterioration was accelerated and the pH rose to 7.7. There were obvious signs of spoilage in these prawns, particularly in the muscle of the first abdominal segment which had become very soft and watery. After boiling these prawns were either unacceptable or of borderline quality.

These data support the view that the measurement of the pH of homogenates of prawns stored in RSW could be used as a simple screening test to evaluate the degree of freshness, especially if it is combined with a visual and organoleptic assessment. If the pH is below 7.5, it can be assumed that the prawns are of prime quality, as this indicates a storage life of less than four days in RSW. As the pH does not rise above 7.6 during the sixth, seventh and eighth days of storage in RSW, other tests are essential to determine the quality. When the pH is between 7.5 and 7.7 organoleptic assessment in conjunction with TMA and TVB estimations should be used to determine if the prawns are acceptable.

Bacterial spoilage

Although earlier workers (Campbell and Williams, 1952) have attributed the rapid deterioration of shrimp quality to the action of bacteria, others have noted that bacterial counts are not necessarily an indication of quality (Carroll, Reese and Ward, 1968; Vanderzant and Nickelson, 1971). A sudden increase in bacterial load is often taken to indicate the onset of spoilage and a count of 10×10^6/g or more indicates spoilage regardless of storage conditions (Bailey, Fieger and Novak, 1956). However, bacterial counts are unreliable in identifying the various stages of degradation in the quality of prawns and will not necessarily indicate that the prawns were freshly caught or have been stored for several days. High and variable total plate counts of between 1.6×10^3 and 1.2×10^6/g were found in freshly caught *Penaeus duorarum* by Green (1949) and Williams, Rees and Campbell, (1952). They attributed the high variability in the numbers of bacteria to the presence of mud and fish slime on the surface of the prawns. The initial bacterial load was reduced by 45% after thorough washing in clean sea-water, and by 90% after removal of the 'head'.

An average bacterial count of 2.3×10^3/g was found in freshly caught *Penaeus plebejus* after thorough washing, and this rose only slightly after six days' storage in RSW at −1.5°C to 30×10^3/g, and after fifteen days, rose to 3.2×10^6/g. Similar counts were obtained for the RSW, indicating that the majority of the bacteria were located on the surface of the prawns. These results demonstrate that bacterial spoilage is not significant during the first week of storage in RSW at −1.5°C if the prawns are thoroughly washed before placing in the storage medium.

RECOMMENDED METHOD OF STORING PRAWNS IN RSW

I have described experiments in which prawns were held in recirculating RSW at −1.5°C or 0°C and after six days they still retained the excellent eating qualities characteristic of the fresh product. Although these prawns were handled under optimal conditions it should be possible for fishermen to duplicate these results on vessels currently in use. Although fishermen can do little to improve the condition of the prawns when caught, the techniques used to sort, wash and store the catch will determine their storage life and their ultimate eating quality.

The prawns should be emptied onto a sorting tray large enough to contain the entire catch. In warm climates a canopy should shade the catch during sorting and washing. Before the catch is placed in the RSW it should be dipped into a solution of sodium metabisulphite to stop black spot. It would be preferable to store the catch in perforated containers which would prevent damage occurring during RSW storage at sea and during unloading.

If the catch is emptied directly into the RSW without sorting or washing, rapid bacterial growth may occur, as not only are the prawns contaminated, but the incidental trash fish carry large bacterial loads. Freshly caught fish can have total bacterial counts of 10^2 to 10^7 (at 20°C)/cm^2 of skin with adhering slime (Shewan, 1961). As these prawns have not been dipped black spot will develop after one to three days' storage.

Prawns that are sorted and washed and then treated for black spot as described above should retain the excellent eating qualities of fresh prawns if they are stored for less than six days in normal sea-water chilled to $-1.5°$ or 0°C. The most suitable type of storage tank is one in which the RSW is recirculated through an external heat exchanger as some degree of temperature control is possible, and 'icing up' is avoided. Prawns held in normal sea-water will not be salty or tough after six days' storage. Extensive washing with fresh-water will not be necessary before processing, as these prawns will not have high sulphite or salt contents.

PART 2.

DESCRIPTION OF PROTOTYPE PRAWN DIPPING MACHINE FOR USE ON PRAWNING VESSELS AND IN PROCESSING FACTORIES

BY A. K. SHARP
Research Scientist CSIRO, Division of Food Research,
P.O. Box 52, North Ryde, N.S.W. 2113.

Black spot will not develop in freshly caught prawns if they are treated with a solution such as sodium metabisulphite before being stored in refrigerated sea water. The main deterrent to adopting this procedure is the heavy labour requirement to dip and drain the prawns, one basket at a time. The dipping machine described below will reduce the labour requirement to a level where one deck hand can dip the entire catch and still have time to help with the sorting.

It is envisaged that after sorting and washing, the prawns will be emptied into standard perforated plastic lug boxes (approx. 0.6 m × 0.4 m × 0.3 m), each of which can hold approximately 43 kg of prawns. If necessary, sorted prawns could be washed as they moved down a perforated chute; jets of water, both from above and below, would remove sand, mud and fish slime, and also provide sufficient buoyancy to flume the prawns into the lug box. When full, the box will be pushed along a slide to the prawn dipper.

As shown in Fig. 1, the prototype prawn dipper comprises a tank containing the solution in which revolves a drum capable of holding four lug boxes. The overall dimensions of the dipper are approximately 1.4 m high, 1.5 m

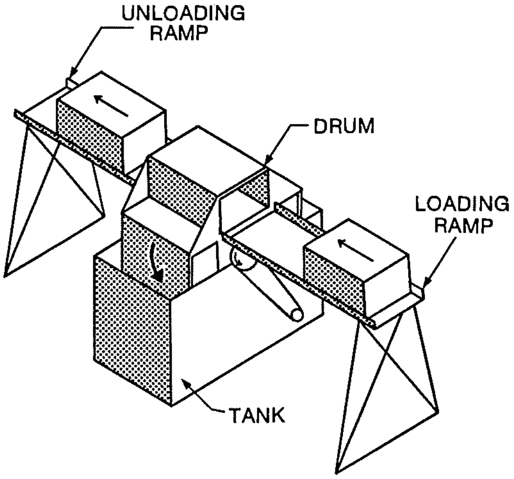


Figure 1. Prawn dipping machine.

long and 0.9 m wide, excluding the loading and unloading ramps. Continuous, rather than intermittent, rotation of the drum was chosen for the prototype in view of cost and reliability. The drum is driven from an electric gear motor which has an output speed of one revolution every two minutes (0.052 rad/s). The drive to the drum is taken by a chain and sprockets, allowing the drum speed to be set at ¼, ½ or 1 rev/min. The lengths and slopes of the loading and unloading ramps can be adjusted to suit the particular installation.

In operation, a box of fresh prawns is pushed from the loading ramp into a vacant position in the drum. As the drum revolves, the box slowly submerges in the solution. The rotary motion of the drum ensures that all air is displaced, and no part of any prawn escapes contact with the solution, as might happen if the box were merely lowered into a bath. After being immersed for approximately ¼ revolution (30 sec. at 0.052 rad/s), the basket emerges and drains for a similar period before reaching the discharge position, where it is pushed from the drum onto the unloading ramp. The unloading ramp slightly precedes the loading ramp to allow time for the dipped basket to be removed from the drum before a fresh basket is loaded. In the prototype dipper loading and unloading are performed manually, but it would not be difficult to mechanise these actions, in which case intermittent rotation of the drum might be preferred to continuous rotation.

With time, the concentration of the active ingredient of the solution will fall, due both to uptake by the prawn flesh, and to dilution by sea water adhering to the fresh prawns (approx. 5% of the weight of drained prawns). Therefore, fresh chemicals must be added to the dip tank from time to time. In the prototype, using sodium metabisulphite as the preservative, a concentrated solution will be added manually, whenever chemical test papers show this to be necessary. However, for long term use it would probably be feasible to drive a metering pump from the drum shaft and thus add a concentrated make-up solution continuously whenever the dipper is in use. The operator would then need only to ensure that the make-up tank always contained a supply of concentrate.

Both the drum and the tank of the prototype are constructed of marine plywood and finished with an epoxy resin. A plastic PVC ball valve is fitted as a drain cock. The loading and unloading ramps are also made of marine plywood, and have nylon rubbing strips to reduce friction. Because the solutions used are acidic, all metal parts in contact with the solution, including the support shaft, and all fastenings, are made from 316 stainless steel. The shaft is hollow, to save both money and weight, and runs in plain bearings machined from nylon blocks. Drive from the 200 watt (i.e. ¼ hp) gear-motor is by mild steel pintle chain running on cast iron sprockets. The chain used has adequate clearance to cope with the harsh marine environment. The drum of the prototype dipper can be easily withdrawn from the tank for ease of transport. When mounted on deck it is envisaged that the tank would be secured to the side of the vessel's sorting tray.

When operated at 0.052 rad/s, giving a 30 second dip, this machine will dip two lug boxes of prawns each minute, which is equivalent to 5 000 kg of prawns per hour, an adequate rate for most fisheries.

LITERATURE CITED

AHMED, E. M., KOBURGER, J. A., AND MENDENHALL, V. T. (1972). 'Factors affecting texture of cocktail shrimp'. *J. Texture Studies*, 3. pp. 186-93.

ALLEN, R. J. L., AND BROOK, M. (1970). 'Effects of sulphur dioxide in animals and man'. *Proc. Int. Congr. Food Sci. Technol.*, 3rd, pp. 799-805.

ANON. (1959). 'Influence of vessel-handling practices on formation of black spot in shrimp.' (1959). *Commer. Fish. Rev.*, 21 (2), 10-16.

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, (1965). *Official Methods of Analysis.* 10th edn., A.O.A.C., Washington.

BAILEY, M. E., FIEGER, E. A., AND NOVAK, A. F. (1956). 'Objective tests applicable to quality studies of ice stored shrimp'. *Food Res.*, 21, pp. 611-20.

BARNETT, H., AND STEINBERG, M. (1968). 'Modification of refrigerated sea-water for the preservation of fishery products'. *Proc. Nat. Shellfish Assoc.*, 59, p. 10.

BETHEA, S., AND AMBROSE, M. E. (1962). 'Comparison of pH, trimethylamine content, and picric acid turbidity as indices of iced shrimp quality'. *Commer. Fish. Rev.*, 24 (3), pp. 7-10.

CAMPBELL, L. L. JR, AND WILLIAMS, O. B. (1952). 'The bacteriology of Gulf Coast shrimp. IV. Bacteriological, chemical, and organoleptic changes with ice storage'. *Food Technol.*, 6, pp. 125-6.

CARROLL, B. J. REESE, G. V., AND WARD, B. Q. (1968). 'Microbiological study of iced shrimp. Excerpts from the 1965 Iced-Shrimp Symposium'. U.S. Fish. Wild. Serv. Circ. 284.

COLLINS, J. (1960). 'Processing and quality studies of shrimp held in refrigerated sea water and ice. Part I. Preliminary observations on machine-peeling characteristics and product quality'. *Commer. Fish. Rev.*, 22 (3), pp. 1-5.

Collins, J., Seagran, H., and Iverson, J. (1960). 'Processing and quality studies of shrimp held in refrigerated sea water and ice. Part II. Comparison of objective methods for quality evaluation of raw shrimp'. *Commer. Fish. Rev.*, 22 (4), pp. 1-5.

Establier, R. (1969). 'Prevencion quimica del ennegrecimiento (melanosis) de los crustaceos congelados y conservados en hielo'. *Invest. Pesq.*, 33 (1), pp. 55-68.

Faulkner, M. B., Watts, B. M., and Humm, H. J. (1954). 'Enzymatic darkening of shrimp'. *Food Res.*, 19, pp. 302-10.

Fieger, E. A. (1951). 'Cause and prevention of black spot on shrimp'. *Ice & Refrig.*, 120 (4), pp. 49-50, 64.

Fieger, E. A., Bailey, M. E., and Novak, A. F. (1956). 'Chemical ices for shrimp preservation'. *Food Technol.*, 10, pp. 578-83.

Green, M. (1949). 'Bacteriology of shrimp. II. Quantitative studies on freshly caught and iced shrimp'. *Food Res.* 14, pp. 372-83.

Higman, J. B., and Idyll, C. P. (1952). 'Holding fresh shrimp in refrigerated sea water'. *Proc. Gulf Caribb. Fish. Inst.*, 5th, pp. 41-56.

Huntington, J. N., and Rutledge, P. J. (1973). 'Single puncture maturometer'. *CSIRO Food Res. Q.* 34, (1) pp. 21-3.

Love, R. M. (1969). 'Anomalous behaviour of frozen cod muscle stored near its melting point', in *Freezing and Irradiation of Fish* (ed. Kreuzer), Fishing News (Books) Ltd, London, p. 119.

Montgomery, W. A., Sidhu, G. S., and Christie, E. M. (1970). 'The Australian Prawn Industry. II. Quality aspects for export prawns'. *CSIRO Food Preserv. Q.*, 30, pp. 44-50.

National Health and Medical Research Council, Aust. (1967). *Report of 64th Session*, Govt. Printer, Canberra, p. 25.

Nayar, M. R., Iyer, K. M., Appukuttan, P. N., and Jacob, S. (1962). 'Storage characteristics of prawns held in crushed ice and chilled sea water'. *Indo-Pac. Fish. Counc. Proc.*, 10th, 2, pp. 294-7.

Richardson, K. C. (1970). 'Chemical preservatives in foods in Australia'. *CSIRO Food Preserv. Q.* 30, pp. 2-8.

Roach, S. W., Harrison, J. S. M., and Tarr, H. L. A. (1961). 'Storage and transport of fish in refrigerated sea water'. *Bull. Fish. Res. Board Can.* Bull. 126.

Seagran, H. Collins, J., Iverson, J. (1960). 'Processing and quality studies of shrimp held in refrigerated sea water and ice. Part III.—Holding variables and keeping quality of the raw whole shrimp'. *Commer. Fish. Rev.*, 22 (5), pp. 1-5.

Shewan, J. M. (1961). 'The microbiology of sea water fish', in *Fish as Food* (ed. G. Borgstrom), vol. I., Academic Press, New York, p. 487.

Shipton, J. (1954). 'Estimation of sulphur dioxide in dried foods'. *CSIRO Food Preserv. Q.*, 14, pp. 54-66.

Til, H. P., Feron, V. J., and de Groot, A. P. (1972). 'The toxicity of sulphite. I. Long-term feeding and multigeneration studies in rats'. *Food Cosmet. Toxicol.* 10, pp. 291-310.

Vanderzant, C., and Nickelson, R. (1971). 'Comparison of extract—release volume, pH and agar plate count of shrimp'. *J. Milk Food Technol.*, 34 (3), pp. 115-18.

Vogel, A. I. (1961). *A Text-Book of Quantitative Inorganic Analysis.* 3rd ed., Longmans, London.

Williams, O. B., Rees, H. B., and Campbell, L. L. (1952). 'The bacteriology of Gulf Coast shrimp. 1. Experimental procedures and quantitative results'. *Texas J. Sci.*, 4 (1), pp. 49-52.

DISCUSSION

Burton. I think you said that the use of refrigerated sea water had gone a long way toward eliminating black spot.

Ruello. No. Not black spot, bacterial spoilage.

Burton. I don't quite agree with this. I think that one of your biggest problems is the dirty tanks. A lot of these boats have very dirty tanks, specially behind the coils which you pointed out and also, if they fill up their tanks within the rivers you'll find that the brine is terrible dirty. This I think, no matter whether they refrigerate or not, will still cause a quantity of bacteria. You said a little while ago that the exporter could clean his black spot up by soaking in metabisulphite for a couple of days but I think that if we did this the Department of Primary Industry would be down on us so quickly that we'd be out of business. Were most of your tests done on king prawns?

Ruello. All tests were all done on king prawns. They are the only species I can get in large quantities close to Sydney.

Burton. I feel that the cleanliness of your boat, cleanliness of your brine is very important in preventing the formation of black spot, and then making sure that your product arrives at the right temperature. Now, in your experiments with CO_2, you say that this stopped black spot did you?

Ruello. Yes.

Burton. Did you also find that if you left them too long in CO_2 that the adverse effect occurred, that the black spot became worse?

Ruello. No.

Burton. I think that this does occur.

Ruello. I did not find that occurred. In fact, I found that what occurred was a pH inhibition of black spot. There are a few other points I'd like to make regarding some of your questions. Although people usually don't like to talk about the use of sodium metabisulphite, it is being used and if you measure the sulphite content of a large sample of prawns, as I have done, I am sure you will find that a considerable number of the prawns do contain sulphite. You were saying that black spot can be stopped by cleanliness of the tank?

Burton. I mean reduced, not stopped.

Ruello. I don't see how cleanliness of the tank is going to reduce something which is caused by an enzymatic reaction.

Burton. Look, if you have got a lot of contaminated prawns caught in behind your coils you're going to have bacteria against your walls. We insist on all our tanks being scrubbed out.

Ruello. But didn't I just say that black spot is an enzymatic reaction. It has nothing to do with cleanliness of the tank.

Burton. But we started up talking about refrigerated sea-water.

Ruello. But you were making a point that clean tanks are important in stopping black spot.

Burton. You've got to have both.

Ruello. Yes. I have found that many fishermen believe that black spot is caused by bacteria and because of this they have an almost undying faith in chemicals—anything that they believe will stop black spot. Now I feel that if fishermen understood what causes black spot they will be better able to prevent it. Now you are making a very good point of cleanliness of tanks. I find those brine tanks that are lined with coils absolutely hopeless for a large fishery like the one you saw. Not only is it difficult for fishermen to clean behind the coils but they ice-up because they are in contact with the sea water, so another shovel of salt goes in to de-ice the tanks and so the salt content of prawns goes up. If the tanks are equipped with recirculating brine there is little problem of 'icing-up', but it is important to keep the filters clean. Most of the bacteria on living prawns are found on the shell and head, and up to 90% of the bacteria can be removed by thorough washing with clean sea-water. Bacterial spoilage will be negligible if prawns are emptied onto a sorting tray, thoroughly washed after sorting, and then placed into clean chilled sea-water. Of course fishermen should not use polluted water in their brine tanks.

Burton. A great deal of the fishermen do fill their tanks beside the Karumba wharf, and that river would be the most polluted river at the moment in the north.

Kirkegaard. I wonder if you could tell us a little more about your taste panel. It was seen that the ultimate aim of this work is to get the best product or the most preferred product on the market. First of all, is the prawn preferred by your taste panel a certain type of prawn? Is this similar to prawns preferred by the export market? Is it also then a suitable prawn for preparation for the export market as, for example, breading or some other preparation?

Ruello. We do have a problem in getting a discriminating taste panel because most Australians do not eat many prawns, and consequently like almost anything you serve. Fortunately the staff at CSIRO Food Research, Ryde, are familiar with taste panels and are, therefore, discriminating about most food. We have found that the appearance of boiled prawns is important in New South Wales because this is how consumers buy their prawns. To avoid the problem of appearance, we serve prawns in two ways, i.e. whole boiled or cutlets. I do not think Australian tasters are as discriminating as the Japanese so I use a small panel of tasters trained on freshly caught prawns, and it is difficult to pass stale prawns as fresh with these tasters. During assessment of the effects of storage on prawn flavour and texture the tasters are always referred back to the freshly caught product. In doing this I hope to eliminate certain taste preferences. For instance, most average tasters prefer a firm textured prawn in preference to a freshly caught prawn which they consider to be too soft—this further indicates that the average taster is familiar only with stale prawns.

Darling. Can Mrs Ruello comment on the importance of bacteria in the spoilage of prawns?

Ruello. There is conflicting evidence in the literature about the importance of bacterial spoilage and the quality of prawns. There is no agreement about the total number of bacteria which would indicate that spoilage had occurred, although there are values given in certain State food regulation Acts. You cannot predict bacterial counts from the appearance of a prawn.

Burton. We insist that skippers of our vessels change the refrigerated sea-water or brine every two days. This is to prevent the water going black. Have you done any expriments which would indicate how often the water should be changed?

Ruello. No, because it is evident from the literature that changing the refrigerated sea-water does not extend the storage time. The water will go black after about 2-3 days on a vessel that does not add any chemical to the brine. A problem with recirculating brine is often in the design of the tank. If the returning brine is sprayed into the tank, the water becomes aerated and black spot will occur faster.

Burton. You just answered my next question.

James. I have done work with changing brine and found that it doesn't have any effect on the bacterial count of prawns. The only thing that you affect is the colour of the brine. Another point I was going to ask was, do you consider that the possibility of using CO_2 or buffered sea-water is a fact only affecting a reduction in bacterial counts?

Ruello. Some workers claimed that addition of CO_2 to the water extended storage life because of reduced bacterial action. However I did not find bacterial spoilage to be as important a problem as black spot formation. CO_2 was successful in controlling black spot, but the prawns would not be acceptable to consumers because they were too tough after cooking. I understand that some species of prawns naturally have a soft texture and would be improved if they were tougher.

James. No, in fact it goes soft with CO_2. I've done quite a lot of work in this field.

Ruello. King prawns stored in refrigerated sea-water to which CO_2 had been added were soft and mushy when raw, but when cooked they became extremely tough, and the cooking losses were about 20 per cent.

James. One more question. In relation to the use of SO_2, apart from the obvious problems that fishermen would have in adding it to the brine, can you give any good reasons why dipping is better than a controlled level in the tank?

Ruello. If fishermen are to produce top quality prawns with no black spot, and with a sulphite content of less than 10 ppm they would have to dip the prawns. My experiments indicated that low concentrations of sulphite in the refrigerated sea-water, say 100 ppm, would not completely prevent black spot formation, and about 10% of the catch would get abdominal black spot although the flesh had less than 10 ppm. The addition of sulphite to the refrigerated sea-water would only be suitable for tanks equipped with recirculating sea-water to ensure equal distribution of the chemical. If fishermen maintain the sulphite level at 100 ppm by checking the concentration daily, I feel sure that abdominal black spot would not develop and high sulphite levels in the flesh would be avoided. However fishermen would be faced with the same problem as with the use of buffered sea-water, they would be required to accurately measure a component in the brine.

James. Just to add a note of warning to the industry—there is quite a possibility that the use of SO_2 will be stopped, which will mean that some alternative will have to be found and the reason for this is that many countries don't want SO_2 as a food additive whereas Japanese and Brazilians and Cubans are trying to up the level from the present 30 ppm to something of the order of 100 to 200 ppm and there's a considerable amount of resistance to this by other countries. Have you tried ascorbic acid?

Ruello. Ascorbic acid is too expensive and it is not as effective as sodium metabisulphite. I would like to ask you a question. With the possible banning of SO_2, does this mean a total ban on the use of sulphites, or does it mean you can use metabisulphites as long as you get no residual sulphite in the flesh?

James. This is a matter we will be having further discussions about. We would like to deal with the justification of the use of SO_2 technologically, which is the only way of getting a certain level permitted, and I feel that we've done this, but with certain countries pushing for higher levels (which is pushing for bleaching levels), it is going to be an increasing problem with countries which do not permit use of SO_2, and no work has yet been done on residual levels after cooking, i.e. in the final cooked product.

Ruello. I have done a lot of work on the uptake of SO_2 by both raw and cooked prawns. I found that normal cooking does not remove very much SO_2 from prawn flesh, but washing for 30 minutes before cooking significantly reduces the SO_2 content. If the initial SO_2 content was low, say less than 15 ppm, the level in the washed flesh was negligible; if the initial level was about 60 ppm, it would be reduced by between 20-80% by washing. Further cooking of the washed prawns did not reduce the SO_2 level. The figures are in my paper.

Pane. Have you done any work on holding prawns frozen at −20°C? You said, I think, some time during your paper that holding prawns at that temperature would stop black spot. We've had a certain amount of problems with this in that we theoretically hold our prawns at −20°C and we find that after a period of time, we could hold some of them for two or three months, we do get some bacterial and black spot action. Have you done any work on this?

Ruello. My work has been limited to RSW storage. However I believe you can get this problem if the internal temperature of the prawns is not below −13°C, as the prawns are not deep frozen unless they are below this temperature. Over a period of 2-3 months unglazed partly frozen prawns will go black. The best safeguard is probably to glaze the prawns immediatly after freezing, especially if they are individually quick frozen. This seals out the air, and even if the prawns are only partially frozen, they should not go black. Have you tried glazing your prawns?

Pane. We have a shore installation which freezes and glazes at the one time. We don't actually glaze afterwards unless we are going to keep them for longer than 2-3 months.

Maguire. You mentioned washing quite a few times. Have you any idea of how much washing the prawns will take before you get leaching of any flavour factors?

Ruello. I do not know an exact time. This could only be established with the use of a taste panel. I would say, however, no longer than 10 minutes. The species is important. With king prawns, 30 minutes is probably long enough to remove most of the prawny flavour.

Moriarty. Presumably ascorbic acid would just maintain reducing conditions. I was wondering how the bisulphite actually works in preventing black spot. Is it simply by maintaining reducing conditions or mopping up oxygen in the tissues?

Ruello. The melanin pigment formation by the tyrosinase enzyme system has been shown to be inhibited by ascorbic acid or other reducing compounds. The inhibition caused by bisulphite compounds is thought not to be due to the reduction of the intermediates in the enzymatic reaction, as that by ascorbic acid is, but has been attributed to the conjugation of the substrate or its oxidation product, with the sulphite compounds.

Moriarty. What I was wondering is if other organic sulphite compounds have been tried?

Ruello. We are limited by two factors in our choice of a reducing compound or sulphite compound. They must be food grade and economic. At present sodium metabisulphite is both food grade and cheap at about 40 cents per kilo.

Anderson. I wonder if you have done any work on species other than the king prawn? Do other species get black spot more readily under the same conditions than king prawns?

Ruello. I have only studied black spot formation in three species—king, school and royal red. These results did not suggest an important difference in the rate of black spot formation amongst these prawn species. However there is a fair amount of work in the literature which does suggest that differences in the rates of black spot formation amongst different species do exist. I cannot get fresh banana or tiger prawns in Sydney to follow up this problem.

Anderson. Does the literature say which species blacken more readily?

Ruello. No. To the best of my knowledge noone has studied black spot formation in banana prawns.

Burton. On this dipping tank that you showed us the slide of, we are very pleased to see CSIRO coming this way but this would be a very slow process wouldn't it?

Ruello. No. The machine will give a 30-second dip. If a lug box is used, 11 000 lb or 5 000 kg can be treated in one hour.

Burton. If you've got a boat that comes in with say 27 or 36 thousand kilos and a couple more to come and they all land at your factory on the same day you've got to get as many through as you can. Personally I don't feel that the dipping would be a proposition for your banana prawns if you get a bumper year. I think that on your tigers and things like this you'd be right but on your banana prawns I think that you'd need a pretty swift machine to handle the product properly.

Ruello. We were hoping that the dipper would be used on board the vessel. The dipping treatment prevents black spot formation for up to 8 days if the prawns are held in chilled seawater. If a vessel unloads a catch that is 2-3 days old, the prawns can be held for a further 3-5 days in the factory before processing, as long as the prawns are not exposed to air. It would not be necessary to treat the prawns again after unloading, thus avoiding the problem you described.

Burton. But if you get a couple of throws in which you get 18 000 kg which was done in the boom years, what happens?

Ruello. You could afford to buy two dippers.

ECONOMICS OF DEEP WATER TRAWLING OFF THE EAST COAST OF NEW SOUTH WALES

BY T. B. GORMAN
Senior Biologist New South Wales State Fisheries
211 Kent Street, Sydney, N.S.W.
and
T. F. MEANY
Principal Research Officer Economic Research Section, Fisheries Division
Australian Department of Agriculture, Canberra, A.C.T.

ABSTRACT

Exploratory fishing by the N.S.W. State Fisheries research vessel Kapala *indicate that a considerable, and as yet unutilised, resource of prawns and fish occur on the upper continental slope off the New South Wales coast. These prawn resources are assessed at a minimum of about 450 000 kg of prawns. This paper discusses the type of vessel most suitable to utilise this resource and presents annual budgets for a 17 m wooden vessel and a 24 m steel vessel.*

Exploratory fishing cruises by the N.S.W. State Fisheries research vessel *Kapala* indicate that a considerable resource of prawns and fish, presently unutilised, exists on the upper Continental slope off the N.S.W. coast. Although fishable grounds have been located in deep water along much of the NSW coastline, detailed assessment has been limited to the grounds located between Port Jackson and Port Stephens. This ground is estimated to be about 960 km^2 in extent. Catch rates so far experienced on this ground indicate a minimum stock availability of about 453 000 kg of prawns. At this stage no indication can be given as to the maximum annual catch which could be taken from this ground, nor is there any indication as to the extent to which the catch would fluctuate from year to year.

The average annual catch of prawns from oceanic waters off the N.S.W. coast is about 1.13 million kg per annum. Therefore, the new grounds between Sydney and Port Stephens could contribute significantly to the current annual catch. The catch which could be taken from the other, less extensive, grounds located by the *Kapala* but not yet subject to detailed study must also be kept in mind.

Fishing to date has indicated that during autumn and the early part of winter prawns are taken mainly at night. In late winter and spring the prawns can be taken both day and night. Fishing conditions become difficult in the late spring and during the summer due to a strong southerly set in the surface current. It appears likely that these conditions may curtail fishing operations on the grounds between Sydney and Port Stephens but boats may be able to work ground further south during this period.

Besides the catches of prawns large quantities of fish have also been taken. Echo soundings indicate that even greater quantities might be taken just off the bottom. All fishing to date by the *Kapala* has been done using a prawn trawl with a low headrope opening. The use of a large fish trawl with a high headrope opening or a mid-water trawl fishing just off the bottom would probably result in substantial catches of fish being taken. Even using the present prawn trawl the incidental catch of fish would provide a considerable amount of additional income.

The main limiting factors on a boat's ability to work are wind and sea conditions. Meteorological data for the past ten years indicates that the wind on the N.S.W. coast exceeds force six on a average of 2.3 days per week. Boats from 17 to 24 m in length, which might be expected to form the basic units in the fishery, should be able, in most circumstances, to work comfortably in winds up to force five. Weather patterns are fairly predictable; a period of two to three days of good weather generally being followed by a period of 12 to 24 hours of winds greater than force six. There are of course much longer cycles but weather conditions will generally dictate trips of two or three days.

Besides these normal weather conditions which affect all fishing on the N.S.W. coast, the distance boats in this fishery will be operating off the coast (up to 56 km) will mean that they will experience strong westerly winds both day and night during winter months (the strength of these winds is much greater offshore than they are closer to the continent). Although weather conditions will influence the amount of fishing time available to boats of 24 m and less it would not have such a marked effect on boats of more than 30 m.

As boats operating in this fishery would often be working out of sight of land the ability to navigate by dead reckoning would be required to locate fishing grounds accurately.

Boats of 17 to 24 m could be expected to work two or three-day trips and there would be no problems in holding fish on ice for this period but an RSW system would greatly increase carrying capacity and ease handling.

The installation of a recirculating refrigerated sea-water system would however be essential to preserve the large prawn catches, which may exceed 1½ to 2 tonnes. Such a system would eliminate the tedious task of icing the catch, and in most cases, the vessels could remain at sea for at least 6 days and still return with an acceptable prawn product.

It is considered that boats in excess of 17 m could satisfactorily work in this fishery. Boats of this length could work almost as many days as boats of 24 m. For any greatly increased ability to work in rougher weather boats would need to be of 30 m or more. Tests using the *Kapala* have indicated that an efficient trawling speed for the prawns is from 2.5 to 2.75 knots. Neither the depth fished nor the sizes of trawls used so far appear to have a great effect on the power required to tow the trawl at this speed. A shaft horsepower of 160 to 200 would be sufficient to meet the needs of the fishery however a contingency reserve would be most desirable and it is suggested that for best results an engine capable of delivering 250 to 300 shaft horsepower should be installed.

It is also suggested that the winch be driven by a separate auxiliary motor, rather than from the main engine. Alternatively, the winch could be driven from the main engine if a variable pitch propeller was fitted.

While a boat length of about 17 m is not considered a limiting factor the actual draught of the boat may be. Many existing boats may not be capable of attaining maximum thrust during trawling due to the shallowness of their draught. In order to obtain the best results a draught of 2.1 to 2.4 m will be necessary. Boats of shallower draught could not use a propeller of the required size due to the risk of loss of power due to cavitation.

BUDGETS

The following budgets have been prepared for two types of boats: a 17 m wooden-hulled boat and a 21 m steel-hulled boat.

In arriving at these budgets the following assumptions have been made:

(a) The catching of prawns takes place throughout the year. For the early part of the year the catching of prawns is restricted to the hours of darkness. From late winter onward equal catches are made both day and night. It is further assumed that the level of catch is constant throughout the year.

(b) For the purposes of this exercise it has been assumed that boats of 21 m have no operational advantages over boats of 17 m, and that all boats work an average of 3 days per week. Boats of 21 m would probably have some operational advantages however but this has not been possible to quantify. 10 weeks are assumed to be lost each year with slipping, refits, etc., this period is assumed to correspond with the period in midsummer when current conditions make fishing difficult. Other maintenance is done on the boats when laid up due to weather conditions and other causes.

(c) When at sea the boats work round-the-clock. When prawns are available both day and night it is assumed that six two-hour shots are made each 24 hours. At other times of the year three two-hour shots are made for prawns each night while two shots of 3 to 4-hours duration are made for fish during daylight hours. (The shorter duration of shots when fishing for prawns is designed to minimise the damage done to the prawns). The remaining time is assumed to be spent in steaming, shooting and retrieving the gear, etc.

(d) Each shot when fishing for prawns is assumed to produce 68 kg of prawns and 450 kg of fish suitable for use in pet food manufacture. (For simplicity it has been assumed that no fish is sold for human consumption. No doubt a significant but unknown proportion of the fish would be marketed for human consumption and this would have the effect of increasing total income to the boat). When fishing only for fish a catch of 1 800 kg of fish suitable for pet food manufacture is taken each shot.

(e) The price of $1.21 per kg is paid for prawns and 11 cents per kg for fish.

(f) Prawns are held in refrigerated brine or refrigerated sea-water while fish are

Budget 1

17 m wooden boat As at January 1974

Working an average of 3 days per week, 42 weeks per year. For 21 weeks six shots for prawns are made each 24 hours. For the remaining 21 weeks three shots for prawns and two for fish are made each 24 hours.

Item	*Explanation*	*New boat*	*Second-hand boat*
Capital invested	—	$110 000	80 000
Catch of prawns	(see assumptions)	38 658 kg	38 658 kg
Catch of fish	(see assumptions)	486 818 kg	486 818 kg
		$	$
Income from prawns	$1.21 per kg	46 777	46 777
Income from fish	for pet food @ 11 cents/kg	53 550	53 550
Gross income		**$100 327**	**$100 327**
Costs			
Fuel and oil	(see assumptions)	4 790	4 790
Ice	@ $12 per tonne (see assumptions)	3 213	3 213
Crew stores	($16 per man-week)	2 688	2 688
Deck stores	—	500	500
Sub-total (trip costs)		**$11 191**	**$11 191**
Repairs and maintenance	—	7 000	12 000
Gear costs	Net, warps, boards, etc.	3 000	3 000
Sub-total (running costs)		**$10 000**	**$15 000**
Licences and other fees		150	150
Accountancy		150	150
Telephone, postage, etc.		200	200
Bank charges		50	50
Subscriptions		50	50
Land rates		200	200
Sub-total (administration costs)		**$800**	**$800**
Vehicles costs	$15 per week	780	780
Depreciation	New boat over 15 years second-hand boat over 10 years	7 333	8 000
Payment to skipper	10% of gross income	10 033	10 033
Payment to crew	7% of gross income each	21 069	21 069
Interest on borrowed money	Assume 50% borrowed at 10%	5 500	4 000
Insurance	Fully insured @ 5.5%	6 500	4 400
Total costs		**$73 206**	**$75 273**
Profit	Gross income *less* total cost	$27 121	$25 054
Return on capital	$\frac{\text{Profits} + \text{Interest on borrowed money} \times 100}{\text{Capital invested}}$	29.7%	36.3%

held in RSW or ice. The amount of ice required is assumed to be 50% of the weight of fish.

(g) Fuel consumption for a 275 shaft horsepower engine averages 27.28 *l* per hour and costs 4.8 cents per *l*, an additional 20% is added to these costs for lubricating oils, etc.

(h) Boats work with a skipper and crew of three.

DISCUSSION

Pane. Just a couple of questions on your 21 m steel boat, your budget No. 2. I've been trying to find out if we've been living in a rather fairy-tale world because we fish four of these boats and we can't get ourselves skippers. If we offer them $13 000 they laugh. If we offer them $25 000 they chuckle and at about $30 000 they start to tune in. I would also like to query your repairs and maintenance of $7 000. To

Budget 2

21.5 m Steel Boat, as at January 1974

Working an average of 3 days per week for 42 weeks per year. For 21 weeks six shots for prawns are made each 24 hours. For the remaining 21 weeks three shots for prawns and two for fish are made each 24 hours.

Item	*Explanation*	*New Boat*	*Second-hand Boat*
Capital Invested	—	**$250 000**	**$150 000**
Catch of prawns	(see assumptions)	38 658 kg	38 658 kg
Catch of fish	(see assumptions)	486 818 kg	486 818 kg
		$	$
Income from prawns	@ $1.21 per kg	46 777	46 777
Income from fish	for pet food @ 11 cents per kg	53 550	53 550
Gross income		**$100 327**	**$100 327**
Fuel and oil	(see assumptions)	4 790	4 790
Ice	($12 per tonne, see assumptions)	3 213	3 213
Crew stores	($16 per man-week)	2 688	2 688
Deck stores		500	500
Sub-total (trip costs)		**$11 191**	**$11 191**
Repairs and maintenance		12 000	16 000
Gear Costs	Nets, warps, boards, etc.	3 000	3 000
Sub-total (running costs)		**$15 000**	**$19 000**
Licences and other fees		200	200
Accountancy		150	150
Telephone postage etc.		200	200
Bank charges		50	50
Subscriptions		50	50
Land rates		200	200
Sub-total (administration costs)		**$850**	**$850**
Vehicle costs	$15 per week	780	780
Depreciation	New boat over 15 years, second-hand boat over 10 years	16 666	15 000
Payment to skipper	10% of gross income	10 033	10 033
Payment to crew	7% of gross each	21 069	21 069
Interest on borrowed money	(Assume 50% borrowed @ 10%)	12 500	7 500
Insurance	Fully insured @ 5.5%	13 750	8 250
Total costs		**$101 839**	**$93 673**
Profits	Gross income less total costs	—$1 512	6 654
Return on Capital	$\frac{\text{Profits + interest on borrowed money} \times 100}{\text{Capital invested}}$	4.4%	9.4%

scrape or to sand and to paint a 21 m trawler will cost in excess of $10 000. You don't seem to have included in these repairs on engines and so on which on average would cost in excess of $5 000 per year. I would just query how you arrived at the repairs and maintenance and at the payment to skippers.

Gorman. Have you ever seen a New South Wales fishing vessel?

Pane. We have several of them which come up to fish for us in Queensland and what they do then is cut the insides out of them and replace them.

Gorman. Frank Meany would have been a better person to speak to about some of these figures here because I didn't get them. The maintenance on the New South Wales boats is often minimal; depending on whether the boats are owner-operated or not. I might add, which I should have done, that this figure is actually for an owner-operated boat, not a company-operated boat. One of the problems the fishing industry has got to face up to is that if they want to get a bloke to go to sea, they have to provide considerably more comfort than companies are prepared to give them at the moment. A bloke can go to sea on a big, safe, comfortable merchant-vessel which doesn't move around and can work a steady shift and he can get paid $15 000 to $20 000 a year for it. Now there is no possibility of attracting these people into the fishing industry. You've also got the problem of competition from ashore. You've got people earning good money, if they're competent. Why should they put up with a mediocre salary on board a boat. They are not going to do it and it's something that the industry has got to face up to. I don't think industry as a whole has woken up to this fact. Anyway you would like to see us uplift our maintenance and repairs.

Kirkegaard. Has anyone expressed any interest in going into this fishery?

Gorman. Oh yes, we've got quite a few.

Kirkegaard. Is anyone preparing to go in with a 200 tonne subsidy vessel?

Gorman. Yes. I might as well tell you this again. I told you it earlier on but you possibly forgot. This fishery has in fact opened up since Christmas time and we've got something like 12 trawlers working there already. They are working down to 290-330 m and they did extremely well last year, in fact they were only going out and doing one trawl and coming home. That's all they needed to do. I forget the actual quantity they were catching.

Evans. I'd like to say that it's important to realise that budgets are not intended to portray exactness. They're only a guide to enable fishermen to assess the likely reliability of going to the fishery. We have a lot of problems with the cost of the 21 m boat because D.P.I. hasn't as yet surveyed a fishery where there are 21 m boats operating. We have done a survey of the northern prawn fishery but at the time of the survey the Japanese boats, in particular, were only just entering the fishery and we weren't able to assess the economics of them. We do intend to do another survey later on. In relation to the payment to the skipper I think it's worth mentioning that although this $13 000 might appear low to say a company trying to operate a boat in the northern prawn fishery, and I agree that it is low in regard to that, for a boat operating off Sydney I'd say that the figure should be reasonably realistic.

Dredge. Have you done a comparable cross-breakdown for shallow water trawlers.

Gorman. We've done it for New South Wales Danish seine fishery and it has been published.

Dredge. How comparable is it?

Gorman. Off hand I can't remember but as I mentioned earlier the shallow water prawn trawlers could expect to earn between 50-60 000 dollars a year gross, off northern New South Wales. At least this is what they tell us. I think this would be about right. They average about 450 kg of prawns a week and the price of those prawns now could be anywhere between $50 000 and $60 000 but if anyone's got any more up-to-date information please don't sit there quietly.

Penn. I've just been doing some arithmetic with your proposed landings and it works out that the average boat is going to land for a 3½ day trip somewhere in the order of 14 500 kg of fish and prawns. If this is an average figure I guess they are going to have to go a lot higher for the times when in fact they don't catch any prawns or fish. It seems unrealistic to expect a boat of that size to be able in fact to store those sorts of quantities.

Gorman. I don't think so.

Ruello. You said that this fishery has been operating since December. Have they been catching prawns?

Gorman. They are only operating during the day with fish trawls. They have been going out and doing one shot and coming home. They haven't attempted to catch prawns. We had some prawn catches from these boats earlier on and they came back with just a sort of black mess in ice.

Ruello. What price would those be at the city fish market?

Gorman. I think they might have got a few cents a kilo.

Ruello. How many think that $1.21 per kg is a justifiable figure?

Gorman. We were given this figure by a likely buyer.

Ruello. By a buyer who realised they probably wouldn't sell well.

Gorman. He was prepared to pay this. You've got to take into account a heading loss of 50%. In actual fact the meat was costing him about $2.20 per kg. Now he could sell that for about $3.30 to $3.85 as tails to a catering firm.

James. Would these people have to change their gear as they change from fish to prawns? If so they'd have to have more than one set of gear.

Gorman. Not necessarily. In fact, this is one of the exercises we have done. It would be much simpler to use just the one net.

James. While working in the North Sea we used to change gear at night and make one run all night for catfish, but you mentioned that you are not considering an industrial production fishery here, but with the price of fish meal as it is at the moment it's getting very close to 9 or 11 cents per kilo.

Gorman. This is a recent development. I don't know how long it will last. It will depend a lot on what happens in South America.

James. Well, fish meal prices are unlikely to come down.

Gorman. Possibly. We had a look at the possibility of industrial production of trawl caught fish but with small vessels I am not so sure. You are talking in terms of about 4.4 cents per kg which is a lot less than 11 cents per kg.

Walker. As you have a rough estimated annual catch of prawns of about 45 000 kg and you have an estimated stock availability of 450 000 kg, do you think that . . .

Gorman. Can I interrupt here? It's not an estimated stock of around 450 000 kg at all.

Walker. Well, it's what the indicated stock is on the graph.

Gorman. It's a stock of prawns indicated by the gear that we used to do the survey. That's all it means. As you remember I pointed out to you that possibly 10% to 12% of the total prawn stock was actually walking around on the sand at any one time so that they are actually vulnerable to the trawl gear.

Walker. Well, if you assume that these boats can catch 45 000 kg prawns surely you have trouble with the number of vessels that could enter the fishery if it was managed as a prawn fishery.

Anderson. Following Mrs Ruello's comments on the edibility of the royal red you've got the price down as $1.21. Assuming that you get 50% yield that brings it at $2.42. I don't think there's anybody paying $2.42 at the moment in the northern area for prawns. Secondly you've peeled these down to meat. By my calculations it is going to cost about $3.96 kg for that meat whereas you can buy imported Singapore meat at the moment, graded, everything, at $2.42 to $2.53. Is that economically viable?

Gorman. First of all about peeling these prawns they peel themselves, for a start. I'm not being funny but this is about right. They're very thin shelled, fragile and very easy to remove. You can pull it off in one piece. I'm not really competent to go into the economics of retailing or wholesaling prawns. I can only actually go on the information I've been given. You have told me what the story is up north. I think that if we relate this back to New South Wales, we would have to take into consideration that we are actually selling to a market that's on our doorstep and in New South Wales, in Sydney alone there is a market with a few million potential buyers in it, and prawns are within three hours reach of Sydney itself so I think these points have got to be taken into consideration. Your cost structure up in the north—I don't think it would be directly comparable. I think it would have to be adjusted to exclude your enormous transportation costs, isolation costs, costs of getting equipment up the north for a start, servicing costs. The cost of getting anything up there must be, I assume, a lot higher than it would be in Sydney.

Anderson. Well at the moment you can buy peeled prawn meat, banana species, 26-50, anything graded in that range for $2.64 to $2.75. How is this going to compete. Even if the prawn jumps out of the water peeled, it's still $2.42 per kg.

Gorman. Well, what figure would you like to put on it. You're the experts in this. We want your advice.

Anderson. I don't know anything about royal red prawns.

Gorman. We'll send you a sample.

PLANNING FOR FISH PRODUCTS AND MARKETS

BY W. MURRAY
General Manager, Queensland Fish Board, P.O. Box 54, Morningside, Queensland

ABSTRACT

It could be of advantage to the individual processor to consider whether he would gain financially by broadening the present line of production in his factory.

Many businesses will get a substantial percentage of their sales volume and net profits this year from products which did not exist a few years ago, and the trend will undoubtedly continue.

The right attitude to planning and developing products is one that constructively encourages and thrives on innovation. The watchword for management thus must be 'innovate or die'.

If it is to survive a firm must be market-oriented, and must allow for the influences of competition and market demand. Product planning and development are no less important in achieving and maintaining an economic operation. In the present strongly competitive atmosphere it bodes ill for any processor who is not competent in all phases of operations, since this would weaken his resilience to withstand other than short-term economic pressures.

The scope of product planning and product development includes whether the firm should expand or simplify its line; what new uses there are for each item; whether the quality is right for the intended use and market; what brand, packaging and labelling should be used for each product; and also whether the processor should brand his product or sell any or all of his output under a middleman's name.

Some processors sell their own brands in competition with one or more middleman's brands, each brand hopefully tapping markets that would not otherwise be secured by the others. There is a strong case for this method if greater penetration can be achieved.

PRODUCTS

It could well be of advantage to the individual processor to consider whether there is some financial gain to be achieved in broadening the present line of production in his factory. Certainly if some other processors are achieving a greater return through a more effective product range, a processor could ill afford not to investigate this aspect closely.

Product planning and development then is a really worthwhile subject for management to consider. The term 'product' is used in the sense that any change in a physical feature, however minor it might be, creates in effect another product.

Whilst it is helpful to have a whole design organisation framework within which to carry on the product planning and product development functions, a more important key to success is the attitude which the entire firm has towards planning and developing products. The right attitude towards planning and developing products must permeate all levels of managerial thinking. The right attitude is one that constructively encourages—in fact thrives on innovation. The watch word for management must then be 'Innovate or die'. Many businesses will get a substantial percentage of their sales volume and net profits this year from products which did not exist a few years ago and this trend will undoubtedly continue.

Specifically the scope of product planning and product development activities include decision making and programming in the following areas:

(a) Should the firm expand or simplify its line? There could well be considerable advantages in extending the line if this results in a reduction in plant idle capacity. There will always be the pressure in season for plant to process product in the shortest possible time, and it is not practicable to undertake at these times operations that will prolong the time in presenting a product in saleable form. However there could for example be advantages in placing aside in storage product of a certain specification for subsequent additional processing to produce a 'new' product rather than to market the product in its 'usual' form. This procedure can only be justified of course if the profit position of the manufacturer is improved as a result.

Quite probably, fairly sophisticated equipment additional to existing equipment might be required to effect the change in the method of operations, as against performing the particular operation mainly by hand at considerably higher cost. The question of factory space could also become critical and it might rule against any modifications to existing procedures. Certainly a proposition of this nature becomes less and less attractive if it finally entails erection of a new factory to carry out the manufacture of the proposed new product. If it is simply a matter of greater utilisation of the existing facilities, the question of a new product could, subject to the other factors to which I will refer, appear to be attractive. The additional finances required having regard also to the delay in achieving a return must also be taken into consideration.

(b) What new uses are there for each item? The product that the processor has under consideration would probably be either an adaption of existing products, involving a single differentiation in the existing article, or an imitative product which is new to your firm but not new to the market.

Most products under consideration would probably be an imitative or a 'me too' product, although it is quite possible when considering the Australian market in isolation that products new to this market may be developed.

(c) Is the quality right for the intended use and market? The wisest course of action here would probably be to test your own test-run against products commercially available. This is of course on the assumption that you are involved with a 'me too' product. Test panels who are not aware of the manufacture of the various samples presented to them are quite useful for this purpose. A study of the type of packaging used by other manufacturers should also be undertaken although probably a full appreciation of all the packaging features will not be gained until such time as in line production is undertaken. Tests that my own organisation have carried out in calling test panels have disclosed substantial differences in the quality of products tested although such disparities might not be anticipated. It would be a very wise course then to ensure that quality is right before becoming committed to a certain method of production.

(d) What brand, packaging and labelling should be used for each product? The word 'brand' is a comprehensive term and in one way or another includes other more specialised terms.

A processor must decide whether to brand his product or whether to sell any or all of his output under a middleman's name.

A processor may elect to adopt the strategy of selling part or all of his output under the brand of one or more middlemen. Financial circumstances are a major reason for this trend. Orders are typically large, payments prompt, and a processor's working capital position is improved. Also a manufacturer may utilise his production resources more effectively, including the plant capacity. Furthermore, refusing to sell under a wholesaler's brand will not eliminate competition from this source. Many middlemen want to market under their own brands, and if one firm refuses their business, they will go to another.

Probably the most serious limitation to marketing under a middleman's brand is that the processor is at the mercy of the middleman. This disadvantage increases as the proportion of his output going to the middleman's brand increases. Furthermore, the processor has no assurance of continuity of orders, and often the unit profit is lower on volume sold under the middleman's brand.

Some processors engage in the practice of selling their own brand in competition with one or more middlemen's brands, with each brand hopefully tapping markets that would otherwise be serviced by the others. There is a strong case then for this method if greater penetration can be achieved.

The type of packaging to be employed in the planned product is of particular importance and it is worthwhile devoting a considerable amount of time to this factor.

The foremost reason for packaging is that the package provides a means of identification of a particular manufacturer's merchandise which might otherwise appear identical to that of competitors. It furnishes a vehicle for brand names, trade marks and labels. Packaging can be used to create a semblance of distinctiveness in product in which little distinctiveness actually exists. It is necessary to ensure that the package is sufficiently rigid to withstand handling throughout the marketing chain otherwise problems will soon arise. If it is proven that the design is deficient in some regard action should be taken to modify the design rather than to persist with a pack that is not doing the job or is not really competitive.

A firm must decide whether or not to develop a family resemblance in the packaging of its several products. Family packaging involves making the entire package identical for all purposes or using some common features on all packages.

The mandatory requirements of the Exports (Fish) Regulations do of course determine in large measure information to be shown in the way of labelling.

(e) In what quantities should each item be produced? It would be reasonable (though not necessarily compulsory) to start at a fairly low level in order to get the feel of the operation within the factory and at the same time test the market in limited geographical areas.

Probably no great capital expenditure would have been incurred to this point, and if management decides, the product could be abandoned without serious disruption. In other words, management must make a final decision regarding whether to market the product commercially.

Once a decision is taken to enter full scale production the product enters its life cycle and external competitive pressures become a major determinant of its destiny.

How should the product be priced? The pricing freedom of every firm is circumscribed by the pricing action of its competitors. The more alike the product within an industry, the more the members of the industry are governed by that of other members.

Unless a product is unique which is unlikely, the processor will probably find it necessary to condition his price to those already established in the industry, i.e. the processor has the options of adopting the optimum price level established, or establishing his price at recognised differentials either above or below it.

It is extremely doubtful in my opinion whether costs play a particularly large part in the fixing of prices. Certainly costs figure predominantly in the businessman's thinking. There is no harm however in emphasising the importance of costs in pricing provided that:

(i) Its function is to set a floor to prices;
(ii) It is not a simple figure (factors of volume, price, costs).

Business executives have a decided tendency to think of floor cost as the level below which they will not price. Economists tend to suggest variable costs as a minimum standard. Probably both positions are extreme.

MARKETS

In fisheries, prices at the landing stage are determined in conformity with general economic rules by the simultaneous action of supply and demand. The very nature of both fish supply and demand has nevertheless led to the introduction of various specific systems aimed at ensuring orderly marketing.

One of the main features of the market for prawns is the highly perishable nature of the commodity. Unless it has been processed in one way or another at sea, the producer is usually compelled to sell his catch as quickly as possible after landing. The fisherman has then no possibility of influencing the price formation by varying the quantity of prawns he offers: In other words, in the short run his supply is virtually inelastic in relation to prices. In addition his product is subject to relatively heavy fluctuations caused by changing biological and meteorological conditions on the fishing grounds, and these he cannot influence at all. On the other hand, demand for prawns is not always ready to follow smoothly the fluctuations of supply.

Intrastate sales in Queensland are confined by law to the Queensland Fish Board. The major segment of the market, the interstate and export markets, is handled by a number of processors in Queensland including the Queensland Fish Board.

In view of the need for orderly marketing and with the aim of contributing to overall economic stability in the industry and ensuring that the fisherman receives an adequate return for his catch, various measures have been introduced by industry or government in many countries. Among these are price systems which differ widely according to the structure of the industry, the markets to be supplied, geographical and other circumstances.

The marketing system can be broken down into two main segments: the market for non-processed product, and the market for processed product. I will refer to each of these separately:

(a) Non-processed product

The following pricing systems apply:

Direct sales

Direct sales, i.e. without any intermediary between producer and buyer, can only legally occur in Queensland where the necessary exemption is granted by the Queensland Fish Board.

Exemptions are normally granted where the sale or purchase of bait is involved or edible product in the case of isolated areas, i.e. areas removed from an established Board market where sales are conducted.

In some instances, the purchaser is exempted, and in others the producer.

Sales are normally conducted at each Board market but there are exceptions. There are twenty-four Board markets and depots in operation along the east coast of Queensland from Southport to Cairns.

Auction

With auction systems, prices are expected to vary according to the quality of the landings, thus giving an incentive to fishermen to take better care of their catches. Auction prices, however, also vary according to fluctuations in supply and demand. Prawns of excellent quality landed on a day of abundant supply might obtain a lower return than landings of worse quality in days of short supply. Nevertheless, the fisherman will usually find that, even under conditions of heavy supply, better quality prawns have more chance of finding a buyer and at a price higher than for prawns of lesser quality.

The auction system is the major method employed in the sale of cooked prawns. The producer has a natural liking for auction sales, in which, ideally, prices are established freely and potential buyers are competing openly for his wares. This applies not only to skippers and owners but also to the crew members who are paid on a share basis.

Here it is wise to bear in mind that the fisherman's interest in marketing has only come to the fore in comparatively recent times. By nature, at any rate in those fisheries with a long tradition, the fisherman is in his element when navigating and finding and catching prawns. The intricacies of processing and marketing have only been explored to safeguard his position.

The inherent danger in the auction system from the fisherman's point of view is that it can allow sudden and serious drops in prices with sometimes drastic consequences to his income. This has led to schemes aimed at limiting price fluctuations.

With the auction system the catch has to be displayed in the market so that the buyer can inspect the product on offer and review the market situation fairly before purchase.

If general conditions allow the introduction of the auction system it is particularly well suited for the disposal of mixed lines of prawns. Demand and supply determine prices which are adapted to a wide variety of landings. It could be said that in a way the choice made by the buyer sufficiently approximates to quality, grading and sorting in the absence of elaborate classifications arrangements which can be recommended for adoption or extension. By the auction method, the best qualities generally obtain the best prices.

Wharf price

The Board operates a 'wharf price' scheme for the purchase of prawns. When a fisherman delivers prawns to a market or depot operated by the Board, he may dispose of his product in any one of four ways:

(i) The Board will buy the prawns at the point of landing at a pre-determined price;

(ii) The fisherman may consign the prawns to Brisbane for sale on the auction floor at the Metropolitan Market with a reserve price if he so wishes;

(iii) If prices fail to reach the fisherman's reserve price, the Board will buy them at the price offered at the point of landing if they are sound and fit for processing;

(iv) The fisherman may consign prawns for sale interstate. In this case, the Board will package them for a fee and the fisherman pays freight costs.

Market support

The Board operates as a buyer of prawns at auctions at the Metropolitan Market so as to ensure the maintenance of satisfactory price levels. The product purchased by the Board in this manner is either processed by the Board, or, if the opportunity arises, re-sold in wet form principally to interstate buyers.

The Board in effect assesses what could be considered to be a reasonable minimum price for product on the day after determining markets that are available in wet form interstate or at other centres throughout Queensland. Alternatively, a price is established based on the processing of the product.

Private treaty

In those instances where it is not possible due to a lack of buyer strength to conduct an auction successfully, prawns are sold to buyers at Board branch markets at prices that are determined either daily or on a longer term basis.

In some cases the prices established at the auction sale at the Metropolitan Market are used as the selling prices at a branch market the following day. It is normal to adopt the price at the top end of the price range on the grounds that the buyer has his choice from prawns that would otherwise be forwarded to the central market for sale and would be expected to select a consignment of top quality.

Another method of fixing prices is for producers and fishermen to reach agreement on prices to apply which prices normally remain current for a period of weeks or even longer. Some flexibility can still be maintained under this arrangement in that where a heavy intake occurs the Manager is vested with authority to reduce the price within certain limits until the level of intake eases.

(b) Processed product

(i) *Export market*

It will probably be found that where a particular export market is well developed the market can be effectively serviced by an export merchant.

In the case of the product to be offered being placed in these circumstances in the hands of several export merchants and the market being clearly defined, it might be found that the product is being offered to the same prospective buyers through a number of channels. This is unlikely to enhance the reputation of the product or the processor in the eyes of the customer to be, and the processor would probably be far better served to operate through one export merchant only particularly if the export merchant has a good working relationship with the customer.

There can of course be no hard and fast rule as to the method of selling to be employed and no doubt the many processors who choose to offer product through a number of channels would undoubtedly claim success for this method.

In certain cases the market may be so fragmented that a particular section of the market may conceivably be overlooked by relying on a sole export merchant. Certainly this would be a case for the use of more than one export merchant.

The more intelligence a processor possesses about the state of a market the better equipped he is to arrive at a marketing decision.

Other processors can logically be viewed as a source of market information.

A decision regarding the sale of product can be fairly straightforward when the market is performing predictably.

However where substantial unforeseen changes occur which affect the return that would otherwise be received, the timing of sales becomes an important factor. In the case of a *falling market*, the following considerations arise:

1. The extent of the fall;
2. Will the market fall further;
3. The level to be set for future purchases of raw material;
4. How long will the market remain depressed and the rate of recovery—is the fall temporary or long term;
5. Cost of funds committed to stocks and return on funds if employed in other functions;
6. Avoidance of a forced realisation.

Rising market

There are times when a market can rise dramatically and not necessarily predictably. The processor then needs to consider whether he should sell immediately or defer offers in anticipation of the market rising further. If the rise in the market appears to be other than temporary, the price paid to the producer should be re-assessed.

The onus is on the processor rather than the export merchant to develop new markets—it is simply not sufficient nor logical to indicate to the export merchant that your organisation is hopeful of establishing a market in a particular country and then expect the export merchant to 'produce the goods'.

The export merchant is probably as well appraised of the potential of the market being considered as anyone, but in the initial stages at least the processor should exercise all channels at his disposal in an endeavour to develop or locate a new market including:

1. Discussions with the Department of

Overseas Trade including the obtaining of names of prospective buyers;
2. Correspondence with the Trade Commissioner in the country of interest;
3. Contact with offices in Australia of importers in intending markets;
4. Dispatch of senior executives on a sales mission;
5. Seek offers from established export merchants in Australia;
6. Communications received from contacts in country of interest.

(ii) *Domestic market*

The domestic market is probably more robust now than at any time in its history, and it is quite evident that this market which is already significant will play an increasingly important role in the future marketing of prawns. It is of course still necessary to be selective in the timing of sales on this market as this can have a very material effect on returns. Prices are however more attractive now than they have been and it is obvious that the domestic market has greater depth than ever before.

Whereas the range of products sought by this market was fairly limited until recently, there has been a broadening of the market and greater support for products that previously did not find particular favour. New products have been developed which has strengthened the ability of the processor in the objective to maximise returns.

Marketing in Australia is in most cases handled through a wholesaler who is a specialist in this field. His usefulness in a channel of distribution is subject to the same circumstances involved in the decision to utilise any other specialist. In any economy, except a very primitive one, it is often not economically feasible for a producer to deal directly with an ultimate consumer. Think for a moment how inconvenient our daily existence would be if there were no retail middlemen, no service stations, no newspaper shops, supermarkets, etc. If we live in a large city, we might think that we could buy things wholesale but if there were no middlemen there would be no wholesalers.

Three general economic reasons for using a wholesaler:

1. Firstly, a firm is seeking optimum utilisation of its financial resources and a wholesaler can perform the physical handling of products at an operating expense percentage lower than that at which most manufacturers can do the job;
2. A manufacturer's concern with the most effective use of his manpower resources, and it makes sense to use existing wholesaling distribution facilities rather than to duplicate them;
3. A wholesaler offers a manufacturer an opportunity to increase sales volume at a more rapid rate than at which total expenses will rise.

It is quite clear that the domestic market is highly competitive and that effective product differentiation is absent. Buyers are well informed about the market pricing. In these circumstances, management may decide to price a product at the competitive level.

DISCUSSION

Ruello. In one of the illustrations you showed you were talking about grading. Prawns were graded into meat and cutlets and what have you. I was under the impression that prawns were graded according to size.

Murray. This was part of the operation. I should have made that quite clear. They are graded quality wise into export tails, cutlets and flesh but in that operation simultaneously we grade them according to size.

Ruello. How do you determine the quality?

Murray. Visually mainly, and of course we have to have regard to the Australian Department of Agriculture. We endeavour to make our standard higher than that determined by this Department and in fact we do this. There was some watering down of their standards quite recently but we didn't change from the standard we have employed overy many years.

Ruello. Do you conduct chemical analyses in old prawns you've measured for salt upkeeping?

Murray. We don't but we do receive some assistance from the State Department of Primary Industries people, the Food Preservation Research establishment at Hamilton, Brisbane, but we haven't got this within our own organisation.

Ruello. If you don't look at the quality from a chemical point of view how can you say that your standards are higher than the Department of Primary Industry standards?

Murray. Well, we believe they are. There is a certain percentage allowed in the case of black spot on prawns, in the case of cutlets. We don't work on that limit, we keep well within the limit.

Ruello. So it's still just a visual test.

Murray. Yes it is.

Ruello. Another point I was going to ask about quality. Do you feel that as the market becomes more competitive and prawns become dearer that there is more emphasis on quality, than so much on supply and demand?

Murray. This is a hard one to answer. I couldn't say. I think there is considerable emphasis now—there is within our own organisation on quality. Whether the escalation will speed up this process, I couldn't rightly say.

Ruello. You don't feel that quality is really simply the size—the larger the prawn is, the higher price it gets?

Murray. No. I think the buyers—we're dealing with buyers— we're selling prawns—cooked prawns might be Moreton Bay King prawns in cooked form—they're quite discerning I think and they know a quality product and this is where the grading does come in when I'm talking about a product that is not destined for processing.

Pane. If I may ask you a question in two parts—in your paper you say that intrastate sales in Queensland are confined by law to the Queensland Fish Board, then later you say that it is quite clear that the domestic market is highly competitive. Would you please say how you can quote those two statements?

Murray. Well, I would say this, that the processors other than the Fish Board came into being because they saw the scope, not in the Queensland market, but settling into the Australian market as a whole, but more particularly the export market. I don't think any processor would have spent money on an establishment at all if they were looking particularly at the local market. People come along and say today 'we can't operate while the Fish Board has an unfair advantage'. The Queensland Fish Board has a responsibility, a very broad responsibility, but I don't believe that this factor influenced the processors when they came into being at all. I think they knew the ground rules at that time and they still do and they came along to process prawns for export market primarily and certainly interstate markets as well.

Pane. I'll agree with that in part. On the second part of the question—what you haven't said is that the Fish Board charges 7½% on goods which it allows processors to sell in Queensland. This means that a company which catches its prawns in Queensland, which transports them out of Queensland, processes them out of Queensland, is then free to sell them in Queensland without the 7½% surcharge whereas companies like ourselves who process entirely in Queensland are forced economically to sell outside of Queensland. We then talk about a breaded product which you were talking about before, breaded prawns, where the Fish Board charges 7½% on the final retail price. This means that the processing company is not only paying 7½% on the cost of the product it buys from the producer but on the breadcrumbs, the labour, the profit that it would have made if the Fish Board hadn't charged the 7½%. Could you perhaps comment on this and comment on the fact that processors outside of Queensland are not covered by Fish Board regulations as well.

Murray. We act under a Queensland statute. I think we are covering the same grounds to an extent. I've already said I believe people like your own organisation didn't come along to service the local market at all. They were created for the purpose of exploiting the ocean prawn grounds and the banana prawns, processing those products for export markets. The fact that the Board does charge 7½%—we are getting back to a local sales situation again. What is not brought forward in this sort of argument is that the Board has a broad responsibility and it discharges this responsibility quite effectively I believe. If I might use an example—during the 1970–71 Bay prawn season we handled tremendous quantities of prawns—usually these prawns occur in the summer months but quite often you'll strike a peak round about Easter. We found that we were being absolutely inundated with prawns at that time. We looked around to find out why and we found that some of the processors decided to gear down so they could trail off nicely and shut down for Easter. Well, this is the sort of thing that we don't do. We don't believe that we can do that. If the product is there we will take it. Consequently we are faced with this sort of situation where we are operating uneconomically. If we had the sort of flexibility that your own company has we wouldn't do that but we don't feel that we have. We follow through and bear this sort of situation and so you say we have an advantage there but I would argue that we have many disadvantages.

SESSION 5

MANAGEMENT

CHAIRMAN: MR J. S. LAKE

AUTHORS

N. V. RUELLO	J. S. HYND
M. OLSEN	N. M. HAYSOM
D. A. HANCOCK	B. BOWEN

BIOLOGICAL RESEARCH AND THE MANAGEMENT OF PRAWN FISHERIES IN NEW SOUTH WALES

BY N. V. RUELLO
Crustacean Biologist. New South Wales State Fisheries
211 Kent Street, Sydney, N.S.W. 2000

ABSTRACT

The history and value of traditional fisheries regulations such as the minimum legal length of prawns, the maximum length and minimum mesh size allowable in nets, and closed fishing areas are reviewed. This paper then describes how the results of recent biological studies on the school prawn (Metapenaeus macleayi) *and the king prawn* (Penaeus plebejus) *are being used to formulate better management policies for New South Wales prawn fisheries.*

INTRODUCTION

Commercial fishing for prawns in Australia probably commenced in Port Jackson (Sydney) in the early 1800s (Ruello 1973a) but was not formally controlled until after the passing of the New South Wales Fisheries Act of 1865. The prawn fisheries in New South Wales gradually developed over the years but did not arouse much interest in the fishing community until the last decade of the 19th century when the 'prawners' in Port Jackson were accused of unnecessarily destroying small fish with their prawn nets. H. C. Dannevig, the Superintendent of Fisheries Investigations in New South Wales (and later, the Commonwealth) investigated this matter in 1903 and thus established the precedent of using the results of scientific investigations in formulating regulations for the management of an Australian prawn fishery. Dannevig's (1904) report has much practical value as well as historical interest.

This paper reviews the history and value of fisheries regulations originally prescribed for the prawn fisheries in the late 19th century and then describes how the results of recent biological research and other activities of the Scientific Section are used to protect and develop prawn fisheries in New South Wales. The historical origins of certain regulations are highlighted because these regulations have survived to the present day essentially unchanged, and also because many of these regulations were subsequently implemented in other States too. A summary of the regulations governing prawn fishing in this State is presented in Appendix I.

FISHING REGULATIONS IN THE 19th CENTURY

The Fisheries Act of 1865 was the first formal attempt to regulate fishing in the Colony; prior to this, fishermen were expected to obey English Common Law. The 1865 Act restricted the length of a prawn hauling net to a maximum of 8 fathoms (14.6 m). This restriction like many subsequent regulations was introduced primarily as a conservation measure to protect fish stocks which were allegedly over-exploited (see below).

There was considerable concern about the condition of the fisheries in the Colony in the 1870s and many fishermen and others in the fishing community claimed that various areas were already overfished. The New South Wales Legislative Council responded to these arguments and appointed a Royal Commission in January 1880 '. . . to inquire into and report upon the actual state and prospect of the fisheries of this colony'. The prawn fisheries at this time were small and restricted mainly to the Sydney and Newcastle areas and therefore received little attention at the Inquiry. However, this Inquiry has had a lasting impact on the Fisheries regulations in the State and it undoubtedly influenced fisheries elsewhere in Australia.

The Commission's report (1880) states that: 'The consumption of this crustacean is so great that fears have been expressed that the supply might become exhausted and it is undoubted that the size of those brought to market now is often much below the average of former years'. W. J. Langham *the* Inspector of Oyster Beds in New South Wales testified that: 'There are nothing at all what there used to be in the Hunter River, Newcastle' (Fig. 1), he added that many small prawns were being caught and wasted. Langham advocated restricting the length of the prawn net as well as the minimum mesh size allowable and he suggested that a

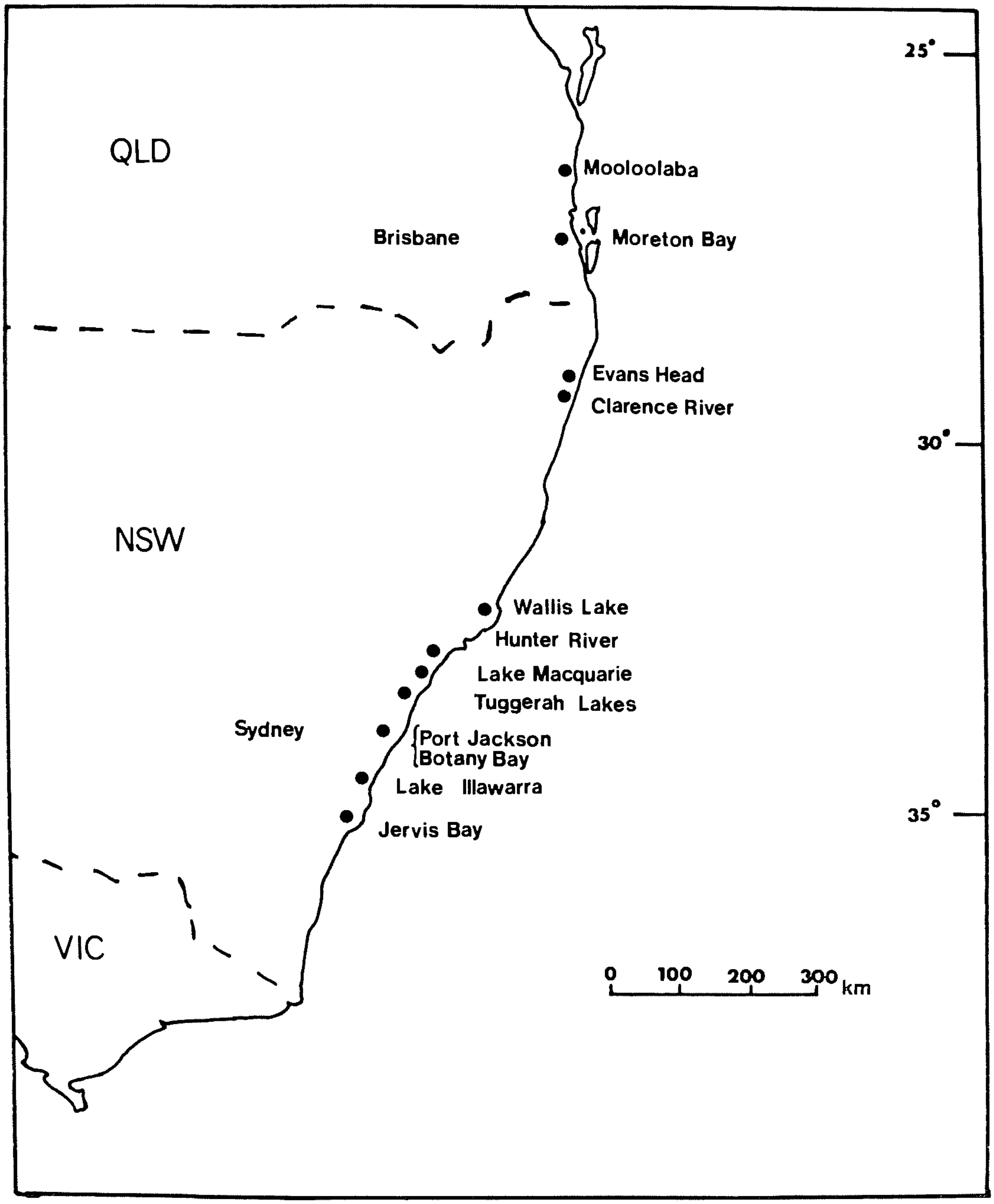


Figure 1. Map of the south-east coast of Australia showing the principal locations mentioned in text.

minimum legal size be prescribed for marketable prawns. It is noteworthy that there has been a fear of depletion of the prawn stocks in Sydney and Newcastle for almost a century now, and yet the annual production of both areas has exceeded 113 000 kg in the last decade.

An immediate outcome of the Inquiry was the passing of a new Fisheries Act (1881) which was based, in great part, on evidence given by Langham, fishermen and others. This Act prescribed closed seasons, closed areas, a maximum length of 15 fathoms (27 m) in prawn hauling nets, a minimal mesh size of 1 in. (25 mm) (measured from knot to knot) and a minimum legal length of 1½ in. (38 mm) for marketable prawns—measured from 'a point between the eyes to the end of the tail'.

The rationale behind these regulations is most interesting. The Report of the Royal Commission (1880) and Dannevig's (1904) comments on this Inquiry indicate that the winter closure on prawn hauling (1 June to 30 September) was introduced to reduce the destruction of 'fish spawn' and small fishes rather than to protect prawns or the prawn fisheries. A 6-month winter closure exists in the Hunter River today while a 3-month closure was recently reintroduced to the Sydney fisheries (Port Jackson and Botany Bay), but this matter will be discussed further in a later section of this paper. The maximum length of the prawn net and the minimum mesh size were limited primarily to protect the allegedly depleted fish stocks, their 'spawn' and their feeding grounds because the nets previously in use were reported as up to 90 fathoms (165 m) in length and with meshes 'as small as mosquito nets'. The declaration of closed areas—usually the upstream bays and reaches of river—also appears to have been intended principally for the conservation of fishes but it prevented the capture of the very small prawns too.

The minimum legal length for prawns was introduced for practical and marketing reasons as well as conservation purposes (*see* Langham's testimony to the Inquiry) but the prescribed size of 1½ inches (38 mm) is paradoxical in view of the concern expressed at the Inquiry about the size of prawns being sold; it must be assumed that the 19th century prawn consumers were not really particular about the prawns' size and that they had ample leisure time to peel the midgets. (The size limit on prawns was gradually raised as the prawning industry expanded its markets over the next 60 years).

Other important outcomes of the Royal Commission were the establishment of a Fisheries Commission and the appointment of five Commissioners of Fisheries and the employment of Inspectors of Fisheries in a number of districts. Hitherto the Fisheries Regulations were supervised (inadequately) by an Inspector of Oyster Beds and nominally also by police officers, hence breaches of the regulations were common.

The appointment of Fisheries Inspectors in the more important areas greatly increased the enforcement of regulations but, equally important, it gave the Department an accessible source of reasonably accurate and reliable information which could be used to evaluate fishing regulations and management policy. The Fisheries Inspectors submitted annual reports upon the condition of the fishery in their district, but regrettably the prawn fisheries often received but passing mention in these reports and in the Department's official annual reports.

THE FIRST HALF OF THE 20th CENTURY

The first recorded scientific investigation of an Australian prawn fishery was conducted by H. C. Dannevig in 1903. Dannevig (1904) conducted 51 test hauls in Port Jackson in the summer of 1903–4 to investigate the alleged slaughter of immature fish by prawn nets. He found that the destruction of small fishes was not excessive nor dangerous and probably no greater than that produced by conventional fishing nets, Dannevig therefore concluded that prawn fishing was not objectionable in view of its economic value. The destruction of immature fish by prawning nets has long attracted criticism and almost half a century later commercial and sport fishermen complained about the 'slaughter' of small fish by prawn trawlers working the newly discovered ocean grounds.

As the prawn fisheries spread along the north and south coast and increased in value over the next few decades the Department called upon its biologists (D. G. Stead, G. L. Kesteven, T. C. Roughley and others), the District Inspectors of Fisheries, the various fishermen's associations and outside experts such as Professor W. J. Dakin (at Sydney University) for professional advice on prawns and prawn fishing but half-a-century passed before another detailed scientific investigation was carried out and published.

THE PAST 25 YEARS

It was not until after the development of the oceanic fishery along the coast of New South Wales in the late 1940s that a biologist was again assigned to carry out special prawn investigations and advise the Department on appropriate management measures. J. C. Wharton commenced field investigations in the Evans Head area in 1951 but took up an appointment with the Victorian Fisheries Department in the following year. A. A. Racek was appointed in 1953 to continue prawn investigations.

Racek examined the taxonomy, ecology and biology of the most important commercial species in New South Wales and adjoining Queensland waters and his taxonomic paper (1955) and Dall's (1957) work helped to clear up much of the confusion about the prawn fauna in Australia. At the conclusion of his field studies Racek recommended a number of major changes to the regulations on prawn fisheries, which are summarised below:

1. The minimum legal length of marketable prawns (3½ inches or 89 mm) should be abolished; and concurrently
2. The legal minimum mesh on prawn trawls should be increased from 1¼ to 1½ in. (32 to 38 mm).
3. Trawling should be prohibited in the Hunter and the Clarence Rivers for six ('winter') months each year and that the upper reaches of these rivers be permanently closed to prawn fishing.

The recommendation that the minimum legal length of prawns should be rescinded was certainly most timely because thousands of pounds of dead prawns were being discarded weekly in northern New South Wales in the early 1950s. Racek (1959) noted that a minimum length for prawns was prescribed when prawns were captured solely in estuaries and was based on the old belief that every prawn (and fish) captured should have had the opportunity to spawn at least once. However, except for greasyback prawns (*Metapenaeus bennettae*) and some male school prawns (*M. macleayi*) most commercial species are immature far above this size and therefore this restriction was not serving its purpose but only resulted in an extraordinary wastage of valuable food. Racek also noted that this size limit was ill-chosen because it is just above the average length of greasyback prawns and because it prevents the sale of *Trachypenaeus* and other species which mature at less than 3½ in. (89 mm).

Racek's first recommendation was, of course, accepted by the Department. If the cost of enforcing regulations is taken into account, as suggested by Gulland (1971a), then the size limit on prawns was indeed a most costly regulatory measure, with negative value to the industry. The minimum mesh size of trawl nets was increased to 1½ in. (38 mm) to raise the average size of prawns caught and thus produce a more valuable product and also because it would increase slightly the escapement of small fish from the net. Some six years later T. B. Gorman conducted a study of the mesh selectivity of a number of trawl nets and found that the 1½ in. (38 mm) mesh size was an optimal minimum size for estuarine conditions.

Racek's (1959) observation that: 'It cannot be denied that the once well stocked but excessively exploited and favoured grounds in Stockton Bight and off Evans Head were seriously affected as far as overfishing is concerned' led to his suggestion of closed areas and a winter closure on trawling in the Clarence and Hunter Rivers to enable the juvenile prawns from these rivers to replenish the stocks in the adjacent oceanic waters. Racek thought there could be a need for a total ban on trawling in these two estuaries but acknowledged the enormous socio-economic and administrative implications of such action in these long established fisheries—the Hunter River fishery was then more than a century old while the Clarence fishery had a history of more than 60 years and both are still profitable today.

The winter closure was therefore adopted as the principle safeguard for the oceanic fishery in the Clarence and the Hunter region on the assumption that these stocks were threatened by overfishing; the upstream areas of these rivers were closed to prevent the capture of the smaller, less valuable, prawns found there. The imposition of a winter closure on trawling in these rivers in 1961 produced a mixed reaction from the industry, naturally, the fishermen directly concerned objected strongly at the time and the Hunter River fishermen are generally still critical of this restriction for a variety of reasons.

In 1967 the author commenced two new research projects. The first was a comprehensive study of the prawn biology and fishery in a small well defined area—the Hunter region—to supplement Racek's more widespread work (in the 1950s). The objectives of this study were to examine the condition of the fishery (and the claims of overfishing) and to evaluate and revise the management policy for this fishery. The Hunter region was selected because of the long history of its fisheries—this is Australia's oldest sea fishery—and its proximity to Sydney; it is only hours away from our Sydney laboratories by road or sea. The second program was a study of the spawning migrations of the school prawn and the king prawn *Penaeus plebejus* and the degree of intermixing of the juvenile stocks from the different estuaries once they have moved out to sea; this study was needed to determine the validity of regulations based on the assumption that the stock in a particular estuary and the adjacent oceanic water is a discrete unit with little (or no) intermixing with neighbouring units. The results of the latter study will be discussed first for practical reasons which become obvious later.

Spawning migration and stock studies

Laboratory tests indicated that an Atkins-type tag was suitable for marking the small (juvenile) prawns found in New South Wales estuaries, and these were substantiated by field experiments in the Hunter and Clarence regions (Ruello 1970). Tagging experiments carried out at a number of estuaries along the coast indicate that the school prawn carries out a limited northerly spawning migration, of up to 30 km, and spawns in coastal waters less than 36 m deep (Ruello 1970 and unpublished). There thus appears to be little intermixing of the stocks emigrating from the different estuaries and the fishery in each region can be treated as an independent unit.

In contrast, the king prawn carries out an extensive migration and spawns in the warmer waters up to 500 nautical miles from its estuarine habitat and the larvae apparently drift to the south with the East Australian Current System (Ruello MS). There is much mixing of the king prawn stocks from the many estuaries in New South Wales as they move along the coast and there is a significant contribution of prawns to the Queensland offshore fishery. Modern fisheries regulations should take into account the recent finding that there is one enormous intermixed population of the king prawn along the south-east coast of Australia. The large area of distribution of the king prawn (*Penaeus plebejus*) and the many juvenile habitats in this range give the species both short and long term advantages, not the least of which is protection against overfishing.

The biology and fishery of the school prawn

Soon after its commencement, the Hunter region research program was concentrated on the school prawn because the king prawn was not usually abundant in the river and the adults (at sea) could not be sampled regularly with the vessels available. There were three subjects of particular interest:

(i) the condition of the fishery;
(ii) the value of the winter closure; and
(iii) the value of the closed areas in the estuary.

There were also three principal sources of information:

(i) Regular trawl sampling at a number of stations provided data on distribution, abundance, sex and size composition of the stock, mating and maturation of gonads and indirect evidence of growth and movements.
(ii) Tagging (and dye marking) experiments provided direct evidence of growth and movements and more precise data on mating and gonad maturation.
(iii) Several fishermen with log books provided details of individual trawls while others provided daily records. Little reliable information was obtained because of inadequate liaison with fishermen due to staff limitations.

(i) *The condition of the fishery*

School prawns in the Hunter River have been netted for more than a century while the adults in the adjacent ocean waters of Stockton Bight were not harvested until 1947–48. The Department's Annual Reports show that the total estuarine and ocean catch rose to a peak of approximately 317 000 kg in 1950–51 then slowly fell over the next few years. Most of the ocean catch consisted of school prawns but king prawns were also taken in substantial numbers; the king prawn catch in the River is negligible for the purposes of this paper (separate records are not kept for each species in New South Wales fishermen's returns or official statistics). From 1953–54 onwards the catch of prawns from territorial and extra-territorial oceanic waters was recorded separately. Regrettably the catches before 1953–54 cannot be compared with those of subsequent years because the territorial catch in the Hunter region consists almost exclusively of school prawns whereas the pre 1953–54 statistics include both king and school prawn catches. (The deeper, extra-territorial waters are not inhabited by school prawns and yield king prawns, and occasionally Racek prawns *Parapenaeus australiensis*). Fig. 2 shows the total catch recorded over the past 18 years.

Figure 2 shows that the catch fluctuates markedly from year to year and that there is no long term trend, furthermore it reveals a remarkable parallel between the Hunter region annual rainfall and the prawn catch of the following year. The coefficient of correlation between the two is 0.64 and is significant at the 5% level. It is noteworthy that the record catch of 1950–51 was taken after a year of well-above-average rainfall, the very high catch in 1971–72 (official figures not yet available) also parallels the previous year's rainfall.

Ruello (1973b) has reported a causal relationship between the annual rainfall and the

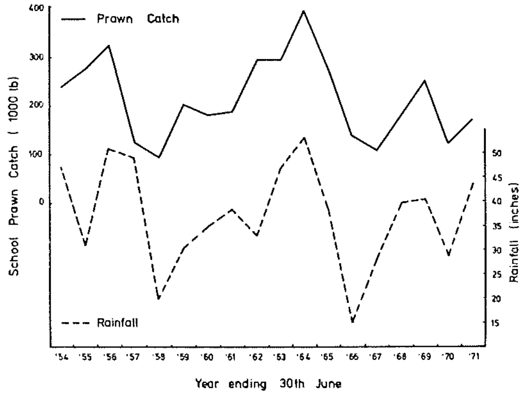


Figure 2. Correlation of Hunter region annual school prawn catch and rainfall of the previous year.

subsequent school prawn catch in the Hunter region. The Stockton Bight catch is generally small during average or dry weather conditions whereas there are large catches after heavy rainfall because of the subsequent emigration of prawns from the river to the sea. Ruello suggested that the increased abundance at sea after heavy rainfall enhances the prawns' reproductive potential and also that the heavy rainfall indirectly assists the recruitment of their young to the estuary and their growth and survival and thereby increases prawn abundance (and catches) in the following year.

The apparent causal relationship between rainfall and prawn catch and the absence of a downward trend in the catch during the past 2 decades negate the suggestion that this stock has been overfished (the efficiency of the fishing fleet has undoubtedly increased over the last 20 years but there is no evidence that the annual (total) fishing effort has increased in this period). The number of vessels that participate in this fishery for only a short period each year has increased in recent years and local fishermen are probably correct in asserting that they, individually, are not catching as many prawns as they once did. The catch statistics show that the average production of the last 9 years is approximately 1% higher than that of the preceding period and the absence of a consistent trend in the catch indicates that the fishery is in a stabilised phase of its development (Kesteven 1971). The economic condition of this long established open entry, heavily exploited fishery (as many as 90 trawlers have participated in the first week of the river fishing season) is unknown and certainly presents an interesting subject for investigation.

Although the Hunter region school prawn stock has sustained the fishing pressure of past years the recapture of up to 32% of tagged prawns in the River (Ruello 1970) also indicates that the juvenile stock is heavily exploited at times, particularly at the commencement of the river season, and may warrant further protection if the fishing effort increases substantially from recent levels. Interestingly, Maclean (1973) recently reported that the prawn fishery in Moreton Bay (Queensland)—another long established, essentially open entry, and heavily exploited fishery—also shows no signs of overfishing despite claims of over-exploitation.

(ii) *The winter closure*

Following Racek's recommendation, the Hunter River was closed to trawling from 1 July to 30 November each year (as from 1961) to allow sufficient prawns to breed and so replenish the stock. The implicit assumption underlying this restriction was that the stock was formerly over-exploited and hence there was a need to safeguard the spawning stock; but it is now widely accepted that few spawners are required to sustain a stock. An important benefit of the "winter" closure, which appears to have been understated in the past, is the protection given to juvenile prawns during spring when growth is remarkably rapid (see Table 1) and undoubtedly outweighs the losses due to mortality.

The winter closure therefore has some economic justification but the question arises as to when is the increment to the stock from the spring growth outweighed by the losses due to mortality and emigration of maturing prawns to the sea. This question suggests that the ocean catch is zero (or negligible). The ocean catches are generally negligible in average or dry weather conditions (Ruello 1973b) and since there is only a very slight chance of substantial rainfall and increased prawn catches being recorded in a particular small interval of time (days or a week) the suggestion of a null value for the oceanic catch is valid for the purposes of this discussion.

The results obtained to date demonstrate annual variations in growth rates (and emigration and fishing mortality) but generally the average growth is rapid throughout September and October and then slowly decreases in November and December. Further observations will be made in the 1973 spring and conclusive statements can then be presented. But, as Gulland (1971 b) noted, management measures cannot be held up pending the completion of scientific studies and accordingly this Depart-

Table 1. 30-day growth of tagged school prawns
(October 1969)

Initial Carapace Length (mm)	*Carapace length increments (25-35 days freedom) mm*												
	Females						*Males*						
27	½												
26½	—												
26	2												
25½	—												
25	1½	1½	1½										
24½	1												
24	1	0	2	1½									
23½	1	1	3	3½	1	½							
23	1½	1½	3	2½									
22½	1½						½						
22	3½	4	3½	3	3½		½	1	1	1			
21½	3½	1½	2	1½			1	½	1				
21	0						1½	1	1	1			
20½	3	2½	3½				1½	1	0	2	1	0	
20	½	3½	4	3	2		1	1	1	1½	2		
19½	½	4½	2½	3½	4½		2	2	2	2½	2	1½	½
19	2½						—						
18½	3½	1					½	2½					
18	3½						3	3½					
17½	—						3	2½	3½				
17	3½	3½	1½	4	4½		1½	3½	3½				
16½	5	4											
16							4½	4	6				
15½							—						
15							—						
14½							5½						

ment has, since 1968, granted a concession (see Fig. 3) to permit trawling in the River to commence from about 20 November *in lieu* of 1 December—routine sampling has shown that by this time the emigration of maturing prawns is well advanced and the prawns at the seaward end of the estuary have reached peak size before moving out to sea. The selection of the opening date of the fishing season on the basis of intermittent sampling data was practised in Apalachicola Bay, Florida, U.S.A., as early as 1953 (Ingle 1956) and this practice has recently been introduced in the Gulf of Carpentaria fishery in Queensland (Anonymous 1971).

Prawn stocks are a particularly dynamic resource and rapidly respond to fluctuations in temperature, rainfall and other factors and rigid regulations such as fixed fishing seasons have obvious deficiencies and should be replaced by a more flexible management policy including an annual assessment of the opening (and closing) date of the fishing season. The economic benefits obtained from a more flexible fishing season should exceed the added administrative and research expenses.

(iii) *Closed areas*

The average length of prawns in the Hunter River decreases noticeably from the sea to the head of the estuary and the area upstream from Raymond Terrace and all of the Williams River (the major tributary of the Hunter) are closed to trawling to prevent the capture of the very small prawns in these areas. The closure of 'nursery areas' is undoubtedly beneficial in view of the direct relationship between the size and market price of prawns. Fishermen are usually content to wait for the prawns to grow and move out of the nursery areas but in dry seasons the emigration of maturing juveniles from the nursery areas to the sea is not marked and impatient fishermen move into the nursery areas to increase their catches.

The cost of determining the nursery areas and the enforcement of the closure in the Hunter River is relatively low and is greatly exceeded by the economic value of the closure because of the geometry of this estuary. The waterway is essentially a long narrow rectangle with the smallest prawns at one end and the largest individuals at the other end and little effort and expense is required to police the

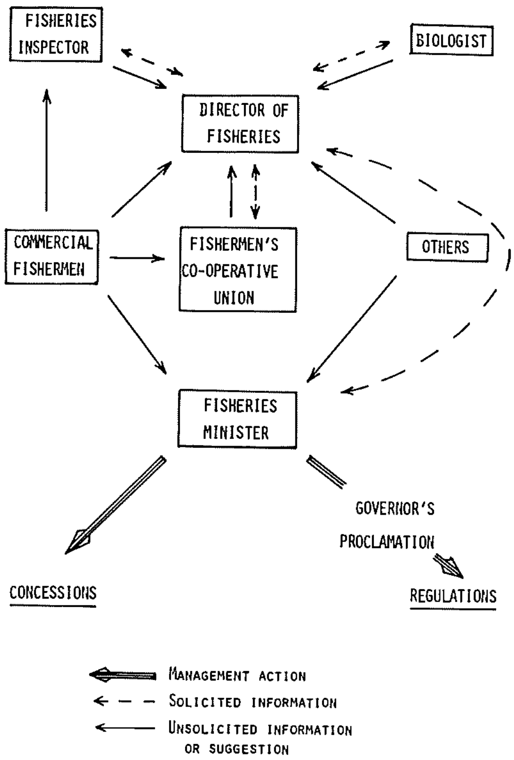


Fig. 3. Information flow diagram showing how new management regulations are produced and existing regulations altered. The Director of Fisheries can receive unsolicited recommendations for a particular action from a variety of sources, either directly or indirectly. The Director then usually obtains the views of the Fisheries Inspector, Biologist, the Union of Fishermen's Co-operatives, and other information where necessary; if warranted, a recommendation is forwarded to the Minister who may grant a concession or submit new or altered regulations for Proclamation by the Governor. 'Others' include sport fishermen, conservation groups, owners of waterside property or any interested person. Sport fishermen may act individually or through a club and then the Amateur Fishermen's Advisory Council.

nursery areas. The costs of research and protection of nursery areas rise rapidly as the geometrical complexity of the estuary increases.

UTILISATION OF ALTERNATE RESOURCES

The functions of the New South Wales Fisheries Department include the protection and development of the State's fish resources and accordingly two new research projects were initiated several years ago to find new resources for the existing fishing fleet (and thus reduce the fishing effort on the traditional fishing grounds) and to create new industries. The first program, the exploratory fishing work along the continental slope of New South Wales has been described by Gorman and Graham in a paper presented at this meeting and need not be discussed again here.

Another program—on commercial prawn culture—is being carried out by I. Smith and G. Maguire at the Brackish Water Fish Culture Research Station at Port Stephens, north of Newcastle. Smith has successfully induced spawning in the greasyback prawn and the western king prawn *Penaeus latisulcatus* and is now developing methods for mass rearing larvae of several species, while Maguire is now investigating the mass rearing and nutrition of the juvenile prawns. The objective of the prawn culture research is to examine the economic feasibility of prawn culture in Australia, with special reference to New South Wales, but this project and the exploratory fishing program could also be regarded as investments or safeguards against a future depletion of the coastal prawn stocks.

An interesting project, started last year by the author, is a study of the physical and biological characteristics of the sediments on the well established offshore king prawn grounds, and the animal-sediment relationship. A study of the relationship between the sediments and school prawns showed that this species has a pronounced preference for a fine grade sand substrate (Ruello 1973 c). If the king prawn demonstrates a similar strong preference for a particular substrate then the cost of finding new fishing grounds may be substantially reduced by first looking for the particular type of substrate and then conducting fishing trials at suitable times (i.e. in relation to diurnal, lunar and seasonal cycles, see Racek 1959). Prawns are not usually distributed randomly hence exploratory fishing effort does not have to be uniformly distributed.

DISCUSSION AND CONCLUSIONS

Although the biological basis of the management policy in New South Wales has been emphasised in this paper, social and economic factors are also considered before decisions are presented. For example: a concession has generally been granted to allow prawn trawling in Lake Wooloweyah (on the Clarence River) on 1 October *in lieu* of the 1 December opening date to enable prawn fishermen to work in their chosen profession for a major part of the year (i.e. 8 months instead of 6), this concession is granted (pending scientific study of this fishery) because of the fact that prawn fishing is a principal industry in the region.

The weekend closure on prawn fishing in estuaries is an excellent example of a regulation brought about by sociological considerations. A weekend closure is commonly sought by fishermen to enable them to spend the weekend away from their usual work; this regulation reduces fishing effort and virtually requires no enforcement but the long term effect of the reduced fishing effort is not clear. A welcome result of this closure is the elimination of the once perennial conflict between commercial and sport fishermen, another result is the elimination of conflict between the commercial fishermen and others who wish to use the water for recreational purposes. Such conflicts were formerly common in the rivers and lakes in the Sydney and Newcastle areas in particular.

Prawn stocks are a valuable renewable resource and biological research is desirable, and sometimes necessary, to protect and develop these resources. While the long term value of the information obtained from biological studies frequently exceeds their costs the benefits from many programs could be increased if economists—and in some cases, sociologists—were consulted in planning the program *as well as* evaluating the results; a viable prawn fishery has three essential elements, viz. prawns, people and profits, but very few biologists have the socio-economic expertise required to resolve satisfactorily the questions they are frequently asked to answer.

The value of the Hunter region school prawn study, for example, could be improved by the infusion of socio-economic expertise. The declared objective of this study is to maximise the sustainable total catch and the gross economic return, however, the maximisation of the net economic yield from the resource might be a more desirable objective, but the realisation of the latter objective would probably require a limitation or a reduction in the size of the existing fishing fleet and the relocation of surplus fishing units. The socio-economic implications of such a radical change in management policy and the more desirable of the two objectives above can only be satisfactorily determined by close collaboration between biologists, economists and sociologists.

Recent economic studies of Australian prawn fisheries (Department of Primary Industry 1970, 1973), conducted virtually independently of concurrent biological studies, have produced valuable data, however, the industry can best be served if economic and biological studies are concurrent, complementary and supplementary.

Overfishing has traditionally been regarded as the major, and the most widely known, threat to commercial fisheries and there have been many unsubstantiated claims of overfishing of several eastern Australian prawn stocks over the last century. Two of Australia's oldest prawn fisheries—in the Hunter region and Brisbane region—have sustained more than a century of commercial fishing but are now seriously threatened by other human activities. The shore vegetation in estuarine areas plays an important role in the food supply of penaeid prawns (Mock 1969, Anonymous 1970, Ruello 1973 c) but is continually being destroyed for various reasons. Ruello (1972, 1973 c) recently discussed the need to protect the natural foreshores and productive shallow areas in estuaries because of their contribution to the nutritional and substrate requirements of prawns. Regrettably, thousands of acres of estuarine areas have been filled in, dredged or otherwise permanently destroyed in several areas of New South Wales and eastern Queensland.

It is ironical that the increasing affluence (domestic and international) which is contributing to the high prices for prawns is concurrently accelerating the despoliation of the coastal environment. The demand for waterside land in New South Wales and south-east Queensland for urban, industrial or recreational purposes is incredible and currently shows no sign of abatement. N.S.W. State Fisheries has for the past decade employed scientific staff to examine the potential impact of various types of development and human activities on aquatic resources to avoid unnecessary despoliation of the environment and depletion of fish stocks. It is to be hoped that the community will recognise that high fish production cannot be maintained indefinitely if the estuarine environment is gradually reduced in size and quality.

LITERATURE CITED

ANONYMOUS. (1970). 'Propagation of shrimps and prawns'. *FAO Fish Cult. Bull.,* 2(2), p. 5.

ANONYMOUS. (1971). 'Temporary closure of Gulf waters for banana prawning'. (1971). *Aust. Fish.,* 30(2), p. 2.

DALL, W. (1957). 'A revision of the Australian species of Penaeinae (Crustacea: Decapoda:

Penaeidae)'. *Aust. J. Mar. Freshwat. Res.*, 8, pp. 136-231.

DANNEVIG, H. C. (1904). 'Preliminary report upon the prawing industry in Port Jackson'. N.S.W. Govt. Printer, 17 pp.

DEPARTMENT OF PRIMARY INDUSTRY, FISHERIES DIVISION. (1970). 'An economic survey of the Shark Bay and Exmouth Gulf prawn fisheries, 1966-67 and 1967-68'. Fisheries Rept., No. 6, Canberra.

DEPARTMENT OF PRIMARY INDUSTRY, FISHERIES DIVISION. (1973). 'An economic investigation of the northern prawn fishery. Costs and earnings of trawlers'. Fisheries Rept. No. 8, AGPS, Canberra.

FISHERIES INQUIRY COMMISSION. (1880). 'Report of the Royal Commission to inquire into and report upon the actual state and prospect of the Fisheries of this colony'. N.S.W. Govt. Printer, 128 + 21 pp.

GULLAND, J. A. (1971a). 'Some general notes on fishery management'. *Proc. Indo-Pacif. Fish Coun.*, 14(II), pp. 1-12.

GULLAND, J. A. (1971b). 'Science and fishery management'. *J. Cons. int. Explor. Mer*, 33(3), pp. 471-477.

INGLE, R. M. (1956). 'Intermittent shrimp sampling in Apalachicola Bay with biological notes and regulatory applications'. *Proc. Gulf Caribb. Fish. Inst.*, 9, pp. 6-17.

KESTEVEN, G. L. (1971). 'Diagnosis of the condition of a fishery'. *CSIRO Aust. Div. Fish. Oceanogr. Circular* No. 6, pp. 7-24.

MACLEAN, J. L. (1973). 'An analysis of the catch by trawlers in Moreton Bay (Qld) during the 1966–67 prawning season'. *Proc. Linn. Soc. N.S.W.*, 98, pp. 35-42.

MOCK, C. R. (1969). 'Natural and altered estuarine habitats of penaeid shrimp'. *Proc. Gulf Caribb. Fish. Inst.*, 19, pp. 86-98.

RACEK, A. A. (1955). 'Littoral penaeinae from New South Wales and adjacent Queensland waters'. *Aust. J. mar. Freshwat. Res.* 6(2), pp. 209-241.

RACEK, A. A. (1959). 'Prawn investigations in Eastern Australia'. Res. Bull. St. Fish. U.S.W., No. 6, 57 pp.

RUELLO, N. V. (1970). 'Prawn tagging experiments in New South Wales.' *Proc. Linn. Soc. N.S.W.*, 94, pp. 277-287.

RUELLO, N. V. (1972). 'The influence of rainfall and man on the prawn populations of the Hunter River region'. *Fisherman*, 4(3), pp. 8-12.

RUELLO, N. V. (1973a). An historical review and annotated bibliography of prawns and the prawning industry in Australia. Paper prepared for National Prawn Seminar, Maroochydore, Queensland.

RUELLO, N. V. (1973b). 'The influence of rainfall on the distribution and abundance of the school prawn *Metapenaeus macleayi* in the Hunter River region (Australia)'. *Mar. Biol.* 23, pp. 221-228.

RUELLO, N. V. (1973c). 'Burrowing, feeding, and spatial distribution of the school prawn *Metapenaeus macleayi* (Haswell) in the Hunter River region, Australia'. *J. exp. mar. Biol. Ecol.*, 13, pp. 189-206.

RUELLO, N. V. (MS). 'Geographical distribution, growth and spawning migration of the eastern king prawn *Penaeus plebejus*' Hess. MS. submitted for publication in *Aust. J. mar. Freshwat. Res.*

APPENDIX

SUMMARY OF PRINCIPAL REGULATIONS ON NEW SOUTH WALES PRAWN FISHERIES

1. The prawn fisheries of the State are open to all fishermen holding a current New South Wales licence.
2. Prawn trawling in estuarine waters is prohibited except in:

   (a) the Clarence River
   (b) Hunter River
   (c) Hawkesbury River
   (d) Port Jackson
   (e) Botany Bay
   (f) Jervis Bay

   (i) Estuarine trawl nets must not be longer than 6 fathoms (11 m) along the headrope.

   (ii) The minimum mesh size (stretched) allowable in prawn trawls is 1½ inches (38 mm).

   (iii) Areas (a) and (b) above are closed for six months (winter) to allow replenishment of the offshore grounds and to protect prawns during the spring, while growth is rapid. Areas (c) to (f) have no adjacent sea fishery and (c) and (f) are open all year whereas, (d) and (e) are closed for 3 months (winter) following a recent request from commercial fishermen.

   (iv) All estuarine trawl fisheries are closed at weekends.
   (v) The upstream areas of most estuaries are closed because they are the major 'nursery areas'.

3. Prawn trawling is allowed in all ocean waters; there are no closed areas, but the minimum mesh size allowable is 1½ inches (38 mm). There are no other restrictions on the sea fishery.
4. Pocket net fishing is allowed in the channels of Wallis Lake, Myall Lake, Tuggerah Lake, Lake Illawarra, Sussex Inlet and several smaller lakes. The absolute maximum length of nets allowable in these lakes is 10 fathoms (18.3 m) (smaller sizes are prescribed for some lakes). The minimum mesh size of nets is 1¼ inches (32 mm).
   (i) The number and location of pocket nets to be used is decided by ballot supervised by the District Inspector of Fisheries.
5. A 'motorised' pocket net is allowed to be used in the Clarence River, by concession from the Fisheries Minister. (The vessel is moored along the river bank and the motor is operated and creates a current which drives prawns into the staked net).
6. Hand hauling (seine) nets are permitted in virtually all estuaries in the State. The absolute maximum length allowable is 75 fathoms (137 m); minimum mesh size is 1¼ inches (32 mm).
7. A modified hauling net (Danish-seine) may be used, as a concession from the Minister, in Wallis Lake, Lake Macquarie, Tuggerah Lake and Lake Illawarra. The maximum legal length is 50 fathoms (91 m) and the minimum mesh size is 1¼ inches (32 mm).
8. 'Running nets' are permitted in most of the lakes. The absolute maximum length is 75 fathoms (137 m) and the minimum mesh size is 1¼ inches (32 mm).

Most of the regulations outlined above have a long history and were implemented basically as conservation measures; the size of each type of net allowable in a particular estuary was usually determined by the size of the estuary and the number of fishing units then existing.

DISCUSSION

Olsen. You've got a section here where you've said 'recent economic studies of Australian prawn fisheries conducted virtually independent of concurrent biological studies'. Could you give us some background towards the recommendations of these economic studies that have been conducted?

Ruello. I'm sorry, I think Graham Evans would be a more suitable person to give you those. You mean actual results of those economic studies?

Olsen. What the recommendations were following the economic studies of the prawn fisheries.

Ruello. These studies were not conducted in N.S.W., they are the ones in the Gulf of Carpentaria and in Western Australia.

Dall. This is a bit of a 'red herring' as far as the management of N.S.W. fisheries is concerned. I was wondering if you could recall in New Zealand, a few years ago, there was a fishery, actually in the Auckland region, I can't recall whether they were schools or king prawns, do you know anything about those?

Ruello. My information from New Zealand came from John Yaldwyn. He told me they'd carried out thousands of trawls in New Zealand, and as you know he's a prawn specialist, he's done some work himself and he assures me that there are no littoral penaeids in New Zealand.

Kirkegaard. What's the catch of the 'mosquito' fleet—what's an annual or monthly or daily rate?

Ruello. I'd say their total production is very small. As you know in an open entry fishery, you can get people coming in for what we call the 'cream'. In N.S.W., you're a licenced fisherman, not a licenced prawn fisherman, and they fish for prawns in the first couple of weeks of the river season and then go back to mullet fishing or something like that. In a season like we've just had, which opened last week, where the catches look like being a record poor year, the 'mosquito' fishermen are in fact the only ones that are going to make a living out of it. The larger trawlers can't afford to work at the moment.

Kirkegaard. Which brings me to my next question. You're talking about predicting possible stock size—no doubt you have considered the effect this will have when Nick Ruello announces that next year is going to be a good year?

Ruello. We are cautious as you know. We would say that 'research results *indicate* that the Hunter River season *may* be better than average'.

Kirkegaard. Does this produce any measurable increases in the numbers in your 'mosquito' fleets?

Ruello. I don't know. An interesting thing, which I'm glad you've brought up, is that because there is a biologist in the Hunter River, fishermen in N.S.W. think that the Hunter River is the best of the estuarine fisheries. We, in fact, produced an artificial situation by doing research there—I'm sure that it attracted a certain number of trawlers. Before we started research in the Hunter River they didn't have this *large* invasion of boats from elsewhere. I think the implicit assumption that fishermen make is that they're doing research there and opening the river earlier, so there must be more prawns there, so let's go down to the Hunter for a couple of weeks. Then they go back home again.

Zed. I'm interested in your rainfall correlations because I've found a similar situation over in the fishery in Spencers Gulf with the western king prawn but the interesting thing is the correlation goes in the opposite direction.

Ruello. That doesn't surprise me as the school prawn likes freshwater and yours doesn't.

Zed. The other question I was going to bring up was the northward migration of the eastern king prawn would be going in the direction against the east Australian current and, from what we've heard from other speakers in the seminar, that current flows at a fairly fast rate.

Ruello. I don't subscribe fully to the views of some of the other biologists here. I don't believe they do. We don't know what goes on at the bottom. I don't think the prawns migrate in midwater or surface. I think they move along the bottom, there are too many dangers if they come up off the bottom, but we don't really know what happens along the bottom.

Dredge. Is N.S.W. Fisheries taking any steps to protect nursery areas and, if so, what steps are being taken?

Ruello. I think N.S.W. has taken a lot of steps. Des Dunstan has been working in State Fisheries for about ten years, basically on these sort of problems. We've got very strong laws regarding the spoiling of mangrove areas, *Zostera* beds and all of these. I'm sure you've got the same problem we have: the key-type developments which are taking up a lot of the intertidal areas. These people seem to want to take up all of the better type water front land, but I think we do have fairly tight legislation. It's not as tight as it could be—I'd like to see some stronger improvements made.

Smith. Does tag data on king prawns give an idea of time from when they leave the estuary and ovary maturation?

Ruello. No, because all of our returns are either very quick (local movements) or very long (distant migration), but with school prawns we have good data, when we tagged them up the Hunter River as juveniles three weeks later they were out at sea ready to spawn. So, apparently there is quite a terrific metabolic rate going on in developing the gonad. One of the interesting things that arises from this is that not only do these king prawns migrate long distances, they also develop their gonads. They arrive up north often ready to spawn but they're also growing quite rapidly. One of the animals we had back increased its weight by about 600% in about four months. One prawn went from about 20 to 40 mm carapace length in several months.

Thomson. In List of Regulations you mention Lake Illawarra, this used to be a great centre for amateur prawners—is amateur effort still going on and is there an effect of this on the fishery?

Ruello. Yes it still is; they do in Tuggerah Lakes and Lake Illawarra as you know. We recognise these as areas that have traditionally been fished by amateurs and we don't allow trawling in those areas. Fishermen are allowed to use running nets, and other nets that don't disturb the public as much, both physically and mentally, and this is important. We recognise that it's not only a commercial fishery. In Tuggerah Lakes one year we estimated the catch of the amateurs as something like a million pound of prawns which is quite a phenomenal amateur fishery and it has a reputation around the east coast.

THE SOUTH AUSTRALIAN PRAWN FISHERY

BY A. M. OLSEN
Director of Fisheries Research, Department of Fisheries,
183 Gawler Place Adelaide, South Australia

ABSTRACT

Several species of prawns were recorded in South Australian waters in 1927, but prawn fishing was not attempted until 1948. In that year a Danish-seiner from New South Wales trawled in Spencer Gulf for three months but returned to New South Wales after catching only eight prawns. Consistent large catches were not made until early 1968. Production reached 1790.194 tonnes in 1972–73.

The South Australian prawn fishery differs from most others in that only one species (Penaeus latisulcatus) is caught in commercial quantities. In April 1969 the 'Preservation of Prawn Resources Regulations' were introduced to prevent excessive fishing and consequent depletion of stocks, to maintain nursery areas and unexploited areas, to measure the effects of exploitation, and to assess the size and location of prawn resources.

Trawlers range from about 12 m (40 ft) to about 26 m (85 ft). Many of the larger vessels were originally tuna clippers and are now fitted for use in both fisheries. Otter trawls of synthetic materials are used. When the prawns are brought on board they are either cooked or chilled green.

Trawling is done at night, and effort is greatest in the autumn and lowest in August-September because calmer winter nights allow more fishing time and some vessels turn to tuna fishing during the summer. Most prawns are exported to Japan with about 10% sold on local markets.

All vessels must be surveyed by the Department of Marine and Harbours, and the skipper must hold a certificate of competency before a trawling authorisation is granted. In addition to research 'daily logs' a monthly statistical return must be submitted. Prawn authorisations are granted on application when known data indicates that additional fishing effort will not harm the resource.

Scientific research on the prawn in South Australia began in April 1970; in 1973 a new prawn research program was initiated. A prawn research officer and two assistants are currently investigating movement, growth and behaviour of prawns, and other work is being done to determine the animal's life history.

HISTORY

As long ago as 1927, several species of prawns had been recorded in South Australian waters but it was not until 1948 that prawn fishing was first attempted when a New South Wales 'Danish-Seiner' trawled in Spencer Gulf. After 3 months only 8 prawns had been caught and the vessel returned to New South Wales.

In 1957 the Department of Fisheries and Fauna Conservation carried out exploratory trawling from the vessel *Weerutta*. The vessel (later refitted and renamed *Investigator*) continued trawling and carried out further intermittent tests up until 1964. Various fishermen also undertook short trawling experiments at their own cost during this time.

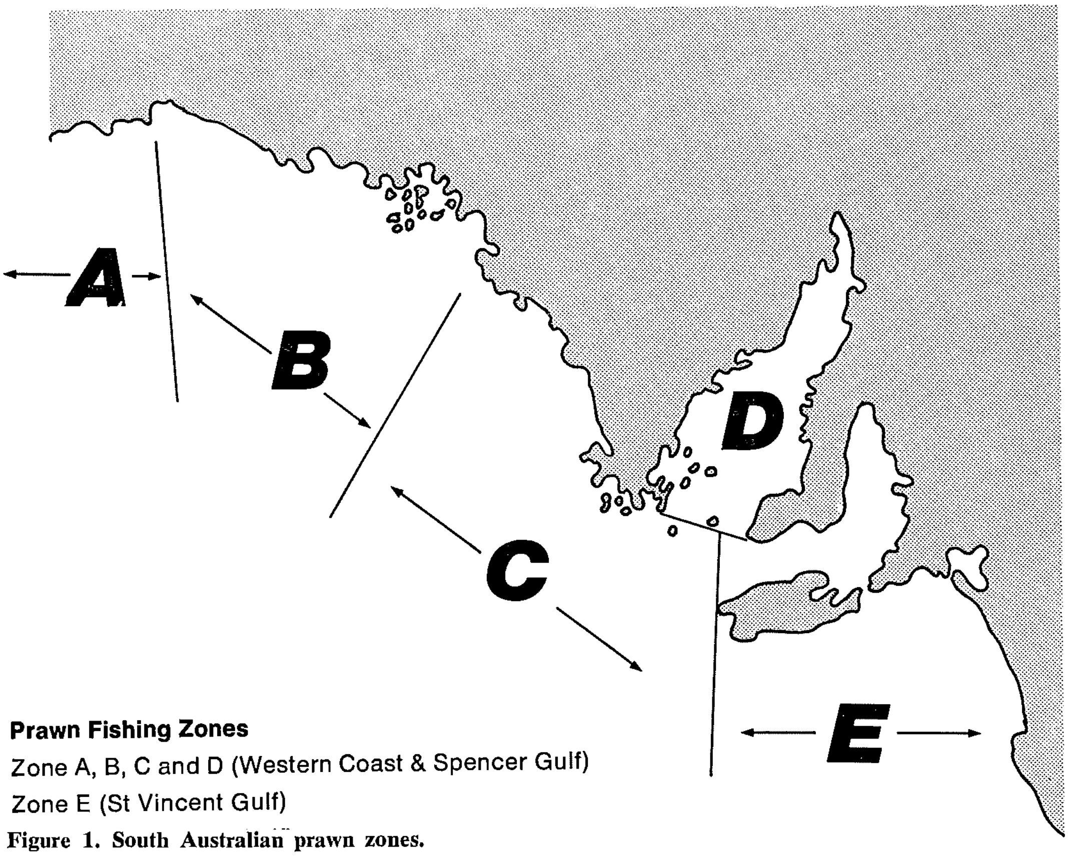
Although results and data collected over this time were promising, at no time were large quantities of prawns caught.

DEVELOPMENT

In December 1967, a Port Lincoln company recommenced the search for prawns and was soon joined by two other South Australian fishing boats and a New South Wales prawn trawler. By early 1968 consistent and large quantities of large Western King prawns (*Penaeus latisulcatus*) were being taken from Spencer Gulf and many more vessels were refitted for trawling and entered the fishery.

To control fishing activities and to collect data on the infant fishery, the Department of Fisheries and Fauna Conservation in March 1968, closed all South Australian waters to trawl nets. The waters were then zoned and permits to trawl were issued for each zone on condition that each boat submitted 'daily logs' recording hourly catches of prawns to the Department. The zoning encouraged skippers to carry out exploratory trawling rather than fish only the newly discovered grounds. (Fig. 1)

In July 1968, acting on information submitted in these 'daily logs' and on scientific knowledge gained from studies on prawns



Prawn Fishing Zones

Zone A, B, C and D (Western Coast & Spencer Gulf)

Zone E (St Vincent Gulf)

Figure 1. South Australian prawn zones.

carried out in other States, the Department closed to trawling all waters in the most northern part of Spencer Gulf as well as all waters of the State less than 9m (5 fathoms) deep. This was to protect all juvenile prawns in nursery areas and also to prevent interference with the 'inshore' scale fisheries (e.g. whiting, tommy ruff, garfish, etc.).

By August 1968, 40 permits had been issued and trawlers were working grounds in St Vincent Gulf as well as Spencer Gulf.

In April 1969, 'The Preservation of Prawn Resources Regulations' were introduced. The aim of these regulations was:

(a) to prevent excessive fishing and consequent depletion of prawn stocks;
(b) to maintain nursery areas and unexploited areas to measure the effects of exploitation; and
(c) to assess the size and location of prawn resources.

In mid-1969 productive grounds were located off Venus Bay on the far west coast of South Australia and this area is now being fished commercially.

In September 1969, 32 vessels were authorised to trawl and most skippers were members of the Western Waters Prawn Boat Owners' Association or the South Australian Prawn Fishermen's Association.

In October 1969, a new co-operative of 13 prawn fishermen was formed and by mid-1970 they had built a new processing plant at Port Lincoln.

In September 1970, 38 vessels were authorised to trawl and the zones slightly altered to encourage further exploratory fishing.

In February 1971, after report of large numbers of small prawns being taken in northern areas of Zone B, the Yarraville Shoal grounds were closed to trawling. This closure was lifted at the end of May, by which time prawns in the area had grown to a good commercial size. The closure was again imposed during February and March 1972.

On 22 March 1973, a proclamation was passed closing the area to the taking of prawns

Table 1. Catch and effort analysis of fishery (calendar year 1972)

	Range in length (m)	*No. of vessels*	*Total catch (kg)*	*Mean No. of months/ year worked*	*Mean No. of nights/ year*	*Mean No. of nights worked/ month*	*Weighted average monthly catch/ vessel (kg)*	*Weighted average catch/ night (kg)*
St Vincent Gulf (Zone E)	10-14	10	245 333	10.8	100	9.9	2 458	195
Spencer Gulf (Zone D)	13-26	21	895 405	8.8	95.2	10.8	4 477	446
West Coast (Zone C)	12-28	14	414 820	8	96	12	3 502	285
		45	1 556 059					

from 15 January to 15 March each year.

In June 1971, 45 vessels were authorised to trawl, and the restriction to zones abolished between Spencer Gulf and the West Coast to encourage more consistent fishing effort throughout these areas.

In March 1971, a $23,000 five-week survey of possible prawn areas in the south-east was carried out. It was financed by the State Government, professional fishermen, and fish processing firms in the south-east. Despite attempts at trawling over a wide area no prawns were found and the seabed was found to be mostly too rocky to trawl successfully. Further expansion of the prawn industry is now limited to the West Coast of South Australia.

CATCH RATE

Although some earlier catches of twin-rig trawlers were as high as 1 814 kg (4 000 lb) per night fishing log returns from July 1968 to May 1969 showed that average catches in Spencer Gulf for twin rig trawlers ranged from 49.9 kg-99.8kg/hr (110-220 lb) and for single rigs from 18.1 kg-72.6 kg/hr (40-160 lb). Catches in St. Vincent Gulf were lower. In the period May 1970 to May 1971, the Spencer Gulf catch rate for twin-rigged boats averaged 61.2 kg/hr (135 lb/hr) and for single-rigged boats 24.9 kg/hr (55 lb). (Table 1)

VESSELS AND GEAR

The size range of trawlers is from about 10 m (33 ft) to about 26 m (85 ft). Many of the larger vessels were originally tuna clippers and are now fitted for use in both fisheries. Only these larger vessels are able to use double-rig gear and most operate in Spencer Gulf or on the far West Coast.

Fishing trips of 3 to 4 days are not uncommon but are governed by weather and capacity of refrigeration and cooking equipment. Prawns are a particularly perishable commodity and great care is needed in handling them.

The smaller single rig trawlers operating in Spencer Gulf and St Vincent Gulf normally fish for only 1 or 2 nights before returning to port as carrying capacity is limited and they are more dependent on fine weather to allow continued fishing.

Vessels are designed with the wheelhouse and accommodation forward which leaves a clear working deck with fish holds below. The winch is generally fitted immediately behind the wheelhouse and the gallows slightly aft. Twin rig trawlers have heavy outriggers and all have lifting booms. Many vessels have gas or diesel cookers and refrigeration methods vary—the most common being chilled water. All vessels are fitted with two-way radio and echo-sounders and many have a thermograph and radar.

FISHING TECHNIQUES

Otter trawls of synthetic materials are used and each shot (or trawl) usually lasts from ½ to 1 hour. The catch is brought on board and the prawns are either cooked or chilled green. Trawling is done at night when the prawns are active.

Although there is no defined fishing season, effort is greatest during autumn and lowest in August and September. There are two reasons for this—the calmer winter nights allow more fishing time, and some vessels turn to tuna fishing during the summer.

PERMITS

All vessels must be surveyed by the Department of Marine and Harbours and the skipper must hold a Certificate of Competency before a trawling authorisation is granted. In addition to research 'daily logs', a monthly statistical return must also be submitted. Prawn authorisations are granted on applications where known data indicate that additional fishing effort will not harm the resource.

PRODUCTION

Most prawns are exported to Japan with about 10% sold on the local markets.

The South Australian Prawn Fishery differs from most others in that only one species is caught in commercial quantities.

PRAWN RESEARCH

Scientific research on the prawn in South Australian waters began in April 1970. In 1973 a new prawn research program was initiated involving a prawn research officer and two assistants.

Movement, growth and behaviour of prawns are currently being investigated and other work is being done to determine the animal's life history. As part of these investigations, many thousands of prawns are being marked with small coloured tags to determine migration patterns. Adult prawns are being studied by biologists working from co-operating prawn trawlers and the study of juvenile prawns is being conducted from small dinghys in the shallow water areas of both Gulfs.

DISCUSSION

Olsen. In St Vincent's Gulf the vessels are all restricted in size (maximum length 14 m) and to single-rig gear. We have made certain recommendations on headline length of prawn trawl nets. There are, at present, in Spencer Gulf and on the West Coast grounds boats working double gear, others are restricted to single gear. As yet the headline length has not been regulated. We have acted this way deliberately in order to obtain comparative data for economic analysis; you need a range of different gears and size of vessels for comparison of catches to determine certain variables and obtain an understanding of them.

Gorman. What is the number of fishing days boats get in the Gulf and what are the gear restrictions?

Olsen. Some vessels in St Vincent's Gulf work 11-12 months of the year for 118-136 nights (mean 124 nights). The skippers fish only during the dark of the moon and because there are only ten vessls in this area you find there is very good co-operation between the skippers. As a consequence they have agreed not to trawl in areas of small prawns and so you have a selective fishing operation and the market is virtually guaranteed the biggest prawns in the area by this co-operative action of the 10 vessels in the fleet. The plots for those four boats working in St Vincent's Gulf which I showed you on the Catch kg/night—Length of vessel graph worked a mean of 11.5 months for 10.8 nights/month for an average catch of 2 859 kg/month or 264 kg/night. You have another group of 4 vessels that worked only 11.5 months/year for an average of 8.0 nights/month. They were skippers who for various reasons didn't like going out too often and were apparently quite happy with their catches because it was economically satisfactory for them and then there were still another group who engaged in other fisheries who only worked in the prawn fishery for 8 months/year.

Haysom. Have you any arrangement for transfer of permits and is this taken into consideration in your evaluation of the boat value?

Olsen. Yes, we did have an administrative arrangement for transfer of ownership of authorised vessels but a fortnight ago a Crown Law opinion indicated that we had no legislative authority to transfer authorities. We now have to cancel the former authority and issue a new one. At this moment there is a value varying from $20 000-$30 000 put on prawning authorities in South Australia. It is the 'taxi plate principle'—it is one of the bad things about limitation on licences which, after all, is only a management measure. Licence limitation

The South Australian Prawn Industry

Financial Years	*Total Production*	*Production Value*
1967–68	133 996 kg (295 411 lb)	$147 700
1968–69	716 190 kg (1 578 929 lb)	$789 465
1969–70	1 302 493 kg (2 871 506 lb)	$1 636 738
1970–71	1 214 368 kg (2 674 820 lb)	$1 551 395
1971–72	1 521 991 kg (3 359 805 lb)	$2 284 662
1972–73	1 790 194 kg (3 943 158 lb)	$3 824 863 (estimated)

is a part of an evolutionary period in the management of a developing fishery. As soon as we can see that we have an established fishery then other ways and means will be used in its management. I consider that licence limitation is not the prime, but one of the many methods of control used in the management of a fishery. Licence limitation has a lot of associated problems. I believe in the theory that if you can get to the situation where you have the maximum number of economically viable units in each fishery and you have got certain qualification requirements for entry into that fishery, i.e. such as a period qualification before becoming a full time owner, then the fishery tends towards stability. The fishermen must know the economics of the various fisheries. When this stage is reached in South Australia then it will be possible to remove many of the licence limitation restrictions and let the fishery 'free float' to find its own level. In any community you will always find there are people sharper than others who have a strong profit motive, others who go fishing as a way of life and others who are content to fish for a living without putting much effort into it.

We have representatives in the first group in Spencer Gulf who work there during the dark of the moon and then steam to the West Coast where prawns may be taken in the light phase of the moon. Thus the average numbers of nights worked has risen from a mean of 110 nights/year to 149 nights/year (one man has fished 190 nights). A second skipper may be used and some of the crew rotate also. In the calculations described in my talk I have tried to relate these changes back to a common denominator.

Penn. In St Vincent's Gulf I would suggest that you may be under-fishing the area because you are catching big prawns with single rigged trawlers—a relatively inefficient gear, i.e. fishing the 1+ stock so not catching enough.

Olsen. Referring to the graph of the Catch kg/night—Length of the vessel for St Vincent's Gulf and remembering we have a maximum length restriction of 14 m and single-rig gear we have plotted the average actual catch/night as a scatter of points and the line so drawn represents the calculated catch/night for vessels of three different sizes. This calculated catch/night has been determined from the results of an economic survey of the operations of prawn vessels and allowing a 15% return per annum on the market value of the vessel and equipment.

From this graph has been determined the calculated catch/night for each of the 10 vessels operating in St Vincent's Gulf (range in length 10-14 m). These catches were summed and the mean figure boat was determined.

The total actual catch of the 10 prawn vessels for the year 1972 was 245 000 kg. (Some vessels were not working more than 8 months for 66 nights/year.)

By calculating the catch which would be taken by all 10 vessels working 10.8 months/year for 10 nights/month for a mean calculated catch/night of 212 kg the 10 vessels would require a total of 212 000 kg per annum for a 15% return on market value of vessels and gear. This calculated total catch is 33 000 kg less than the actual catch and it has been assumed that this difference in the actual and calculated weight represents a weight of prawns which could be taken by additional fishing units assuming the 245 000 kg per annum represents the maximum annual catch which may be taken.

From our analysis we know that a vessel of 10 m requires 16 000 kg prawns per annum for a 15% return on market value of vessel and equipment then it is assumed that the difference between the actual and calculated catch will support 2 vessels about 10-11 m going into the prawn fishery in St Vincent's Gulf.

We recognise that we may be underfishing the stock of 1+ prawns and hence one of our approaches to management is from economic considerations realising that our objective is to take the catch with the maximum number of economically viable units.

We will be watching closely through the monthly statistical catch returns the effect of these two additional vessels fishing in the prawn fishery of St Vincent's Gulf.

Evans. A thought on implementing logbook work—are you happy with your results from these?

Olsen. I have said before in this talk that the prawn daily logs are only estimates of the actual catch taken in that trawl. When the catch lands on the deck and is sorted into baskets the skipper estimates its weight. However, the recording of duration of each trawl and the number of hauls/night are reasonably accurate and the total weight of the night's catch is obtained from the factory when the catch is received there. We combine the data on catch and effort from the daily logs with the total catch recorded in the monthly Bureau of Census and Statistics fish catch returns. We are able to use both sets of data to obtain catch and effort figures of particular areas.

We have confidence in our catch figures because in 1970 there was an argument between the processors and our Department concerning the accuracy of fishermen's returns. The processors claimed that the fishermen were not supplying true catch figures whereas theirs were and in order to refute the processors' statements we extracted the data of sales to processors from our monthly statistical returns on which we require fishermen to tell us to whom they sold their prawns. The Minister in charge of fisheries in South Australia requested the processors to provide details of their purchases of prawns to a certain date which they did. Our figures checked with sales to the processors but the fishermen also disclosed that they had also made additional sales through other outlets unknown to the processors.

Neal. In the Gulf of Mexico we have a situation where we would like to limit licences but it is very difficult to back up and get fishermen to agree. So a lot of managers there are envious of you here and I would encourage you to stick with some form of licence limitation if it is possible. I was surprised to hear you are limiting gear which amounts to limiting efficiency of the harvesting operations.

Olsen. I agree with you that we are limiting efficiency in the fishing operations. This action is a deliberate one because we have an owner-operator policy and want the maximum number of economically viable fishing units in the prawn fishery. You could have a minimum number of fishing units which in effect would mean a few big vessels with very efficient gear taking all the prawn catch but the philosophy of our management of the prawn fishery is for the maximum number of vessels to be operating so you must necessarily restrict the efficiency. It is those fishermen, who have an authorised vessel in the prawn fishery, who are always wanting to increase the size of their vessel—they want to go into a bigger vessel. In order to go up to a larger craft they will need to catch more prawns per annum to pay for the purchase of the vessel and its higher operating costs. The question comes back to what are your objectives and philosophy of the management of the South Australian prawn fishery and built into these management measures is a certain degree of inefficiency—I recognise that.

THE MORETON BAY PERMIT SYSTEM
AN EXCERCISE IN LICENCE LIMITATION

BY N. M. HAYSOM[1]
Senior Administrative Officer, Fisheries Branch, Department of Primary Industries, 76–86 George Street, Brisbane, Queensland

ABSTRACT

A brief account is given of the development of the Moreton Bay prawn fishery and the difficulties and problems associated with the implementation of the restricted entry policy which has operated in the Bay since 1970.

In view of the fact that there is strong interest in a proposal to introduce licence limitation into the northern prawn fishery some of the lessons from the Moreton Bay situation and licence limitation programs elsewhere should be noted.

The permit system stabilised the bay prawning fleet at a time when this limited expanse of water was under increasing fishing pressure and individual catches were falling. While the limited entry system may not have achieved all its goals in the way intended by the architects of the scheme, it halted the escalation of the size of the fleet and perhaps solved some of the adverse economic effects associated with free entry into an attractive fishery.

As a general management measure the Moreton Bay permit system was a sound orthodox precautionary measure. However, because Moreton Bay was not a virgin fishery the licence limitation system produced its own brand of social and political problems.

Although this particular exercise had some unfortunate teething troubles, licence limitation appears to be the only alternative to management by legislation enforcing inefficiency.

Its main weakness is that in some fisheries its end result could be a very high level of income for a select few derived from a common property resource. The difficulty of overcoming this objection is in deciding what the level of income of a fisherman should be.

INTRODUCTION

The history of commercial prawn trawling in Moreton Bay dates back to 1949. It developed rapidly in the mid-fifties, and, apart from two minor slumps in the 1960–61 and 1966–67 seasons, expanded steadily (see Fig. I) to a peak production of 1.6 million kg in 1967–68, which year saw the accelerated growth of the Gulf of Carpentaria fishery and a 22% expansion of the Queensland prawning fleet. Its history over this span of time was remarkably stable by comparison with the fluctuating production of many other prawn fisheries. It is a multi-species[2] fishery, however, and the relative importance of the three main species involved has changed markedly over the years. (See Table 1.) The little information which is available to compare catch rates over this period is set out in Table 2, which indicates that individual boat landings have remained in the same order of magnitude though it should

Table 1. Proportional landings by species, Moreton Bay fishery.

	1952–53 %	*1953–54* %	*1966* %	*1967* %
Greasybacks	38[a]	56[a]	41	38
Tigers	56	27	9	8
Kings	6	17	46	52
Others	—	—	4	2

(a) *Note:* Large quantities of greasybacks were dumped at sea during December and January of these years because of market gluts, so that these figures do not represent the proportions of the species actually taken by fishermen.

Table 2. Average landings of prawns per boat-year[a], Moreton Bay fishery

1952–53	.... 17 195 lb (exclusive of dumped greasybacks)
1953–54	.... 23 158 lb (exclusive of dumped greasybacks)
1965–66	.... 17 934 lb
1966–67	.... 16 247 lb
1967–68	.... 24 995 lb

(a) *Note:* This is a figure obtained by summating the average monthly boat landings, in other words what an 'average' boat would have landed during the year if it had fished every month of the year.

---

[1] 1975, Assistant Executive Officer with the Queensland Fisheries Service, Department for Aboriginal and Islanders' Advancement and Fisheries.

[2] The three main species are greasybacks (*Metapenaeus bennettae*) eastern king (*Penaeus plebejus*) and tiger (*Penaeus esculentus*).

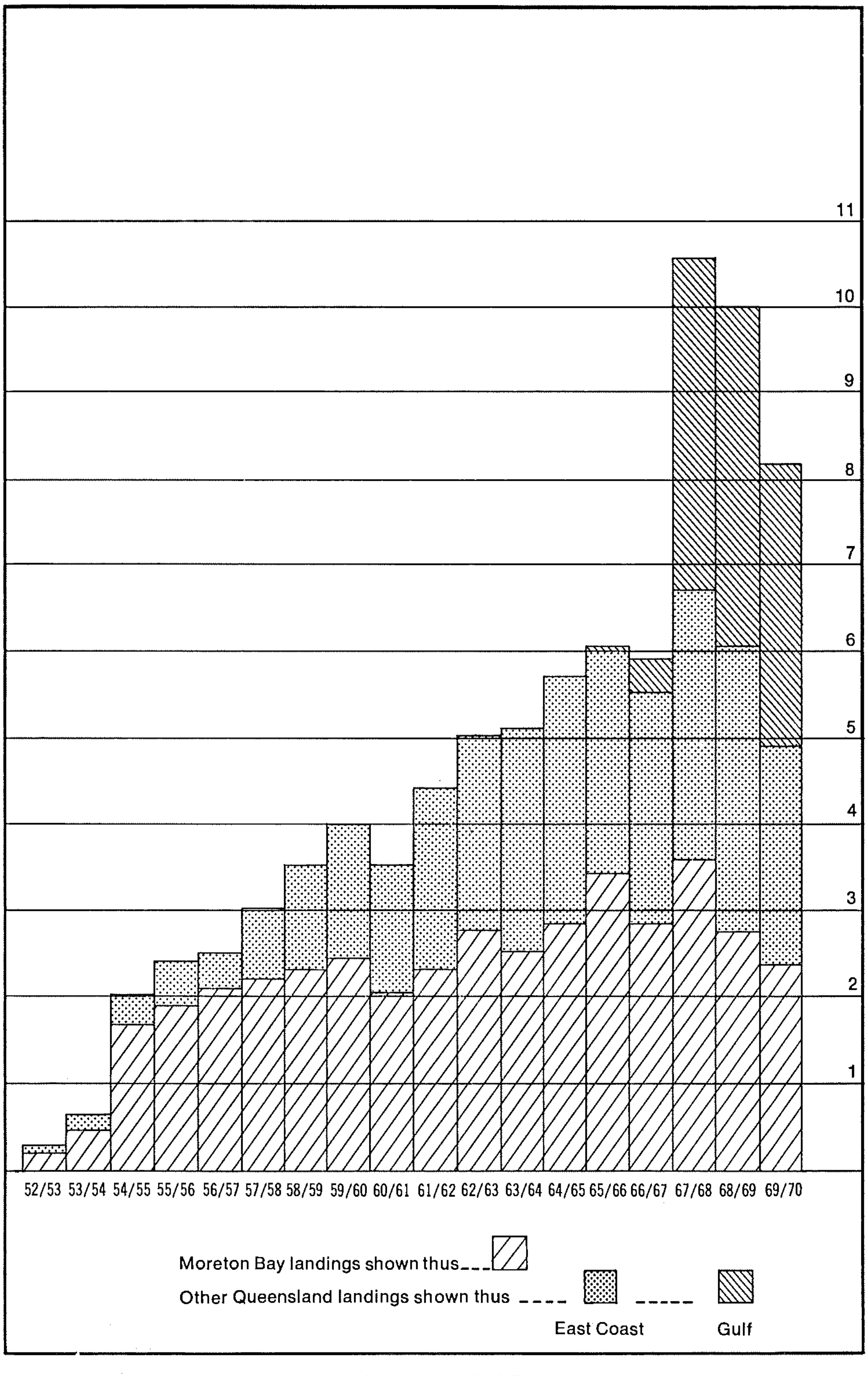


Figure 1. Annual landings of prawns (1952-53 to 1969-70).

be borne in mind that large quantities of greasy-backs were dumped at sea during December and January of the 1952–53 and 1953–54 seasons, because of market gluts.

By 1967–68, the number of boats participating in the Moreton Bay fishery at the seasonal peak was approaching 250. Within the following two years, however, production had declined to the level of landings made a decade previously. Concern over this situation, and fears of a further influx of trawlers, were influencing the thinking of resident Bay fishermen at the close of the nineteen-sixties.

BASIS FOR REGULATORY MEASURES

The philosophy underlying the application of management measures in the Queensland prawn fishery has been loosely based on the following assumptions:

(a) That prawns are virtually an annual crop.
(b) That prawns are highly fecund and that annual recruitment is not directly dependent on the size of the spawning stock.
(c) That prawns have a rapid growth rate and it is desirable to protect the juveniles to take advantage of this rapid growth, particularly in view of the higher prices commanded by the larger-sized prawns.
(d) That it is desirable to keep prawn trawling vessels away from areas of intensive angling activity.
(e) That 'fisheries that are unlimited become unprofitable'. (Graham, 1949, as quoted in Bevan, 1965).

Based on assumptions (a) to (d) above, a set of regulatory measures applicable to the Moreton Bay fishery has evolved over the past two decades. In essence, the use of otter trawls is restricted to those with a maximum spread of 15 m, and with a minimum mesh of 38 mm, and trawling is totally prohibited in the shallow 'nursery' areas on the western and southern portions of the Bay. In more recent years, however, a limitation on participation in the fishery has been imposed. This limitation, one may say, is based on assumption (e) above, and it is this particular measure which is the subject of consideration in this paper.

DEVELOPMENT OF THE PERMIT SYSTEM IN MORETON BAY

On 13 November 1969, a meeting of representatives of some elements of the local prawn-fishing industry and other interested persons expressed concern over the acceleration in the growth of the prawning fleet in Southern Queensland. Many of the traditional Bay fishermen were not equipped to fish open coastal waters. They feared that competition from the larger offshore trawlers, which move into the Bay during the peak of the Bay season, and from an expected influx of new vessels, would render Bay fishing uneconomical for those fishermen unable to shift their operations to grounds further afield during the off-season. They further pointed out that many of the Bay trawlermen had been in the fishery for a long time, were permanent residents of the bayside towns and suburbs, and had established family roots in these communities.

Stemming from this meeting, a Committee with industry representation was set up to report on the possibilities of limiting the Moreton Bay fleet.

Having in mind that the Queensland Fisheries Acts of 1957 to 1962 made no provision for the granting of a special licence for a particular fishery, this Committee recommended that a closed season be declared in the Bay, but that selected fishermen be granted permits to fish during the closed season, in accordance with section 70 (3.) of the above Acts. The permits were to be available to any licensed fisherman who had consistently operated prawning vessels in the Bay for a period of several months in each of the previous three years.

This policy was adopted and came into force in March 1970. The Committee recognised that in the early stages of implementation of the policy, 'some flexibility would be needed in special cases', one development of which was that a number of persons who had recently acquired or who were already in the process of building or buying boats *suitable only for the Bay fishery* were granted permits, even though they did not qualify for these permits in other respects.

Towards the end of 1970, as a result of complaints that the policy virtually blocked the sale of small Bay trawlers, modifications were introduced to allow newcomers to enter the fishery by purchasing a small trawler (i.e. one not exceeding 14 m in length) currently covered by permit, to provide for the periodic replacement of vessels by permit-holders under certain circumstances, and to make provision for the eventual phasing-out from the Bay fishery of the larger classes of trawlers (initially those over 15 m in length, but with a view to the eventual elimination of all trawlers over 14 m in length). In fairness to the original Committee, it must be stated that its members were not involved in the discussions which led to the implementation of these modifications.

DIFFICULTIES AND PROBLEMS ARISING OUT OF THE IMPLEMENTATION OF THE POLICY

First and foremost, the main problem lay in applying the initial criteria for qualification as a permit-holder. The Committee's comment that 'some flexibility would be needed in special cases' was a classic of understatement. The Committee was either ignorant of, or disregarded the fact that the Department did not have reliable records of fishermen's past histories of fishing on a monthly and locality basis. I believe Committee members pinned their faith on the system of monthly catch-and-effort returns which had been operating in Queensland for some years previously. However, these returns were far from complete, and those which were in our possession frequently did not permit the retrieval of the information required, because they were designed for a different purpose.

This led to the granting of permits to a large number of applicants who probably did not qualify on the basis of the criteria laid down, and conversely to the rejection of some others who should have received a permit.

The position was further aggravated by the later decision to phase-out vessels over 15 m in length. Approximately a dozen trawlers above this limit were affected, the greater proportion of which had a long history of fishing the Bay. The owners, some of whom regarded themselves as pioneers of the Moreton Bay fishery, naturally objected to their exclusion, particularly when complete novices had right of entry merely by buying a small vessel to which a permit was already attached.

DISCUSSION

Those officers involved in the implementation of this particular exercise in licence limitation might be excused for regarding it as having no redeeming features. However, there is no doubt that the Bay, which is after all a comparatively limited body of water, has been under increasing trawling pressure over a long period of time, and that falling levels of individual catches were of considerable concern to those fishermen who were entirely dependent on the Bay fishery. Symptomatic of this concern is the fact that within the last decade, virtually every small type of prawn in the Bay (including *Trachypenaeus* spp., *Metapenaeopsis* spp., and even Alpheids) has come to be regarded as grist to the mill.

What, then, has the permit system achieved? The Bay fleet has been stabilised at a level of approximately 180 boats. While it may not have reached its goal in quite the way intended by the architects of the scheme, it did at least halt escalation of the fleet, and perhaps avoided some of the climactic adverse economic effects associated with free entry into an attractive fishery. The attractions in this particular case include:

(a) The ability to participate at a low level of experience in fishing and boat-handling—Moreton Bay has long been regarded as a kindergarten for budding trawlermen.
(b) Fishing grounds only a few minutes steaming from port, and on the doorstep of a large city.
(c) A fishery conducted in comparatively sheltered waters, which reaches its peak at a time when operating conditions in neighbouring fisheries are at their worst.

As a general management concept, the Moreton Bay permit system could be described as a sound, orthodox precautionary measure. It is, however, in its mechanism and application and the side-effects thereof that it is mostly open to criticism.

As Moreton Bay was not a virgin fishery, it was obvious that introduction of a licence limitation system would produce its own brand of social and political problems. It is far more provocative and disturbing to tell a fisherman that he has to get out rather than to tell him that he can not come in. Yet the implications of this were not adequately considered.

Probably the worst feature of the scheme was the vagueness of the criteria laid down. Those officers charged with the practical implementation of a policy should not have to rely in a large proportion of cases on a value judgment based on meagre information. Inevitable corollaries of such a situation are accusations of victimisation or favouritism, constant reviews of particular cases, and a progressive dilution of the policy in frustration of the aims of its originators.

Another criticism involves the basis of fisheries management generally throughout Australia rather than a specific censure of this particular exercise. Here was a problem, in common with so many other fisheries management problems, which was essentially one of economics, and yet the attempted remedy was spawned without the assistance of any economic data or studies. Even conceding that the lobbying was almost impossible to resist politically, it is disturbing that such a decision should be made in the absence of pertinent raw data, and even more so that the only fisheries management agency in Australia with a staff structure in which economics is given its due level of importance in the management scene, is the one which has the least to do with fisheries management legislation. Moreover, as Crutchfield (1965) states, 'fisheries present peculiarly difficult problems in satisfactory economic performance', and it is perhaps not sufficient to have access merely to conventional economic advice. One should be able to consult economists who have studied the specifically peculiar problems which fisheries present.

In view of the fact that there is strong interest in a proposal to introduce licence limitation into the northern prawn fishery, it may be of value to list some of the lessons derived from the Moreton Bay situation and other licence limitation programs elsewhere.

(a) It is highly desirable that the management agency should have a sound prior knowledge of the economic structure of the fishery. One should not be bulldozed into precipitate action just because a group of fishermen say they are going broke without evidence that their story is true, without consideration as to whether the group are the 'born losers' or are inherently inefficient.

(b) In an established fishery, any licence limitation policy involving reduction of the fleet by direct legislation is inviting friction and bitter controversy. It is generally far better to freeze a fleet at its existing level and allow wastage or 'drop-outs' eventually to reduce the fleet to the level desired. Alternatively, some overseas agencies have solved the problems involved by a 'buy-back' policy, in which the State buys back vessels or equipment made redundant by licence limitation legislation, (Fletcher, 1965). This can be an expensive proposition.

(c) It is essential to have clear-cut criteria, which can be applied at clerical level, as a basis for initial decision on inclusion or exclusion. Suppose the criterion is that to obtain a licence a fisherman shall have fished an area for the past twelve months. Does this mean that if he missed even one month, he is automatically disqualified? At the other end of the scale, if he made only a single day's trip in each month, does he qualify? Where does one draw the line?

(d) If the criteria selected rest on some form of statistical records, a check should be made that the specific data required are in a form which can be used, and moreover are readily extractable by clerical staff. This is where the Moreton Bay exercise fell down badly. It was expected that the print-outs of monthly catch-and-effort returns would give all the required information on fishermen's activities, whereas the returns related primarily to boats, and furthermore were not in sufficient detail for the purposes required.

(e) Licence limitation can lead to various repercussions of a social, political and legal nature, and it behoves the administrator to examine the proposal carefully for potential side-effects. To date, Australian fishermen have not been prone to challenge the constitutionality or legality of local legislation, but the *Bonzer* v. *La Macchia* case would seem to indicate a growing awareness of such aspects.

(f) Finally, because of its very nature, it is highly desirable that such legislation should be preceded by a full and wide consultation with *all* the fishermen affected. Failure to do so invariably leads to deputations to Ministers and emotional vituperation, or perhaps results in hasty policy amendments, which again produce their own characteristic set of problems.

CONCLUSION

The foregoing paper has been in the form of a brief post-mortem on an exercise in licence limitation masquerading under another name. Although this particular exercise had some unfortunate teething troubles, licence limitation appears to be the only alternative to management by legislation enforcing inefficiency. Its main weakness is that, in some fisheries, its end result could be a very high level of income for a select few, derived from a common property resource. The difficulty of overcoming this objection is in deciding what the level of income of a fisherman should be. Unfortunately, Solomon left no formula for the guidance of fisheries administrators!

LITERATURE CITED

CRUTCHFIELD, J. A. (1965). 'Economic objectives of fishery management', in *The Fisheries: Problems in Resource Management* (Ed. J. A. Crutchfield), University of Washington Press, Seattle, pp. 43-64.

BEVAN, D. E. (1965). 'Methods of fishery regulation', in *The Fisheries: Problems in Resource Management* (Ed. J. A. Crutchfield), University of Washington Press, Seattle, pp. 25-40.

FLETCHER, R. L. (1965). 'Constitutionality of limiting the number of fishermen in a commercial fishery', in *The Fisheries: Problems in Resource Management* (ed. J. A. Crutchfield), University of Washington Press, Seattle, pp. 95-119.

GRAHAM, M. (1949). *The Fishgate* Faber and Faber Ltd, London, p. 153.

DISCUSSION

Lucas. I'd like to make two comments. First, relevant fishing power of boats in Moreton Bay fishing industry this year was not more than 100 boats operating. Of these, the top 20 caught half, earning $40 000. The remaining will pick up the crumbs. Second, annual variation in stock size: the 1970-71 catch was approximately 1.8 million kg, so you get annual fluctuations.

Haysom. Where did your figure of 1.8 million kg come from?

Lucas. From processors and 20% that was sold privately.

Penn. Small boats can make a profit and also get this where larger boats can't make a profit. We should look for smaller boats that can fish more economically.

Haysom. It might be interesting to see whether the economists could find out whether the ones that Chris Lucas referred to as 'picking up the crumbs' are in fact making a living.

Potter. One of the boats 'picking up the crumbs' is making about $200 per week on crabs, squid and prawns.

THE MANAGEMENT OF AUSTRALIAN PRAWN FISHERIES FROM THE VIEWPOINT OF A FISHERIES BIOLOGIST

BY J. S. HYND
Principal Research Scientist CSIRO, Division of Fisheries and Oceanography,
P.O. Box 21, Cronulla, N.S.W. 2230

ABSTRACT

Australian prawn fisheries are based on species in which large fluctuations in numbers occur due to natural causes. The result is that catches also fluctuate widely with consequent hardship for the fisherman and problems for the administrators. This paper deals largely with the role of the fisheries biologist in assisting industry and administration in making management decsions. In particular it is important for the biologist to determine whether a particular fishery is in a developing state or is fully developed: and if the latter, to establish a system of forecasting catches in advance so that fishing effort may be deployed most efficiently.

INTRODUCTION

Australian prawn fisheries are based on species of the genera *Penaeus* and *Metapenaeus*. Most species of these genera have a life cycle of one year and a natural mortality rate about two orders of magnitude greater than moderately long lived scale fish. In other words the annual crop is based on one year class only. In addition, fluctuations in abundance due to natural causes are common and quite large. The result is that annual catches tend to fluctuate rather widely with consequent problems for management.

METHODS OF REGULATION OF AUSTRALIAN PRAWN FISHERIES

Historically five methods of regulation have been used in Australia. Examples of each with comments are given below.

(a) *Minimum size limits*. N.S.W. at one time had a minimum size limit on all species of prawns. The necessary culling was both time consuming and wasteful of young prawns and was finally abandoned in favour of closed nursery areas, closed seasons and minimum mesh sizes. Minimum sizes are still nominally in force in other States.

(b) *Closed areas*. Closures of this type have been applied in most Australian States at some time or another. Most have been or are intended to prevent the taking of small prawns, presumably on the assumption that these prawns are below the optimum biological size at first capture In point of fact unless the values of F and X for a fishery are known such assumptions can only be (? inspired) guesswork. However, where there is some overriding economic factor such as a special premium for larger sized prawns, optimum biological size can become irrelevant.

(c) *Closed seasons*. Closures of this type are intended to operate in the same manner as closed areas and are used in the same manner, e.g. closed seasons in the Gulf of Carpentaria were originally introduced to prevent the taking of young prawns which were unacceptable to the processors (an economic factor). However, the situation has changed and the smaller prawns have become acceptable. Hence maintenance of this method of regulation results in loss of catch especially of the smaller prawns which are probably (? inspired guesswork) above optimum biological size.

(d) *Mesh size*. Most Australian States have lower limits on the allowable size of mesh in the tunnel and codend of the nets. This is usually 1¾" (44 mm) stretched mesh between knots (1½" (38 mm) in some States). With the types of net normally employed in prawn fisheries escapement of young prawns below about 4" (102 mm) total length from 1¾" (44 mm) mesh is good and they escape in good condition. I have not seen, as reported by Gulland (1972, p. 7), small Penaeid prawns entangled in a net by their legs and contrary to Gulland I believe that mesh regulation is an effective means of controlling minimum size in prawn fisheries provided large catches are not made in a very short time(such as in some banana prawn fisheries) and provided there is not a large amount of trash to choke the meshes.

(e) *Licence limitation.* Licence limitation is applied to maximise some feature of the yield from the fishery or at least to prevent some unsatisfactory feature developing. It was applied in W.A. (originally at least) in order to keep the financial yield to the industry at a satisfactory level. However, given that there are wide fluctuations in abundance not associated with fishing there is only one solution that ensures that the nett financial return to industry is never less than zero and that is to base the number of licences on the lowest expected annual catch. The result of such a procedure is that the fishery is extremely profitable on the average and a licence acquires a monetary value. This subject is dealt with at length by B. K. Bowen in another paper in this series.

Another approach to management which has been employed in Australia is to have free entry. Notable examples are the N.S.W. fisheries and the Gulf of Carpentaria fisheries. Free entry in a developing fishery has biological and economic benefits in that full exploitation is achieved at a maximum rate limited only by availability of capital, manpower and enthusiasm. However, as Gulland (*op. cit.* p. 3) remarks there is a tendency to overshoot in capital investment with consequent economic problems.

THE ROLE OF THE BIOLOGIST

The decision whether or not to regulate a fishery is basically a moral or political one and as such is outside the professional responsibility of the fisheries biologist (though he may have, and is entitled to have, his private opinion on the wisdom or otherwise of a particular decision). His role should be:

(1) to provide to the best of his ability the answers to the questions that management may ask about what is likely to happen if this or that is done or not done;

(2) to alert management if there is a need or a possible need to consider taking regulatory action.

In this latter function I think the biologist is entitled to step a little outside his formally qualified field and offer advice in the realm of elementary economics if he sees such a need arising.

The sorts of questions that management ask the biologist do not vary much from fishery to fishery. Basically management wants to know how to maximise some feature of the fishery without endangering stability. In order to give answers to these questions the biologist needs to know some basic biological facts though not always in great detail. For example in all Australian prawn fisheries so far investigated the contribution to the catch from individuals over one year old can virtually be ignored. A further assumption that can be made is that if the proportion of returns from a properly conducted tagging experiment is low the ratio of F to X is low. This follows from the relationship:

$$\frac{n}{N_0} = \frac{F}{F+X}$$

where n is total recoveries
N_0 is the number released
F is the fishing mortality coefficient
X is the natural + etc. mortality coefficient

If $\frac{n}{N_0}$ is small F must be small relative to X.

In this situation the possibility of overfishing to the extent of recruitment being affected can be ignored.

Other important information that is needed is:

(a) the geographical limits of individual stocks;

(b) whether there is migration or segregation by size within these limits;

(c) the growth rate;

(d) the values of F and X for the various sections of the fishery.

The priorities that should be assigned to the collection of these data will vary with the age of the fishery, e.g. in an old well established fishery it is likely that many years records on catch, effort, size composition and yearly and areal distribution of size composition are available and hence the requirements of (a), (b) and (c) above can be satisfied immediately. What is generally not available are the values of F and X for the fishery. First priority should therefore be given to establishing the values or at least the magnitudes of these coefficients. As an example of this I refer to the Moreton Bay fishery for juvenile eastern king prawn. Lucas

(MS.) has by a series of tagging experiments established values for F and X which, accompanied by some work on growth rates, allow him to predict that if effort were increased by 25% in this fishery the total yield in weight from the species would increase by 16%. The study was not extended to include changes in the value of the catch due to changes in size composition.

In a developing fishery priorities should centre most heavily on establishing the geographical limits of the stock and the migration and segregation by size within these limits. The administrator will undoubtedly require information on how much expansion can take place in the fishery with safety. Any procedure whereby individual stocks can be delineated should be immediately employed, e.g. in the Gulf of Carpentaria banana prawn fishery we are attempting to establish the likelihood or otherwise of these prawns constituting a unit stock and if so what are the internal migrations.

The methods employed are mainly:

(a) studies of the population size of juveniles in the nurseries at various times of the year;

(b) tagging of migrating juveniles;

(c) tagging of adults in the commercial fishery. This program of course has a spin off in that it will confirm or deny whether $\frac{n}{N_0}$ is small.

So far we have discussed the ways in which a biologist might act in order to discharge his responsibilities as described in (1) above. His responsibilities as described in (2) above tend to be different in that information must be conveyed in 'real time' in order to be of use. I will explain by giving two examples.

(a) Using the abundance of juveniles in rivers 3 to 4 months earlier as a basis, we are attempting to predict the catch of adult banana prawns (*cf.* work being done at Galveston, Texas—Temple [1973, p. 17]). The system appears to work well in the developed fishery in Nickol Bay. The situation in the Gulf of Carpentaria, however, is different in that to date the fishing area has continued to expand and comparisons of catch with prior juvenile densities are difficult to interpret. The value of such a prediction system for banana prawns lies in the fact that for most prawn fishing boats there are other prawn fisheries available, unexplored or extremely underexploited areas where prawn fisheries might be developed and fisheries not based on prawns in which they might participate. The scope of choice varies with the type of boat and geographical situation but three months warning of an impending bad season could result in a considerable saving in time and therefore money.

(b) Although the fishing area for banana prawns in the Gulf of Carpentaria has continued to expand to date it cannot go much further geographically. The catch in the last 3 years has been between 4 and 6 mllion kg, this in spite of the increased area searched and an approximate doubling of the number of boats and a trebling of their tonnage (and presumably fishing power). These facts could be interpreted to mean that the catch cannot be increased much further. If so we have an economic situation which warrants close investigation for the following reason.
Boats of about 24 m L.O.A. require approximately 90 000 kg of prawns per year to operate economically. In other words 50 such boats require a total of 4.53 million kg. There are already about 50 boats of this size operating in the Gulf of Carpentaria together with about three times this number of smaller boats. Do we have here an example of overshoot?

LITERATURE CITED

Gulland, J. A. (1972). 'Some introductory guidelines to management of shrimp fisheries'. F.A.O., I.O.F.C./DEV/72/74.

Lucas, C. (MS.). Preliminary estimates of stocks of the king prawn *Penaeus plebejus*, in south east Queensland.

Temple, R. F. (1973). 'Shrimp research at the Galveston laboratory of the Gulf Coastal Fisheries Center', *Marine Fisheries Review*, 35, Nos 3-4, pp. 16-20.

DISCUSSION

Pane. Would you subscribe to the theory that the prawn catch in the Gulf is steady because prawns are schooling in closed season?

Hynd. No, I don't think that the closed season is responsible for anything more than a minor loss of catch in the Gulf of Carpentaria. I'm quite sure that because there is a closed season that the catch is down from what it could be. You're probably thinking of the idea that some fishermen have that if you don't give these prawns a chance to school up in large schools then your catch is going to be down a bit.

Pane. In the 1973 season, spotters reported seeing boils in large numbers till three days before the season started then they vanished.

Hynd. Did the spotter say whether they were prawn boils or fish boils? My experience is that unless you put a boat through with try-gear you don't know what they are.

Penn. A major problem is no one has come up with a tag mortality figure that is realistic and effort is on the low side and unrealistic.

Hynd. I agree—however work is going on. Chris Lucas is interested in this and he is already at a stage where he can make rough guesses as to what the initial tagging mortality that's operating might be, and even a wild guess, as you might call it, of what the continuing tagging mortality might be; but you can do numerical studies of these various situations and take various values of these mortalities and see how it will effect your result, and without wishing to pre-empt any of Chris's work, as I remember it, you could have an initial tagging mortality of up to 50%, perhaps 40%, without appreciably altering the ratio of N. Also, you could allow continuing tag mortality of .03 weeks^{-1}, which is on the same order as natural mortality, and still not have your result appreciably affected. When I say appreciably—we had a 5.5% return of tags from 35 000 releases in the Gulf of Carpentaria this year. On the face of it, that would indicate a pretty low *F*. However we have to allow for a 15% non-reporting of tags by the processing plants—possibly another 15% non-reporting by fishing boats, possibly an initial tagging mortality of 40-50% and possibly an increase in mortality due to tagging of .03 weeks^{-1} or something like that. But it still comes out at catching something like less than a fifth of the total prawns which means *F* low relative to *X*.

Gorman. As Nick told you this morning, probably the most important conservation measure adopted in N.S.W. was the introduction of a minimum legal mesh size. It's been drawn to my attention that there's some doubt in people's minds about the effectiveness of this as a conservation measure. It's always been a very contentious issue in our State, so we carried out a comprehensive program on mesh selectivity.

Allan Stark, who was CSIRO's mathematician at the time actually designed the mathematics of the experiment, and Allan Collins did the analyses for the final escapement data. The system we used is the standard one in the FAO manual on fish escapement. It took us months to design a covered codend system that satisfied us. We did a lot of underwater work on it and we eventually came up with an arrangement which we thought was particularly good, very good in fact. We did four experiments to coincide with the seasons so that we'd encounter normal variation in the prawn lengths. We used the N.S.W. longitudinal extension gauge to measure the meshes.

We had five detachable codends each with a different mesh size and we used a heavily tarred polypropylene continuous filament for the codend twine. This is a strong material with a very low extensibility. One of the problems that you come up against immediately in mesh selectivity is that the mesh size is never exactly what you want. So, in fact every time you do an experiment, you have to measure that codend. You've got to keep on doing this throughout the trials, in fact, you've got to start off right at the very beginning and do a whole series of trawls to tighten up your knots, before you even start the experiment. We calculated the minimum number of meshes you need to measure to give you a satisfactory average figure for each experiment.

We chartered a commercial trawler for each of the four experiments and they were able to fish as they chose, any time of the day or night, or any area to similate normal commercial practice in the area. In the estuaries, of course, you strike a lot of trouble with jellyfish, much more so than you do in open sea. You also find leaves, branches, mud, catfish and large quantities of weed. Anyway, 135 trawls and some 72 000 prawns later we came up with the data shown in Tables 1, 2 and 3. Normally, this is presented as a curve, however this can be transformed into a straight line for each mesh size. The 50% selection point for each mesh size is shown.

Allan Collins then fitted a regression line to the 50% selection points for each mesh size and we used this to derive the 50% selection point for the 38 mm mesh size. The details are as follows:

By fitting a regression line between columns 2 and 6: a co-efficient of correlation 0.8 was obtained which represents 64% of the variation.

The regression line $y = 2.6x - 0.7$ was the least squares line of best fit.

Therefore 50% selection size for 38 mm mesh = 82 mm total length prawn.

Table 1. Results of prawn selectivity trials—summary sheet

	1	*2*	*3*	*4*	*5*	*6*
Nominal Mesh Size	*Experiment Number*	*'x' Actual Mesh*	*Nearest Fractional Equivalent*	*Decimal Equivalent*	*50% Selection Carapace Length*	*'y' Prawns Total Length Equivalent*
$1\frac{1}{4}$	1	$1\frac{3.85}{32}$	$1\frac{1}{8}$	1.125	1.25	2.25
	2	$1\frac{4.0}{32}$	$1\frac{1}{8}$	1.125	0.95	2.1
	3	$1\frac{3.9}{32}$	$1\frac{1}{8}$	1.125	1.4	2.3
	4	$1\frac{4.4}{32}$	$1\frac{1}{8}$	1.125	1.0	2.1
$1\frac{3}{8}$	1	$1\frac{5.9}{32}$	$1\frac{3}{16}$	1.1875	1.8	2.48
	2	$1\frac{6.2}{32}$	$1\frac{3}{16}$	1.1875	2.0	2.55
	3	$1\frac{5.9}{32}$	$1\frac{3}{16}$	1.1875	2.0	2.55
	4	$1\frac{6.1}{32}$	$1\frac{3}{16}$	1.1875	1.5	2.35
$1\frac{1}{2}$	1	$1\frac{10.4}{32}$	$1\frac{5}{16}$	1.3125	2.8	2.9
	2	$1\frac{10.5}{32}$	$1\frac{11}{32}$	1.34375	3.5	2.2
	3	$1\frac{10.5}{32}$	$1\frac{11}{32}$	1.34375	3.0	2.99
	4	$1\frac{10.9}{32}$	$1\frac{11}{32}$	1.34375	1.1	2.19
$1\frac{5}{8}$	1	$1\frac{13.1}{32}$	$1\frac{13}{32}$	1.40625	3.5	3.2
	2	$1\frac{13.2}{32}$	$1\frac{13}{32}$	1.40625	4.3	3.54
	3	$1\frac{12.9}{32}$	$1\frac{13}{32}$	1.40625	2.9	2.95
	4	$1\frac{13.4}{32}$	$1\frac{13}{32}$	1.40625	2.2	2.65
$1\frac{3}{4}$	1	$1\frac{17.25}{32}$	$1\frac{17}{32}$	1.53125	3.8	3.32
	2	$1\frac{17.3}{32}$	$1\frac{17}{32}$	1.53125	4.7	3.70
	3	$1\frac{17.9}{32}$	$1\frac{9}{16}$	1.56250	2.9	2.95
	4	$1\frac{17.9}{32}$	$1\frac{9}{16}$	1.56250	4.2	3.50

Table 2. Calculated 50% selection points for various mesh sizes.

Mesh size	*50% Selection Point—Prawn Length in Inches*
1¼″	2.56
1⅜″	2.89
1½″	3.22
1⅝″	3.54
1¾″	3.87

Table 3. The total number of prawns and trawl shots involved in the selectivity trials.

Experiment Number	*Total Number of Prawns*	*Number of Trawl Shots*
1	22 611	11 × 5 = 55
2	5 076	6 × 5 = 30
3	27 625	7 × 5 = 35
4	16 930	3 × 5 = 15
Grand Total	**72 242**	**135**

As shown in the figures, there is a significant escapement from each codend as well as significant differences between the various mesh sizes. This is despite the very adverse conditions often encountered during trawling, i.e. the presence of mud, jellyfish, weed, etc. in the codend.

In summary, I believe the data shows that minimum mesh sizes are an effective management tool in prawn trawl fisheries. Our fishermen realise that escapement is high so they use every imaginable strategy to reduce the escapement from codends, i.e. they hobble them; put bags inside them; double them up; attach heavy weights to them to elongate the meshes and close up the lumen.

This point took longer than I anticipated; but I do want to clear up this issue about the effectiveness of minimum mesh sizes.

Pane. What is the optimum mix between a biologist, an economist a government department and the fishing industry?

Hynd. I don't think there's any such thing as an optimum but I know that the smart biologist tries to keep out of the trouble that's usually associated with prawn fisheries or any fishery for that matter. The basic problem is for the administrator to make the decision about whether regulation is necessary and who's going to benefit by it. I have my own private views on some of the measures that have been taken in Australia, but I don't think we'd gain anything if I aired them. I think perhaps the best arrangement would be to make sure that if you've got a fishery starting that some one is there to collect information right from the start and preferably a biologist who's going to have to wear it later on when working the data up. In other words, it will be his data and he's got to produce the answers. The fishermen and the processors become involved also in that they'll be providing a lot more of these data. I think you can often come to a semi-amicable agreement with this four-way arrangement of people but I don't think there's any optimum.

THE BASIS FOR MANAGEMENT OF WESTERN AUSTRALIAN PRAWN FISHERIES

BY D. A. HANCOCK
Chief Research Officer, Marine Research Laboratories, Department of Fisheries and Wildlife P.O. Box 20, North Beach, W.A.

ABSTRACT

Prawn fishing in Western Australia has been pursued as a successful commercial venture only during the past decade, with total annual landings reaching a maximum of 7 million lb (3.34 million kg).

The main prawn fisheries are in Shark Bay for predominantly western king prawns, Exmouth Gulf for tiger and king prawns and a very variable fishery for banana prawns in Nickol Bay.

The basic method of managing the W.A. prawn fisheries is by limiting the number of licences granted, followed by a phased increase in the number of boats.

With increasing number of boats in a fishery, total catch will increase, but catch per boat will decline. In conjunction with this position the total revenue from a fishery will increase to a maximum and then decline to a level which may not even meet running costs of the fleet. Maximum economic yield is made at a point where the amount of fishing effort put into the fishery gives a catch that is less than the maximum sustainable yield.

It is on this basic philosophy that licence limitation has been introduced into the Western Australian prawn fisheries. The procedure has been to licence a smaller number of vessels than the estimated optimum number, allow them to work and collect data for three years, then on the basis of that data re-estimate the optimum number of vessels and issue more licences. This procedure is then repeated, the number of licences approaching the estimated optimum number.

The method has proved successful with the relatively stable stocks of king and tiger prawns. Its success with the less stable banana prawn stocks in the north of W.A. remains to be seen.

The paper stresses the need for biological research in order to understand properly the causes of fluctuations and trends in the yield of a fishery.

INTRODUCTION

Crustacean fisheries in Western Australia have been developed over the years by regulated fishing within a framework of licence limitation. Within this limited entry system there has been a phased expansion aimed towards the rational exploitation of the individual fisheries. In this paper, the history of the Western Australian prawn fisheries will be described, the rationale behind the system of management will be explained, and the advantages and disadvantages of the method discussed, together with a review of the basis for utilising or rejecting traditional regulatory techniques. The consequences of licence limitation from the social and economic viewpoint will be discussed in a separate contribution by B. K. Bowen.

THE FISHERIES

The major prawn stocks in Western Australia have so far been located only in relatively enclosed bays and inlets. Exploratory surveys in offshore waters of between 18 m and 36 m in the Dampier Archipelago to Port Hedland area have been undertaken by J. P. Robins (pers. comm.), but although echo-soundings indicated areas of trawlable bottom, and sediment samples were typical of king prawn habitat, subsequent try-netting showed that virtually all the area investigated is at present untrawlable due to the heavy growth of corals and sponges. No investigations have yet been made of offshore deeper waters such as those in which prawns have been located off New South Wales.

Minor fisheries for school prawns (*Metapenaeus dalli*) and western king prawns (*Penaeus latisulcatus*) are pursued in the shallow waters of the Swan River, Peel Inlet and other south western estuaries, while J. W. Penn (pers. comm.) has estimated a stock of western king prawns amounting to around 100,000 lb (45 000 kg) in Cockburn Sound (Fig. 1). This once supported limited fishing but in recent years the area has been closed to trawling, partly to allow its use as an ex-

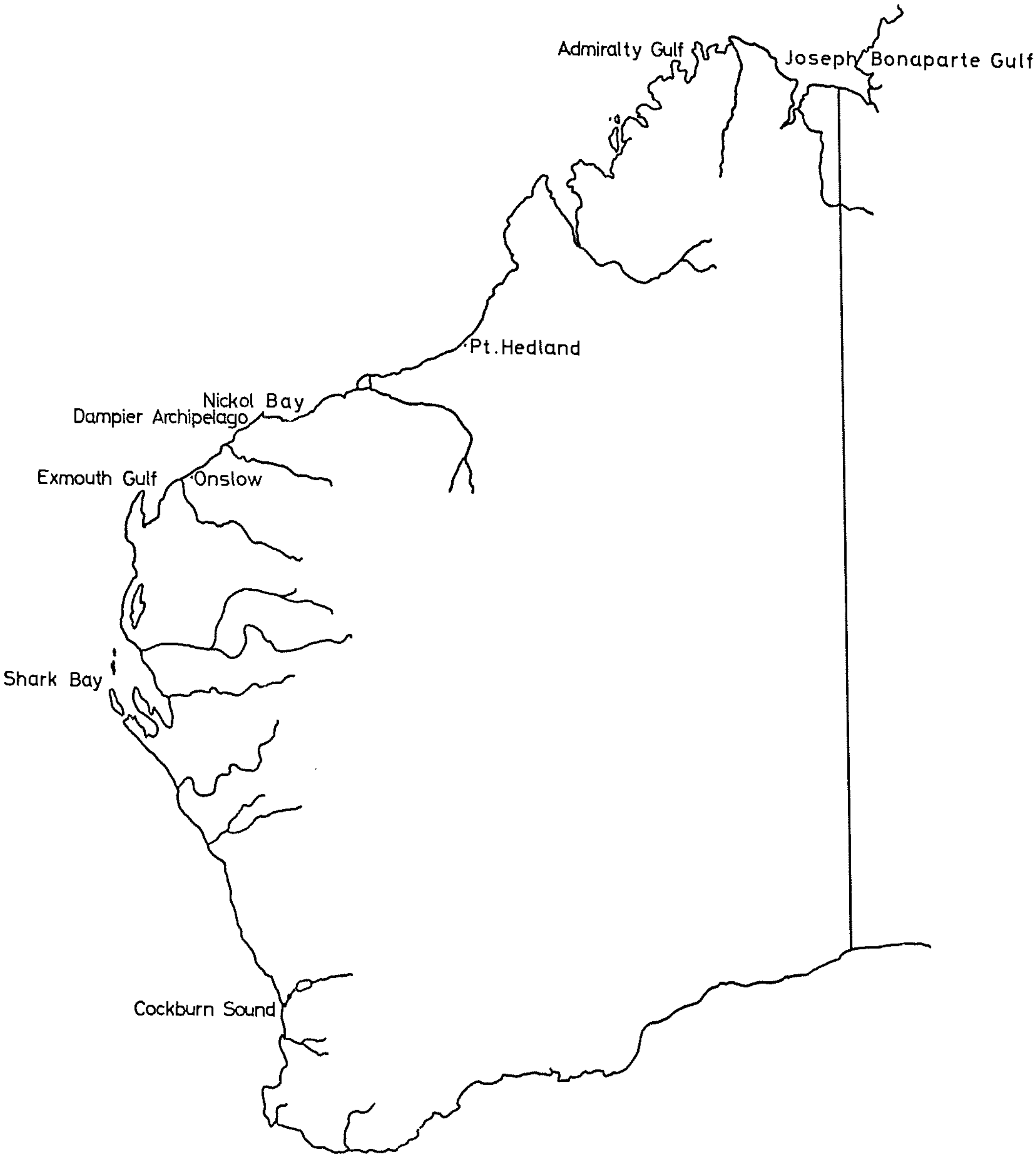


Figure 1. Sketch map of Western Australia showing areas mentioned in the text.

perimental area for prawn research (Penn, 1973) and partly to give protection to an important nursery area for various fish species.

The major fisheries are concentrated in Shark Bay, Exmouth Gulf and Nickol Bay, with a new fishery developing in the York Sound/ Admiralty Gulf area of the north-west (Fig. 1). Farther north indications of banana prawn stocks have been found in Joseph Bonaparte Gulf (Robins, pers. comm.) but a detailed investigation of the potential of that area has not yet been attempted. The few boats working out of Onslow are exploiting prawn stocks thought to be an extension of those in Exmouth Gulf. The distribution of the total 1972 catch of 7 million lb (3.18 million kg) is given in Table 1.

The Shark Bay fishery

Details of the catches of prawns from Shark Bay since the commencement of the fishery in

Table 1. 1972 Landings from Western Australian prawn fisheries (lb).

	King prawns	*Tiger prawns*	*Banana prawns*	*Endeavour prawns*	*Total*	*Maximum No. of boats**
Shark Bay	3 060 509	818 798	—	—	3 879 307	31
Exmouth Gulf	803 196	1 482 668	—	463 800	2 749 664	23
Onslow	3 979	46 247	5 334	—	55 560	9
Nickol Bay	—	—	108 357	—	108 357	5
Admiralty Gulf	—	2 024	199 412	15 042	216 478	7
Total	**3 867 684**	**2 349 737**	**313 103**	**478 842**	**7 009 366**	

* Maximum number of boats fishing during any month, but may be present for only a short period of the year (see Tables 3, 5, 7, 8).

Table 2. Prawn landings—Shark Bay 1962–72
(*Weight in lb, heads on; Effort in hours trawled*).
Data given in Table 2 *et seq.* may be subject to minor modifications following more detailed analysis.

Year	*King*	*Tiger*	*Total*	*Effort*	*Maximum No. of boats**
1962	216 940	94 393	311 333	2 255	3
1963	792 312	535 166	1 327 478	9 898	22
1964	1 114 588	896 472	2 011 060	13 960	26
1965	941 365	843 624	1 784 989	17 223	27
1966	547 367	851 318	1 398 685	18 254	28
1967	502 174	1 484 402	1 986 576	31 644	30
1968	912 494	1 100 825	2 013 319	36 379	29
1969	1 759 951	1 014 733	2 774 684	37 210	27
1970	2 257 088	1 596 158	3 853 246	45 675	32
1971	2 047 751	1 328 841	3 376 592	46 153	32
1972	3 060 509	818 798	3 879 307	51 456	31

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

Table 3. 1972 Shark Bay catch and effort

Month	*King*		*Tiger*		*Total*		*Effort*	*Maximum Number of Boats**
	Catch (lb)	*Catch/Effort (lb/hr)*	*Catch (lb)*	*Catch/Effort (lb/hr)*	*Catch (lb)*	*Catch/Effort (lb/hr)*	*(Hours)*	
Jan	3 672	11.3	5 182	15.9	8 854	27.2	325	8
Feb	140 796	38.1	51 201	13.8	191 997	51.9	3 699	28
Mar	385 132	51.4	157 683	21.1	542 815	72.5	7 490	31
Apr	615 361	79.7	245 457	31.8	860 818	111.5	7 718	31
May	674 398	89.9	161 833	21.6	836 231	111.5	7 500	31
Jun	514 702	67.4	124 952	16.4	639 654	83.8	7 631	31
Jul	320 256	49.8	53 931	8.4	374 187	58.2	6 433	31
Aug	205 167	37.3	14 578	2.6	219 745	39.9	5 502	25
Sep	81 835	30.2	3 517	1.3	85 352	31.5	2 709	19
Oct	102 074	51.7	399	0.2	102 473	51.9	1 974	15
Nov	17 116	36.0	65	0.1	17 181	36.2	475	7
Dec	—	—	—	—	—	—	—	—
Total	**3 060 509**	**59.5**	**818 798**	**15.9**	**3 879 307**	**75.4**	**51 456**	

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

Table 4. Prawn landings—Exmouth Gulf 1963–72
(Weight in lb, heads on; Effort in hours trawled)

Year	*King*	*Tiger*	*Banana*	*Endeavour*	*Total*	*Effort*	*Maximum No. of boats**
1963†	2 282	33 312	114 575	s	150 169	1 799‡	12
1964†	36 528	73 799	132 604	s	242 931	2 063‡	6
1965†	35 438	298 110	125 331	s	458 879	8 380‡	13
1966	158 678	926 950	86 266	s	1 171 894	11 097‡	23
1967	90 966	1 552 810	48 642	s	1 692 418	16 651‡	21
1968	368 221	468 230	s	s	836 451	17 667	23
1969	169 113	1 042 494	s	231 283	1 442 890	26 245	19
1970	458 686	1 957 047	s	651 161	3 066 894	38 764	25
1971	297 773	515 152	s	330 753	1 143 678	29 706	21
1972	803 196	1 482 668	s	463 800	2 749 664	45 039	23

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

† Adjusted catches.
‡ Estimates
s Small quantities only

Table 5. 1972 Exmouth Gulf catch and effort

Month	*King*		*Tiger*		*Endeavour*		*Total*		*Effort*	*Max. No. of Boats**
	Catch (lb)	*Catch/ Effort (lb/hr)*	*Catch (lb)*	*Catch/ Effort (lb/hr)*	*Catch (lb)*	*Catch/ Effort (lb/hr)*	*Catch (lb)*	*Catch/ Effort (lb/hr)*	*(Hours)*	
Jan	—	—	—	—	—	—	—	—	—	—
Feb	16 567	20.0	6 464	7.8	3 517	4.2	26 548	32.0	829	6
Mar	24 835	8.8	77 277	27.5	33 362	11.9	135 474	48.1	2 814	16
Apr	15 349	3.0	322 642	63.6	39 655	7.8	377 646	74.5	5 070	19
May	30 883	5.4	275 724	48.1	51 238	8.9	357 845	62.4	5 732	20
Jun	46 900	8.4	192 898	34.7	40 231	7.2	280 029	50.4	5 557	22
Jul	130 362	22.3	173 722	29.7	59 625	10.2	363 709	62.2	5 851	23
Aug	191 108	34.3	114 701	20.6	71 756	12.9	377 565	67.7	5 575	23
Sep	127 512	24.1	120 120	22.7	69 534	13.2	317 166	60.0	5 282	22
Oct	156 149	31.2	110 795	22.1	57 830	11.6	324 774	64.9	5 006	22
Nov	49 426	17.0	83 494	28.7	35 131	12.1	168 051	57.8	2 905	20
Dec	14 105	33.7	4 831	11.6	1 921	4.6	20 857	49.9	418	6
Total	**803 196**	**17.8**	**1 482 668**	**32.9**	**463 800**	**10.3**	**2 749 664**	**61.0**	**45 039**	

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

1962 are given in Table 2. Slack-Smith (1966, 1969 and in press) has described the history of this fishery which, following the identification of commercial catch rates by exploratory surveys undertaken during the 1950s, has developed to the annual catch levels of up to 3.8 million lb (1.7 million kg) taken today.

The proportion of each species taken from year to year is variable but the most important species in Shark Bay is the western king prawn with usually smaller quantities of tiger prawns (*Penaeus esculentus*) (Table 2).

Fishing is pursued virtually throughout the year (Table 3), with highest catches from April to June, usually exceeding 1000 lb (450 kg) per boat-night, but is limited by strong southerly and cyclonic winds during the summer months (November to January).

Exmouth Gulf

The most important species taken in Exmouth Gulf in recent years has been the tiger prawn which is taken together with smaller quantities of western king prawns (Table 4). From 1963 to 1967 moderate catches of banana prawns (*P. merguiensis*) were taken. In recent years these ceased to be available, but, from 1969 on, endeavour prawns (*Metapenaeus endeavouri*) have featured in the landed catch.

Table 6. Prawn landings—Nickol Bay 1967–72
(Weight in lb, heads on; Effort in hours trawled)

Year	*Banana*	*Effort*	*Maximum No. of boats**
1967	1 049 908	13 560	22
1968	90 456	no record	no record
1969	110 889	710	7
1970	266 639	2 446	10
1971	409 228	1 268	10
1972	108 357	401	5

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

Table 7. 1972 Nickol Bay catch and effort

Month	*Banana Catch (lb)*	*Catch/Eff.*	*Effort (hours)*	*Maximum No. of boats**
March	26 640	1 585.7	16.8	2
April	37 368	428.5	87.2	5
May	37 823	220.3	171.7	5
June	5 914	94.2	62.8	5
July	—	—	—	—
Aug	612	9.8	62.2	1
Total	**108 357**	**270.4**	**400.7**	

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

Table 8. 1972 Onslow Area catch (weight in lbs, heads on)

Month	*King*	*Tiger*	*Banana*	*Total*	*Maximum No. of boats**
June	—	23 956	3 466	27 422	6
July	3 551	17 426	1 489	22 466	9
Aug	428	1 691	—	2 119	5
Sept	—	3 174	379	3 553	3
Total	**3 979**	**46 247**	**5 334**	**55 560**	

* Maximum number of boats fishing during any month, but may be present for only a short period of the year.

The latter species is incidental to the taking of tiger and king prawns. As in Shark Bay, fishing occupies most of the year but at a greatly reduced level during the summer months (Table 5). During the seven years from 1966 the total catch has only once been less than 1 million lb (450 000 kg) and twice has exceeded 2 million lb (900 000 kg) (Table 4). Catch rates are generally lower than in Shark Bay.

Nickol Bay

Data available from 1967 (Table 6) show that the Nickol Bay fishery for banana prawns has had mixed fortunes, with catches in recent years of usually considerably less than 0.5 million lb (227 000 kg). Fishing has been discontinuous there, due to unreliable stocks and weather, and though up to 13 boats have been permitted to fish, there have so far never been this many boats at any one time. Catches may be large, up to 10,000 lb (4 500 kg) per boat-day, but infrequent.

The season is relatively short with maximum catches in April and May (Table 7). The 1973 season has been better than in previous years and up to 15 boats have been fishing the area.

Onslow

The area off Onslow provides moderate catches of tiger prawns with much smaller quantities of banana and king prawns (Table 8). The interest in the area varies with the availability of prawns, and in 1972 up to nine boats took a total of 55,000 lb (25 000 kg) of prawns during a short season (Table 8). There are no licence restrictions, and boats from concession fisheries may fish the area at certain times of the year.

This area was fished during the 1960s for banana prawns by boats from Shark Bay and Exmouth Gulf, and some of these catches appear with Exmouth Gulf catches (Table 4). Insignificant catches of banana prawns have however been made off Onslow since the late 1960s. Fremantle Co-operative Society boats made a survey of the area in 1970 as a result of which a processing factory was installed at Onslow in 1972.

Admiralty Gulf/York Sound

Exploratory trawling in this area from 1968-71 for banana prawns has given promising catch rates (Robins, pers. comm.) and the results of a season of fishing by two commercial vessels during 1972 have prompted a major W.A. company to proceed to the next phase of development agreed with the State Government. This provides for a mother vessel as well as catcher vessels. Details of these arrangements will be given in the following section.

History of licences

Historically, the development of each prawn fishery in Western Australia has been a pioneer operation involving capital investment in, as yet, remote areas. In order to encourage investment by major fishing companies the W.A. Government offered guarantees against excessive competition by creating limited entry prawn fisheries and issuing an agreed number, or proportion, of boat licences to the pioneering company or companies.

In Shark Bay, the number of vessels permitted to trawl in 1963 was limited to 25, 10 licenses being issued to Nor'West Whaling Company, 5 to a second company (the two companies were later amalgamated by William Angliss Pty Ltd) and 10 to independent fishermen. Encouraged by the high catch rates of these boats the maximum number of vessels was increased to 30 in 1964. In 1971, Nor'West Whaling Co. were allowed 2 additional 'stand-by' licences to allow for breakdowns or other contingencies with licensed vessels, and this position was rationalised by issuing 32 full licences for the 1972-1974 triennium. Eighteen of these are held by the Company and 14 by independent vessels. A condition of licence is that the vessel must fish in Shark Bay from 1 May to 31 July. Recent discussions conducted by Western Fisheries Research Committee were aimed at determining the number of licences for issue in Shark Bay and Exmouth Gulf for the 1975-77 triennium.

In Exmouth Gulf, 15 licences were issued in 1965. The total was later increased to 17, then to 20 plus 3 stand-by vessels for 1970 and 1971, when the area was extended northward, and to 22 for the 1972-74 triennium. Of these latter, the majority of eleven was issued to M. G. Kailis Gulf Fisheries in recognition of that Company's pioneer investment, 4 to a second Company, which also established a processing plant on Exmouth Gulf, and 7 to independent vessels. Exmouth Gulf licencees are obliged to remain within the concession area from 1 May to 31 July.

Security was given to those boats wishing to fish for prawns in the Nickol Bay area in 1971 by issuing 13 licences, 8 to Geraldton Fisherman's Co-operative and 5 to Markwell Ross Fisheries Pty Ltd, both of whom built prawn processing plants in the area. There were 13 authorisations for the years 1972-74. In recognition of the unreliability of the banana prawn stock, boats are not obliged to remain in the area for a specified period as in Shark Bay and Exmouth Gulf.

The pattern established in Shark Bay, Exmouth Gulf and Nickol Bay has recently been followed as the basis for an agreement between a W.A. Company, Seafarer International Pty Ltd, and the W.A. Government, covering the development of a fishery in Admiralty Gulf. This remote and undeveloped area, some 2 100 km north of Perth, was previously only visited by prawn trawlers travelling between west coast and northern waters, until exploratory fishing by the W.A. Department of Fisheries and Wildlife drew attention to the potential catch rates of banana prawns. Under the terms of the Agreement the Company has completed a preliminary evaluation programme using two prawn trawlers and has proceeded to a capacity evaluation programme using a fleet of 8 to 12 vessels with a mothership. If the outcome is successful the Company will establish, by December 1975, a shore-based facility including a fishing boat harbour and prawn receival; engineering, fuel, and cold storage facilities; and subsequently a shore-based processing establishment. In return the Government will control the prawn fishery as a limited entry fishery from or before December 1975, granting to the Company 60 or 70% of the licences, depending on whether a second Company undertakes a concurrent capacity evaluation programme. In this event the second Company would acquire 20% of licences and independent vessels 20%. The number of licences to be issued will need to be decided from the results of the evaluation programmes.

TOWARDS THE MAXIMUM SUSTAINABLE YIELD

(a) Theory

It would be difficult to proceed far without reference to the many contributions on the subject of rational fishing by J. A. Gulland of F.A.O. Gulland (1968) presented two basic graphs (his Fig. 1), showing how catch per unit of effort declines while total catch increases, with increasing effort in a fishery. Since information at higher levels of effort has seldom been available, the precise direction of the graphs is uncertain, and the various interpretations include a total catch which is:

(i) maintained
(ii) falls slightly, or
(iii) falls sharply (Schaefer model).

With penaeid prawns, which are highly fecund and have a life span of little more than one year, the problems of decreasing catch due to reduced size and lowered recruitment are likely to be much less manifest than with longer lived species. Whichever the case, at levels of effort beyond that required to achieve the maximum sustainable yield, increases in effort will be accompanied by, at best, no increase in catch.

Similarly on an economic basis total revenue will rise with the development of the fishery to a maximum and may then begin to decline towards or beyond the point where the total revenue is no more than the total costs incurred by the fleet (Fig. 2 of Gulland, 1968). Maximum profit would be obtained at the point of maximum economic yield which occurs at a lower level of effort than the maximum sustainable yield.

In terms of practical management the desired result will probably be a compromise between the attainment of the greatest benefit to the community in terms of maximising the yield from the fishery, and maintaining an adequate return on capital by the individual boats, i.e. somewhere between the maximum economic yield and the maximum sustainable yield.

(b) Practical approach to prawn fisheries

Gulland (1972) has enumerated a series of possible procedural steps for development of a limited entry prawn fishery which are so basic to the decision-making already undertaken in W.A. fisheries, and to the future development of the Admiralty Gulf area, that they justify being quoted fully here. They are:

(i) Examine the extent of the area involved, and estimate, on the basis of comparison with other areas, the likely number of trawlers required for operations at the optimum level (say for example 50).
(ii) Issue licences for the operation of rather less than this optimum number (say 30). A condition of obtaining a licence would be provision of full statistical data on the operations, including catches of each size of shrimp, fishing effort, and location of fishing.
(iii) Allow the operation of these vessels for two or three years without modification. Then examine the statistical and other data, assess the stocks, and then obtain a revised estimate of the optimum number of vessels (e.g. 55) —this may be above or below the original estimate.
(iv) Issue further licences, to bring the total number of vessels licensed closer to, but still below, the revised estimate of the optimum (e.g. 45).
(v) Make economic studies to estimate the likely profitability of each boat when the fleet approaches its optimum size.
(vi) Decide, particularly if this profit is large, what use should be made of it, and introduce appropriate additional conditions on licence holders, e.g. substantial licence fees, commitment also to land defined quantities of fish, etc.
(vii) Repeat steps (iii) to (vi) at intervals.

The philosophy underlying Gulland's approach is that the initiation of management measures during the early stages of a fishery is likely to achieve the greatest benefit and the least disturbance. This may mean taking action on imprecise information and shortage of data, but is infinitely preferable to the alternative of doing nothing until a crisis occurs. This pattern of management, using a step-by-step approach 'pre-supposes close contact between the industry, the scientists and the administration'. The practical and social consequences of introducing limited entry restrictions into an over-populated fishery are best avoided.

(c) Application of theory to Shark Bay data

The number of licences issued in Shark Bay has been gradually increased from 25 in 1963, to 30 in 1964, to 32 for the 1972-1974 triennium. During this period the average size and efficiency of the boats has increased, but so far adequate profit margins have been well maintained. Recently it has been necessary to review the data in order to make proposals for the number of licences to be issued for the 1975-1977 triennium.

As a first step the raw data were used to prepare the traditional catch/effort and catch per unit of effort/effort relationships (Fig. 2).

These graphs demonstrate in a general way the expected increase of catch, and decrease in catch per unit of effort, with increasing effort, remembering that all the catch per unit of effort figures are based on total effort for the two species. It would be difficult to base any reliable forecast of maximum sustainable yield on the shape of these graphs. The steep decline in both the catch per unit of effort and the catch of king prawns from 1964 to 1966, which continued to 1967, but which was followed by a rapid recovery to present catch levels, was concluded to have resulted from natural causes, possibly with cumulatively poor recruitment from 1964 on, followed by a recovery from 1968 (Hancock, 1972). The trend was probably exaggerated by the behaviour of the boats, which in poor king prawn years are likely to concentrate on known areas of tiger prawns—this would help to account for the peak in tiger catch per unit of effort in 1967. Hayasi (1971) used part of the same data from Slack-Smith (1969) to suggest a maximum sustainable yield of 500 ton (= 1.12 million lb) for king prawn in the belief that the falling catch in 1965 and 1966 was obtained at a level of effort in excess of the optimum. This underlines not only the danger of basing such an interpretation on data over an inadequate time series, but also the need for allocating the effort to the appropriate species.

(d) Separation of effort in a mixed species fishery

The graphs in Fig. 2 raise the perennial problem of multiple species fisheries, since the assumption that effort is not preferentially directed is seldom satisfied. If it is not, and this is certainly the case in Shark Bay, units in a time sequence for individual species based on total effort could give quite misleading annual comparisons on which to base judgments on the state of the stock. In allocating effort to each species information is therefore required on the 'intention to fish' for a particular species, which may be influenced to some extent by the relative economic values of the species concerned.

The latter is not a problem in Shark Bay where king and tiger prawns have similar demand and values. It was, however, in the analysis of the Chilean mixed fishery for shrimps and langostino (Hancock and Henriquez, 1969) in which an attempt was made to allocate effort on the basis of catches which were composed entirely or principally of one species. This type of analysis was resorted to in the absence of any information on the intention to fish one or other of the two species which have overlapping depth distributions.

A real problem in Shark Bay is the fact that with a major (king) and a minor (tiger) species the catch/effort relationship for the most abundant species will dominate the relationship for the two species combined (Fig. 2), and this will bias biological conclusions for the separate species. The use of total effort with the combined catch of two or more species is however a valid basis for total yield considerations.

An attempt is being made to record for future analyses whether trawling is being directed to one or both species. Meanwhile, there is some information from research surveys, and from interviews with fishermen, about the fishing grounds inhabited by predominantly single or mixed species. This has enabled a preliminary analysis to be made of past effort records (Penn and Hall, pers. comm.) on which to base a more realistic apportionment of effort to the two species. As a first attempt, on the basis of information available, they subjectively assessed each statistical block fished as 0, 25, 50, 75 or 100% king prawn habitat, the complement being regarded as tiger prawn habitat. This assessment was used to apportion the total effort expended in each statistical block between the two species. The revised result (Fig. 3) certainly appears to give a much more realistic and useful presentation of the data.

(e) Source of the data

Of fundamental importance to the success of a management policy such as that outlined in the previous paragraphs is the collection of reliable statistics. The procedures for obtaining these have been outlined in a previous article by the author (Hancock, 1973). In addition to compulsory monthly returns of catch and effort by professional fishermen and processing factories, which are processed by the Australian

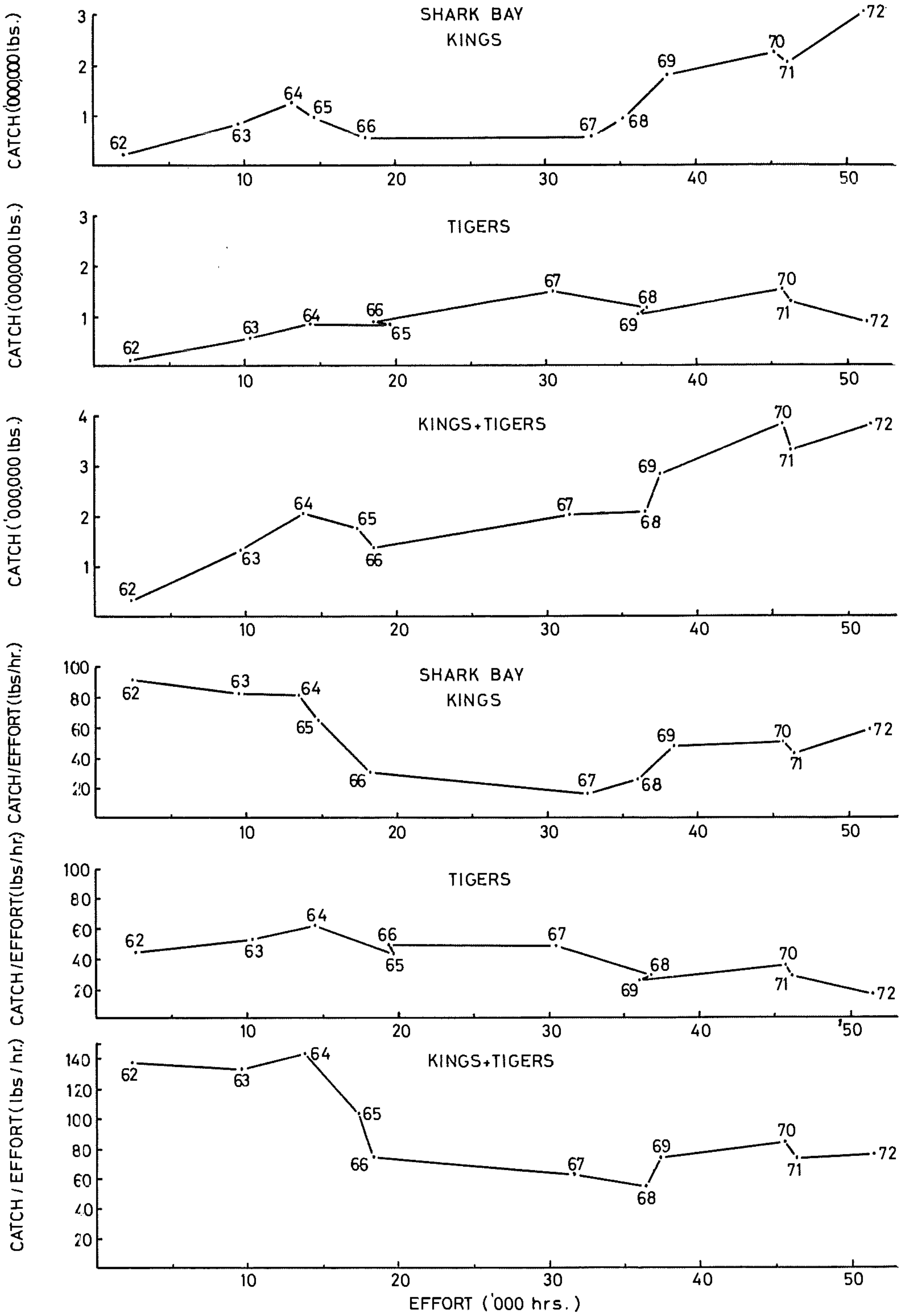


Figure 2. Catch and catch per unit effort of king and tiger prawns, separately and in total, related to total effort for the two species, Shark Bay 1962–72 inclusive.

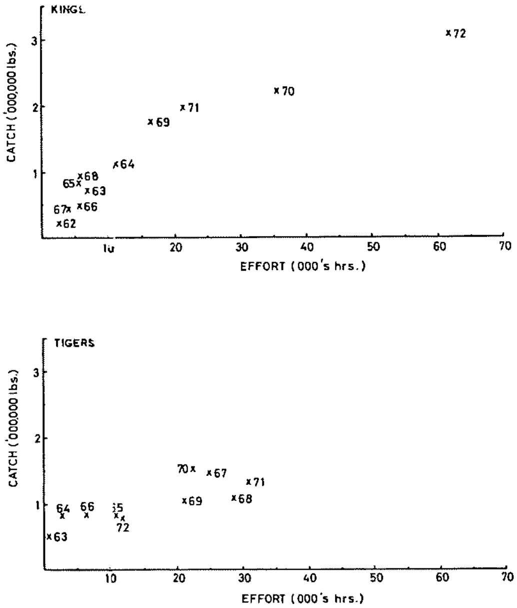


Figure 3. Catch data from Figure 2 related to effort allocated to individual species.

Bureau of Statistics, is the voluntary completion of log books. The latter are completed by virtually all W.A. prawn fishermen and it is considered to be one of the requirements of a licence. The basic ingredients of success with such a scheme have been found to be:

(i) sustained personal contact with fishermen;

(ii) computer validation for spurious log book entries;

(iii) validation between fishermen's and processors' returns and log books;

(iv) rapid availability of data for management; and

(v) prompt feedback of information to participants.

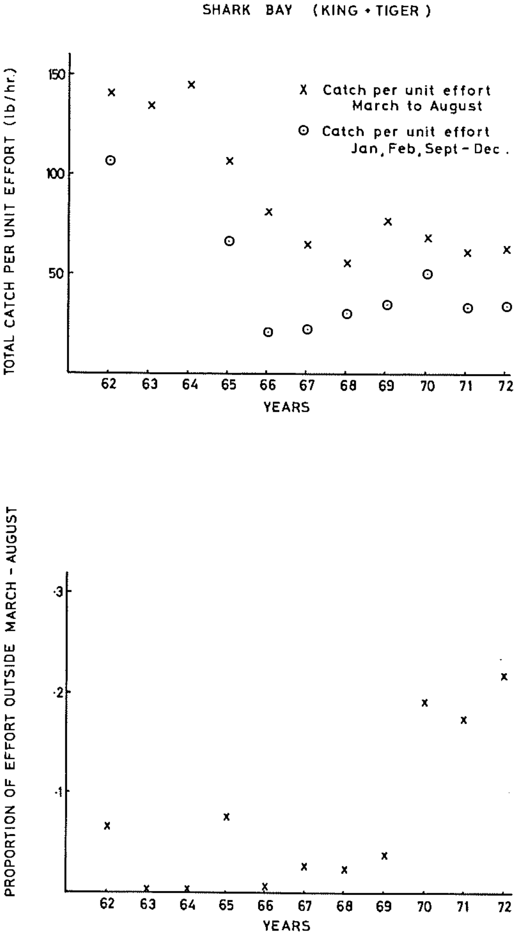


Figure 4. (Above) Comparison of catch rates for the periods March to August inclusive, and September to February inclusive, (Below) Proportion of the total annual effort expended outside March to August inclusive, Shark Bay 1962–72.

(f) Future refinements of the data

Hancock and Henriquez (1969, p. 11) pointed out that in considerations of catch per unit of effort, the influence of improved vessels and gear, of improved techniques and experience of crews, and of improvement in the collection of statistics, must be considered. In Shark Bay to these must be added the gradual extension of fishing to the remaining new grounds within the limits of the fishing area. This latter cause would have lead to relatively higher values of catch and catch per unit of effort generated by each unit of fishing effort. The gradual increase in efficiency, power and size of vessels and the conversion from single to double-rigged trawlers will also have had their effect on the shape of the curve. Slack-Smith (1969) attempted to make allowance for the relative fishing powers of vessels, and this has been included to some extent in the data presented here, though further refinement is still required. The changeover from single to double-rig has been estimated as increasing the catch rate by a factor of 1.5 (kings) or 1.1 (tigers) (Penn and Hall, pers. comm.). In addition, the length of the season has steadily increased to include periods of lower catch rates (Fig. 4) and this would have gradually depressed the relative average catch rate over the years. When interpreting the significance of

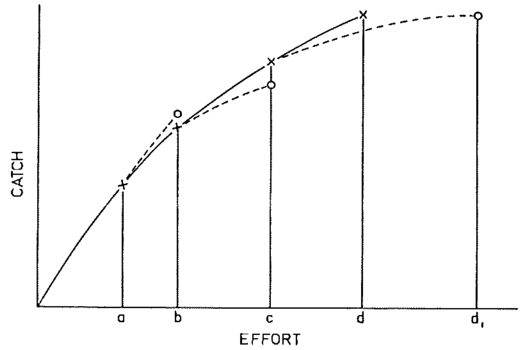


Figure 5. Schematic presentation of adjustments to raw data required to take account of (i) reduced average catch per unit of effort between *a* and *b* due to prolonging the season, (ii) additional fishing ground between effort levels *b* and *c*, and (iii) increased efficiency between effort levels *c* and $d = d_1$. *x* —— *x*, raw data; *o*, adjusted value.

the slope of the catch curve in terms of numbers caught, the effect of increasing effort on the mean size of prawns in the catch will also need to be considered, i.e. with greater effort early in the season more prawns will be fished at a smaller size so that if the catch is expressed in weight (as in Fig. 3), the same weight yield would represent a relatively larger *number* of prawns caught.

Fig. 5 shows the direction in which adjustments will need to be made to take into account some of these causes of bias, and Segura (1973) has applied a more sophisticated approach along these lines to the Schaefer model when assessing optimal fishing effort in the Peruvian anchoveta fishery. Clearly, in the step-by-step advance towards optimum yield followed for the Shark Bay prawn fishery such refinements assume most importance in the proximity of the asymptote of the yield curve. Fig. 5 can be of use in making subjective judgments as well as pointing the direction of quantitative adjustments.

(g) Assessment of the Shark Bay fishery for future licences

Bearing in mind the limitations of the data considered in the foregoing paragraphs, the situation in the Shark Bay fishery was discussed in 1973 in scientific 'workshops' of the Western Fisheries Research Committee. The conclusions reached included:

(i) The Shark Bay fishery is still in an expanding phase, i.e. there is no suggestion that the total catch of king and tiger prawns has reached the maximum sustainable yield. Catches have continued to increase in recent years during which the limits of fishable ground, the length of season and the efficiency of the fleet had become more stabilised.

(ii) Calculations by Penn and Hall (pers. comm.) indicated that maximum increases in total catch of 3%, 10% and 17% and maximum decreases in catch per unit of effort of 3%, 9% and 14% would be likely with the addition of 1, 3 and 5 extra boats respectively. These figures were based on years of average abundance, but a poor season must be anticipated from past records with a probability of *c.* 1 in 10.

(iii) On the basis of known levels of return per unit of capital for Shark Bay boats, it was concluded that the addition of boats considered in the previous paragraph would not cause an unacceptable decrease in individual profitability, but the relationship between the resulting increase in total revenue and the increased effort costs remains to be assessed.

(iv) There was no suggestion from the data available that fishing the breeding stock in Shark Bay has so far affected subsequent recruitment, or that it is likely to do so. Boerema (1972, manuscript) has found no clear examples from world shrimp and prawn fisheries of a danger that a fishery will develop to a level where the stocks become so depleted that the number of adults will not be sufficient to maintain sufficient offspring.

(v) In the final analysis the chance of gain in total catch needs to be weighed against the estimate of reduction in catch per boat. In an economic sense the predicted maximum decrease per boat of around 7% return on capital which would accompany the addition of 3 boats to the fishery was not considered unacceptable, bearing in mind that a satisfactory increase in total catch could point to even more substantial long term gains. However, since there are areas of imprecision in the data, only a relatively small increase is justifiable (i.e. the step-by-step approach towards optimum exploitation favoured by Gulland), but to be of any use in understanding more about the potential for production from Shark Bay, it was considered that the result from any increase of less than 3 boats, i.e. less than 10%, would be masked by year to year variations in natural abundance.

(vi) The recommendation was made that the number of licences to be issued for the 1975–1977 triennium should be 35, the additional 3 licences being issued as provisional licences with no obligation for renewal at the end of three years. This would allow a trial assessment of the practical and economic consequences of the increase before making a decision about the permanent status of the new licences, and recognises that a step-by-step approach need not always be forward, but should be flexible enough for a step backward should any unpredictable changes take place.

(h) The Exmouth Gulf fishery

A similar evaluation of the Exmouth Gulf fishery resulted in the recommendation for three additional provisional licences, but recognising that from past records (Table 4) the chance of poor years is greater than in Shark Bay.

FOR AND AGAINST LICENCE LIMITATION

Management by licence limitation is a system which, for various reasons, has not received universal approval in the past. The Report of the National Fisheries Seminar (Canberra, 1971) lists many of the objections to licence limitation, though it would probably be fair to say that many of its opponents agreed, if reluctantly, that it has been a workable and acceptable approach in the Western Australian situation. There now seems, however, to be an increasing acceptance of the view that tight control over a fishery in its early development with perhaps a slow movement towards optimum exploitation is far preferable than trying to remedy a situation which is getting out of control, or worse, is past help. Sokoloski (1973) stated 'virtually all discussions of management plans emphasise licences, or quotas, or some form of right which will accrue to a reduced number of harvesting units'. Keen (1973) believes that 'Whether one is concerned with maximum sustainable yield or with maximum economic return, limitation of entry obviously is a powerful tool and one that deserves greater use'. He concluded that although the regulatory system developed in Japan could not be considered a complete success 'few would argue that the fishery and the country were not served better by limitation of entry than they would have been had no controls been imposed on the number of craft'. So is the belief in Western Australia. The system does have its in-built faults. These were summarised by Bowen (1971) who said that licence limitation:

(a) Tends to depress exploratory fishing, and development of new areas.
(b) Tends to create monopolies.
(c) Tends to give a value to the fishing boat above its intrinsic value.
(d) If used in developing fisheries, like the Shark Bay prawn fishery, in Western Australia may tend not to utilise the total resource available, i.e. may be over restrictive for short lived species.
(e) Discriminates against those outside the system.
(f) Tends to support inefficient operators.

Bowen (1973) will be discussing these objections more fully as well as the impracticability of the view expressed at the National Fisheries Seminar that although licence limitation is of value to assist in the development of new areas the measure should be on a short term basis.

The possibility raised by Gulland (1972) that limitation of entry may discourage innovation by the operators has not been apparent in either of the restricted Western Australian fisheries for rock lobster and prawn. Rock lobster fishermen are constantly experimenting with new types and sizes of pots with additional points of entry, and alternative baits, while the prawn fishery has seen the increased size and efficiency of vessels which have changed from single to double rig, and more recently with experiments using three and four trawls. The problem is more on the part of management to standardise the unit of effort at a level of efficiency which is appropriate to the existing social and economic situation (Gulland, p. 8). Attempts to reduce the number of licences proportionally (as proposed by Gulland) have only been marginally successful in the rock lobster fishery and can rarely be achieved with adequate speed.

RELEVANCE AND USE OF REGULATIONS IN W.A. PRAWN FISHERIES

Most of these have been considered by Gulland (1972) and the following discussion will be confined to the situation in Western Australia.

Catch quotas

Apart from the fact that objections levelled at licence limitation are even more valid for catch quotas, it is agreed with Gulland (1972) that with short-lived species such as prawns, with fluctuations in abundance from year to year, it would be virtually impossible to determine in advance of the season what the quota should be. Quota levels set for the average year may not be reached in years of poor abundance, and any surplus in good years will be rapidly dissipated by natural mortality.

Closed seasons

Hancock (1972) considered a proposal by Shark Bay fishermen to limit the fishing season from 1 March to 31 August and concluded that the suggested close season would not contribute significantly either to the survival of spawning females and subsequent success of recruitment, or to improved catches following lowered fishing effort on young prawns entering the fishery from protected nursery grounds. However the question of a closed season in relation to nursery areas and minimum useful size needs considering separately (see below).

Closed areas

Slack-Smith (1966, 1969) has described the nursery areas of Shark Bay, with the result that certain areas were closed to trawling throughout the year (Fig. 6). A similar study by T. White (pers. comm.) led to closure of part of Exmouth Gulf (Fig. 7). The value of these closures as a protection to the nursery environment is questionable, since the main habitat of the very young prawns is in the weed beds of banks fringing the usual trawling depths. However, they fulfil the purpose of delaying fishing until the size of first capture is nearer the optimum level (Gulland, 1972). This is a level for which it is not easy to determine mortality and growth rates of prawns, and the most widely used criterion of size of first capture is a practical one (see below).

A recommendation of the National Fisheries Seminar was to 'fish (prawns) early in the life of the fishery, except nursery grounds' which 'should be protected not only from fishing, but also from all forms of disturbance'. A problem of the latter type has arisen in Shark Bay from the annexure of an arm of the sea, Useless Inlet, for salt evaporation. That it was a source of nursery prawns was confirmed by the appearance of quantities of western king prawns within the embayment, and this led to a rash of applications, so far disallowed, for leases of areas for prawn culture.

In the Nickol Bay fishery, trawling has been prohibited in one area (A, in Fig. 7) before 5 April each year as a protection to growing prawns. In recognition of the fact that prawns in that area sometimes reach marketable size (66 per kg whole) before 5 April (J. S. Hynd, pers. comm.) the regulation was changed in 1972 to read 'No vessel shall trawl in Area A until a date to be set by the Director based on the growth rate of the prawn population as shown by sampling. The date to be not earlier than 1 March nor later than 1 April 1972'.

Legal minimum size

Apart from the protection of small prawns within nursery areas, size limits for prawns have not been considered appropriate in W.A. As Gulland (1972) has pointed out, survival of small prawns brought onto the deck is not high even if returned to the sea at once, and usually there is some delay until after the gear has been reshot and during sorting.

However, either formal or informal arrangements have been used to take into account the minimum acceptable market size. Until recently, little fishing effort has been concentrated on the small prawns leaving the nursery grounds in Shark Bay because these were too small for export requirements. The expansion of local markets has led to greater demand of the smaller sizes of prawn, with consequent heavy fishing in the area close to (Blocks 29 and 30), and sometimes illegally within, the closed area (Fig. 6), often incurring wastage of prawns still too small for the local market. To overcome this, a recent proposal in Shark Bay is to include Blocks 29 and 30 (Fig. 6) in the closed area until monitoring has shown the prawns to have reached an acceptable market size. (*c.* 66 per kg whole). In Exmouth Gulf in 1972 licensed fishermen, by voluntary agreement, refrained from fishing the southern part of the area until prawns had reached an agreed size, and the formal arrangements in Nickol Bay have been referred to in the previous section.

Mesh regulations

The shape of shrimps and prawns does not lend itself to any precise selection by nets, and small prawns become entangled by their appendages. Hence regulation by mesh size has not been considered to be a very effective measure. However, the selection of mesh regulations for trawling in Shark Bay for saucer scallops (*Amusium balloti*) by boats not licensed to take prawns needed to consider a

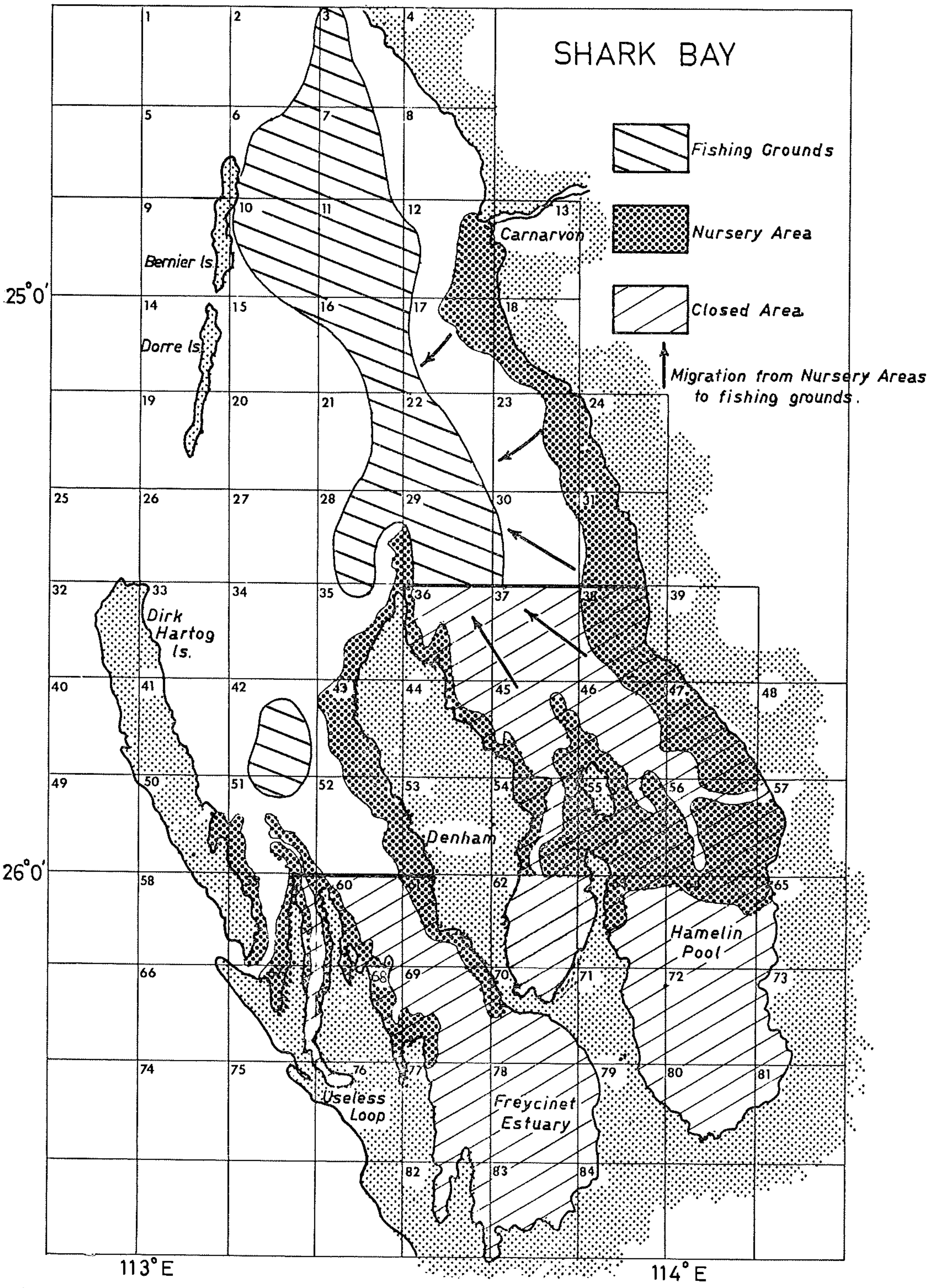


Figure 6. Plan of Shark Bay showing nursery areas, main fishing grounds and areas of closure. (adapted from Slack-Smith, 1966).

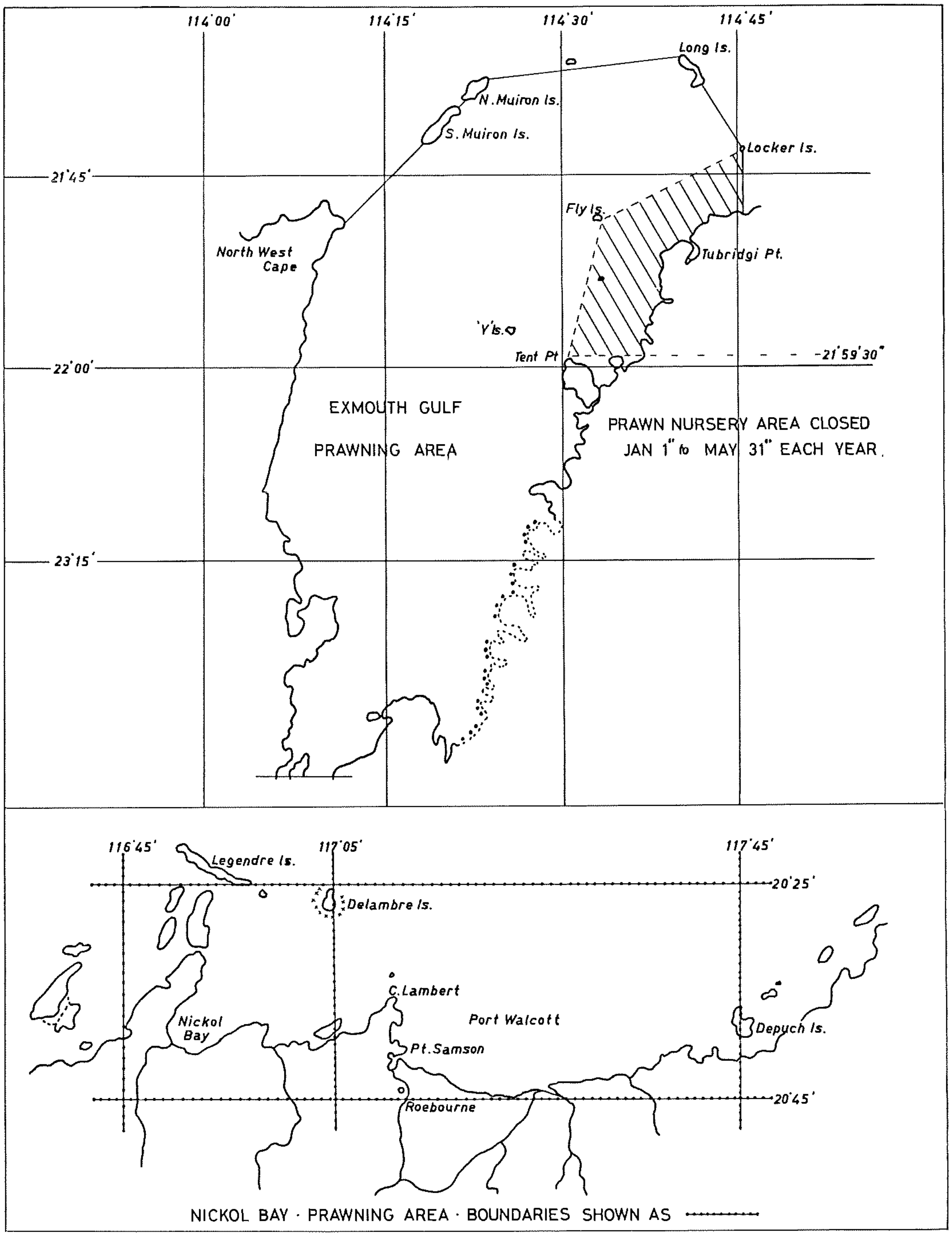


Figure 7. (Above) Plan of Exmouth Gulf showing closed area, (Below) Nickol Bay, showing the boundaries of the fishery.

mesh which would release prawns as well as undersized scallops, and the mesh chosen is 100 mm.

Protection of spawning females

Penaeid prawns do not carry eggs externally, so that regulation of 'berried' females is neither appropriate nor practical. The western king prawn is a species of high fecundity containing in excess of 400 000 eggs at the time of spawning (Penn, pers. comm.), and is therefore not in a category normally requiring protection. In Shark Bay it was concluded (Hancock, 1972) that little advantage would accrue from shortening the season to reduce the catch of mature females, and Boerema (MS.) concluded that there is little danger of a fishery for penaeid prawns developing to such a level that insufficient spawners remain.

Gear restrictions

There are no restrictions on normal trawling gear in W.A. It is however clear that continual trawling must alter the configuration of the bottom and the composition of its fauna and flora. In fact it is often not possible to trawl an area effectively until the superficial epifauna has been reduced. There is no precise information of any cumulative effects on the bottom deposits and the biomass on the future productivity of prawns. B. W. Logan (pers. comm.) concluded that the rate of formation of finer sediments in Shark Bay is very slow and if disturbed would take a considerable period to become re-established. In recognition of this fishing by dredge (for scallops) is a prohibited method in Shark Bay.

Control of oilspills

The National Oilspill Plan and its State supplements will include contingency measures for dealing with oilspills. The use of dispersants is being discouraged in W.A. prawn fishing areas in view of the recommendations of various authors including Shelton (1971): 'In shallow water, especially in semi-enclosed bays and estuaries, the use of dispersants could well cause significant damage to marine life. To safeguard fishery interests, dispersants should not be used in the vicinity of inshore fish-nursery grounds, near sub-littoral shellfisheries, or in estuaries with important fishery resources. . .' In Shark Bay, for example, since adult prawn stocks are situated on the bottom below depths of 11 m, surface oil is not likely to be harmful, even if mixed through the water column by turbulence. Fringing weed along the nursery areas should provide some measure of protection against stranded oil, which should be very much less harmful than an oil/dispersant emulsion to young prawns. The alternative of oil sinking procedures, which would cause tainting of prawns and fish and clogging of trawl nets, would be equally unacceptable.

DISCUSSION AND CONCLUSIONS

Management of Western Australian prawn fisheries has its basis primarily in regulations based on practical and economic considerations. Licence limitation has proved to be a practical system of management for the relatively stable stocks of king and tiger prawns, but how successful the extrapolation of this method will be to the much less predictable banana prawns remains to be seen.

Much of the data employed in assessing the permissible level of effort are still in need of standardisation before any precise forecasts of catch can be made, but the information is available and the techniques recognised for the appropriate refinements to be made. Judgments based entirely on catch and effort data can, at best, only produce a record of the situation with perhaps a basis for prediction based on chance, but without the necessary biological observations there is no possibility for interpreting the reasons underlying the events nor for ensuring that the management measures employed are the most appropriate. A biological programme is therefore being maintained to obtain more information on the level of stocks, and the dynamic parameters of the fishery, to enable the proper expansion of the prawn fisheries to their optimal exploitation.

LITERATURE CITED

BOEREMA, L. K. (MS.) 'Provisional note on shrimp assessment and management'. First draft, 6 June 1972, 13 pp.

BOWEN, B. K. (1971). 'Summary of syndicate conclusions and discussions'. Proceedings of the National Fisheries Seminar, Part 1, pp. 63-71.

——. (1973). 'The social and economic consequences of licence limitation'. (This seminar.)

GULLAND, J. A. (1968). 'The concept of the maximum sustainable yield and fishery management'. FAO Fish. tech. Pap. 70, Rome, 13pp.

——. (1972). 'Some introductory guidelines to management of shrimp fisheries.' IOFC/DEV/72/24, FAO, IIOFSDP, Rome, 12 pp.

HANCOCK, D. A. (1972). 'Shark Bay prawn fishery —consideration of a closed season proposal'. *Fish. Ind. News Serv. West. Aust.*, 5, (2), pp. 33-35.

——. (1973). 'Why Log Books?' *Fish. Ind. News Serv. West. Aust.* 6, (1), pp. 3-9.

—— and HENRIQUEZ, G. (1968). 'Stock assessment in the shrimp (*Heterocarpus reedi*) fishery of Chile'. *FAO. Fish. Rep.*, 57, (2), pp. 443-465.

HAYASI, S. (1971). 'Stock Assessment'. IOFC/ DEV/ 71/3, FAO, IIOFSDP, Rome, 34 pp.

KEEN, E. A. (1973). 'Limited entry: The case of the Japanese tuna fishery'. *NOAA Technical Report, NMFS, Circ.* 371, pp. 146-158.

PENN, J. W. (1973). 'Tagging experiments with the Western king prawn *Penaeus latisulcatus* Kishnouye.' (This seminar).

SEGURA, E. L. (1973). 'Optimal fishing effort in the Peruvian anchoveta fishery.' *NOAA Technical Report, NMFS, Circ.* 371, pp. 57-64.

SHELTON, R. G. J. (1971). 'Effects on fisheries and their evaluation', in *Coastal Water Pollution of the Sea by Oil Spills.* CCMS No. 1, NATO, pp. 10.1-10.8.

SLACK-SMITH, R. J. (1966). 'The Shark Bay prawning industry'. Western Australia, Government Printer, 13 pp.

——. (1969). 'The prawn fishery of Shark Bay, Western Australia.' *FAO. Fish. Rep.*, 57, (3), pp. 717-734.

——. (in press). 'History of the Shark Bay prawn fishery.' *Fish. Bull. West. Aust.*

SOKOLOSKI, A. A. (1973). 'The status of Fisheries Management Research: an overview.' *NOAA Technical Report, NMFS, Circ.*, 371, pp. 1-6.

DISCUSSION

Lucas. I'd just like first of all, to expand a little bit on the right hand side of the catch and effort curve. When you have a fishery where you have a whole series of age classes and you commence your fishing on the 1+ or 0+ age group, and as your effort increases, your catch initially increases and then you commence to catch more and more of the 0+, 1+ fish and the total weight that you then catch starts to decrease. Now, carrying this across to prawn populations, we would get this same sort of curve if we were thinking in terms of ageing our prawns by weeks, and we were catching the week 1 age-class, week 2 age-class, etc. Effectively, we would in fact get that dotted line at the right-hand side if all our prawns we were catching were about 13 mm long. I think that this is where that situation comes in, because we don't commence to catch our prawns until they're in the age-class, that corresponds to a 5+ age-class on a ten-year-old fish. We don't in fact get the dotted line on the right-hand side and the curve does tend to go up or level out. I suppose there could be some circumstances if you're fishing on relatively small juvenile prawns you might get it to go down to the right-hand side. That was the first point.

The second point is the interpretation of the catch and effort curves for Shark Bay. First of all there is the problem of variable recruitment, and this is a very real problem, but just looking at the third curve, (Fig. 2) where the kings and tigers are grouped together, if we're game enough to forget about the variable recruitment and we wish to draw a line through those points, or a straight line instead of the way in which they've been joined up, then looking at the point where the effort is 20, the straight line would possibly go through at a point of about 1½ million lb, go up to the point 50, which is 2½ times the effort, 2½ times 1½ million lb is approximately 3¾ million lb, which is possibly what the catch is. This tends to suggest to me that when we look at the original catch and effort figure on the blackboard that the Shark Bay fishery is well down the left-hand side of the curve and there's possibly room for expansion.

Hancock. We do believe there is room for expansion, but I also believe that there is a great danger in interpreting the total species curve because we recognised that there is this real problem in difference in recruitment which you can see with the king prawns. You seem to have a drop from 1964 onward and then levelling out and coming up again while the tiger prawn catches remained steady. So, when you combine the two together you get something that's a little bit difficult to interpret—but we do believe that the fishery is still expanding.

Thomson. I think that Chris Lucas is quite right that the reason why the shape of curve does not apply is this growth phenomenon. However, if one took it as numbers rather than weight, I think on probability that the shape of the curve ought to be followed provided something else doesn't happen as a result, e.g. as the catch per unit of effort declined the fishermen there changed their fishing strategy, possibly the lower density of the prawns may result in the prawns behaving differently, maybe they remain buried, maybe they go up in the water. Provided that everything remains even, I would think that the shape of the curve should be followed, but I suspect that in fact things will not remain absolutely even, other instances will come in. However, what I wanted to take up was the point about your licence limitation system. I just have an ingrained bias against limitations until they are necessary. I like to suggest if you could achieve the same end by allowing no limitation to begin with, keeping a careful eye on your catch statistics and then applying the limitations when it becomes obvious that these are necessary. I can't imagine that the fisheries are going to expand at such a remarkable rate that this would be impossible. I would think myself that the only argument for the original limitations is that this may be more psychologically acceptable to the fishermen but that I don't know.

Hynd. I agree, that as long as you've got stable recruitment you have some sort of rational basis for limiting licences but the problem arises of the 'bad' year. If you get one you're in deep trouble. Now the example of this is Nickol Bay last year when the catch dropped to one fifth of the normal amount. As a result, one chap's gone bankrupt, two others are in trouble. Now, if you're going to have some sort of licence limitation system in operation in areas like this, you really need some sort of buffering arrangement—financial buffering arrangement—not the buffering arrangement I mentioned earlier today. Has any consideration been given to this?

Hancock. In considering additional licences, we have taken into account the probability of poor years. The individual fishermen will need to budget for these, but I agree that problems can arise if the first year of a licence is a bad one.

Temperley. Could I suggest, as an engineer not a biologist, that a lot of trouble with these equations starts from trying to measure effort which to me means energy in terms of hours or man hours which builds into the deal an assumption which requires much interpretation that effort is proportional to hours and while I can't explain this in terms of this type of situation I think there is an answer to this situation where it is possible to translate man hours or trawler hours into equivalent energy hours that takes away from these equations the need for all these interpretations. I think this can be done. It has been done in engineering situations.

Hancock. A great deal of work has been done to adjust the fishing powers of different vessels so as to obtain comparable standard hours or units of effort.

Neal. I may have missed it in your presentation, but how would you define your management objectives on this fishery?

Hancock. Simply that we're trying to reach towards the optimal usage of a natural resource, in this case the prawn resource, so as to achieve as much from that resource as practical while retaining a level of profitability which is acceptable to the individual fishermen, remembering that with a common property resource we have a responsibility for ensuring maximum revenue to the community at large.

Gorman. I remember in Melbourne, Alec Fraser describing in great detail the reasons for and the methods behind licence limitation introduction into Shark Bay. They had described them in fair detail and then the manager from North West Whaling Co. promptly followed him and told us that, in order to utilise these licences properly, they were going to work them 24 hours a day. So immediately, instead of having 25 boats, or whatever it was, you have in fact 50 boats. This is a classic example in which licence limitation can be used wrongly, but within the letter of the law.

Hancock. Duplicate crews were employed in Shark Bay for a while but the system soon proved unacceptable and uneconomic. Currently we have the tendency for larger boats, and 3 and 4 trawl units (since prohibited) all of which exceed the standard unit of effort per licence contemplated originally.

Haysom. I was rather interested in the control of oil spills. I see that in Western Australia, you're working against the use of dispersants in areas of prawn fisheries. In Queensland, our policy at the moment is, of course, not to use detergents at all, anywhere around the State except where there is a risk of loss of life, fire and in certain specified areas where perhaps important bird rookeries might be in danger. I'd be rather interested to know whether you've had any sort of fight with the Australian Government on this, because we have. They tend to think that we're stockpiling dispersants, therefore we ought to use them.

Hancock. Like all the States, Western Australia is currently working out a mutually acceptable approach to the oilspill problem.

THE ECONOMIC AND SOCIOLOGICAL CONSEQUENCES OF LICENCE LIMITATION

BY B. K. BOWEN
Director, Department of Fisheries and Fauna, 108 Adelaide Terrace, Perth, W.A.

ABSTRACT

Throughout the world countries of all political persuasions are moving towards more controlled economies as a method of obtaining maximum economic advantage from the financial output, and within this context interest will increase in the control of fishing operations.

Some 12 countries are at present experimenting with the limitation of the number of fishing units, and within the area of the Indian Ocean Fishery Commission licence limitation is used either partially or totally in the management of the shrimp fisheries of Mozambique, Iran, Madagascar and Australia.

In Western Australia successive Governments have recognised that management of fishery consists of more than simply regulating a stock of fish on biological grounds. Management must integrate the biological requirements of the resource and the social and economic impact of man on it. The use of licence limitation regulation as a fisheries management tool provides a method of partially controlling the exploitation rate and capital input, but its implementation requires close contact between industry, the scientist and the administrator.

The manager may deem it appropriate for licence limitation regulations to be introduced if one or more of the following conditions prevail:

- (*a*) *The product from the fisheries resource is a luxury item such that the price paid has a potential to rise at a higher rate than the rate of inflation.*
- (*b*) *The return per unit of capital investment is higher than the return in other fisheries in the same area, or higher than that for other investment opportunities, even taking into consideration the risk factor involved.*
- (*c*) *The fleet is operating over a unit stock of fish.*
- (*d*) *The resource is highly vulnerable to the fishing gear being used.*
- (*e*) *It is desirable to maintain high economic returns to fishermen in order to encourage exploitation of a new area.*

If successfully operated the measure provides economic security and high profitability, but it also impinges upon the personal liberties and freedom of choice of fishermen.

The manager has to ensure that biological, economic and administrative understanding is at a level which ensures that the fisheries involved are fully developed, monopolies are not created, both government and industry benefit financially, and that if new licences or authorisation are granted the system of selection is one that is accepted by those interested in obtaining entry into the limited fishery.

INTRODUCTION

In giving this paper, I make no pretence to being either an economist or a sociologist, but offer it as the experience of an administrator who has the responsibility, *inter alia*, of managing the prawn fisheries of Shark Bay and Exmouth Gulf and, in co-operation with the Fisheries Division of the Department of Agriculture, Canberra, the rock lobster fishery of Western Australia.

In introducing this topic I want firstly to place the use of management by licence limitation in its correct perspective. It seems to me that throughout Australia fisheries managers have become polarised into those who totally reject management by this method, and those who see it as a powerful tool, which provides a new method of ensuring persisting and stable fisheries.

Crutchfield (1965) specifies two major ways of controlling fishing mortality through regulations: one is to protect select proportions of the stock of fish, the other is to limit the size of the take. In limiting the size of the take, he lists three methods: by catch limitation, by limitation of the number of fishing units, and by limiting the efficiency of the gear. Limitation of the number of fishing units then is simply one of an array of management tools available to the administrator in the regulation of a fisheries resource. Throughout the world there are some 12 countries experimenting with the use of licence limitation (i.e. limitation of the number of fishing units) at the present time, and there is certainly a developing interest in its use.

Within the Indian Ocean Fishery Commission area, licence limitation is used either partially or totally in the management of the shrimp fisheries of Mozambique, Iran, Madagascar and Australia. Throughout the world, countries of all political persuasions are moving towards more controlled economies as a method of obtaining the maximum economic advantage from the financial input, and within this context I believe there will be an increasing interest in the control of fishing operations.

In Western Australia, successive Governments have recognised that management of a fishery consists of more than simply regulating a stock of fish on biological grounds. Management must integrate the biological requirements of the resource and the social and economic requirements of man operating upon that resource. McHugh, in considering the management of the Atlantic coastal fisheries resources states: 'A fresh approach to coastal fisheries problems is needed; one including more biological and educational work and the investigation of the economic, social and political factors which are potent influences in the interaction of fisheries resources and man.'

In the years which lie ahead, there will be an increasing need for fisheries managers to consider the implications of utilising a licence limitation regulation, noting that like all other regulations it has advantages and disadvantages to be used on some occasions, but to be rejected on others as inappropriate to the situation.

USE OF LICENCE LIMITATION REGULATIONS

The manager may deem it appropriate for licence limitation regulations to be introduced if one or more of the following conditions prevail:

(a) The product produced from the fisheries resource is a luxury item such that the price paid has a potential to rise at a rate higher than the rate of inflation.

(b) The return per unit of capital investment is higher than the return in other fisheries in the same area, or higher than that for other investment opportunities, even taking into consideration the risk factor involved.

(c) The fleet is operating over a unit stock of fish.

(d) The resource is highly vulnerable to the fishing gear being used.

(e) It is desirable to maintain high economic returns to fishermen in order to encourage exploitation of a new area.

The first four criteria were certainly operating when a decision was made in 1963 to limit the entry of further fishing vessels and additional gear into the fishery on the western rock lobster. The resource was, in fact, being fully exploited. The return on capital was high, even with a decreasing catch per unit of effort. The number of rock lobster pots in the water increased by 66% from 1958–59 to 1961–62, but the production increase was only 8%. Even so, because of the luxury classification of the product, and the elastic nature of the price, the profitability of each fishing boat unit remained high. Data from economic surveys of the western rock lobster fishery show that this state of affairs was maintained through the years 1962–63 to 1968–69. Although the average catch per boat dropped from 14 000 kg to 10 000 kg during these years the price per kg of rock lobster increased from $0.81 to $2.18.

If licence limitation had not been introduced the number of fishing vessels and rock lobster pots would certainly have continued to increase rapidly.

In the Canadian lobster fishery licence limitation was introduced in the Maritime Province in 1968, but by this time the annual production of lobsters per vessel had fallen to approximately 1 300 kg. With a production of approximately double that of Western Australia's catch, the number of vessels operating is about 8 500 compared with 830 in the western rock lobster fishery.

A decision to limit licences in the western rock lobster fishery and reduce the number of pots being used was taken at a time when the resource was being fished intensively. However, decisions to use this same philosophy of licence limitation have also been taken when the fisheries involved were still in the developing stages and where, from experience, it had been shown that the resource was likely to be developed quickly and over capitalisation likely to occur. It is this state of affairs which Gulland (1972) described, and for which he enumerated a series of possible procedural steps for development of a prawn fishery. Hancock (1973) has listed these steps and applied the theory to the Shark Bay prawn data. Each of these two situations, i.e. licence limitation in a fully exploited system and licence limitation in a developing fishery has economic and sociological consequences for the fishermen. In discussing these the western rock lobster fishery and the Shark Bay prawn fishery have been used as examples.

WESTERN ROCK LOBSTER FISHERY

(a) Sociological

(i) Fishermen realise the advantages accruing to them if they hold a rock lobster licence and recognise the security of a good return on finance and manpower invested. Because of this security and high financial return they tend to increase their material possessions with finance being relatively easily obtained. It is recognised that finance may also be readily available to fishermen not operating in a limited licence system. However, there is no doubt that finance houses have contacted the Department on many occasions to check that a fisherman does hold a rock lobster licence before providing finance.

(ii) When material security seems assured, fishermen tend to want to increase their investment in the fishing industry by the acquisition of larger, safer, and better equipped, faster vessels. This has the disadvantage from the fishery administrators point of view, in that the efficiency of operation of the vessel is increased, thus increasing the exploitation rate. This can have serious repercussions if licence limitation was introduced because the resource had been biologically over extended.

(iii) Fishermen, when first acquiring financial stability rely to a large extent on the financing ability of processing companies and thus are pleased to provide throughput to that processing establishment in return for loans of finance and servicing facilities. However, when financial stability is assured, fishermen tend to search for the highest bidder for their product. This is to be expected and within the rock lobster fishery is a good thing.

(iv) Fishermen who retire from the industry seek to benefit from the preferred position in which they were placed when licence limitation was introduced. Initially it was considered that such benefit would not be allowed to accrue to a fisherman retiring from the industry. However, in practical terms it is not possible to prevent a fisherman from thus benefiting. To be persuaded to this view one has only to consider the situation of a Company-owned rock lobster vessel where the Company remains in perpetuity but where the share-holders change from time to time. The share value rises in accordance with the profitability of the fishing venture which has been made profitable by the action of the Goverment in introducing licence limitation regulations. In effect, the value of the shares which change hands reflects the value of the licence.

(v) Because the ownership of a vessel with a rock lobster licence has high earning power, the loss of that licence, by ministerial or court decision as a result of breaches of conditions applying to the licence, is a strong deterrent against breaking the rules and regulations of the fishery.

(b) Economic

When licence limitation was first introduced in 1963, the potential value of owning a licensed rock lobster vessel was not fully appreciated and a number of fishing units changed hands at a value approximately equal to that of the vessel and gear. However, in more recent years it has become recognised that there is a high value attaching to the ownership of a rock lobster vessel with a licence. This value has not been well documented because although each sale of a rock lobster vessel requires Departmental approval the sale price shown does not indicate the actual vessel value. However, as a result of the increasing desire of fishermen to acquire larger rock lobster vessels, together with additional rock lobster pots, and because of the desire of industry and the Department to encourage the removal of sea-going processing establishments (freezer-boats) from the rock lobster industry, a system has been devised whereby the owner of a freezer-boat may remove his vessel from the industry and have the pots from that vessel distributed to other vessels already in the industry. The financial encouragement to the freezer-boat owner is that the pots may be distributed to other rock lobster vessels at an agreed price and with the Department's approval. At the present time members of industry are prepared to take additional rock lobster pots at a price of $250 per pot. It is reasonable to suggest, therefore, that a vessel other than a freezer-boat is likely to change hands at a value equal to the intrinsic value of the boat plus a figure of approximately $200 per pot (i.e. about $50 per pot less than the sale price as pot units). Thus the asking price for a rock lobster vessel worth about $15 000 which is licensed to operate 100 pots in the rock lobster fishery, is likely to be about $35 000. This reflects the profitability of the rock lobster industry. (See also Table 1).

However, this high profitability is payable

Table 1. Average return on capital for different measures of capital and rates of payment to skipper. 1968–1969

Skippers allowance		*Vessel value*	
		Without licence	*With licence*
	Geraldton	$9 786	$26 805
		Return on capital %	Return on capital %
$5 000		69.0	25.2
$6 000		58.8	21.5
$8 000		38.3	14.0
	Fremantle	$11 025	$28 202
		Return on capital %	Return on capital %
$5 000		54.6	21.4
$6 000		45.7	17.9
$8 000		27.4	10.8

Source: Original data from Department of Primary Industry, *Report of Economic Survey of the West Australian Rock Lobster Fishery—1966–67 to 1968–69.*

really only to those who were in the industry when licence limitation was first introduced or those who bought a vessel in the early years of licence limitation. Those who have purchased in more recent years when catches were relatively high and prices very high, have been placed in difficulty as a result of the 1972–73 season, which saw a reduced total catch (down by about 15%) together with two revaluations in the Australian dollar and a devaluation of the American dollar. Fishermen tend to continue to buy at prices higher than that deemed desirable by a well judged forecast of profitability for the ensuing 5 years.

SHARK BAY PRAWN FISHERY

In this fishery, licence limitation was introduced in 1963 so that management could be undertaken following the general principles outlined by Gulland (1972). Here the main considerations have been economic viability of the fishing unit, economic viability of the processing establishment and the effect of exploitation on the prawn resource of the Bay, noting that the resource consists mainly of two consistent species of prawns. *Penaeus latisulcatus* and *Penaeus esculentus.*

(a) Sociological

In general the philosophy of fishermen who hold prawning concessions in Shark Bay tend to equate to those in the rock lobster industry, but there is the added consideration in that additional licences have become available during each three-year period, and three new licences will again be available for the 1975–77 triennium. Fishermen outside the Shark Bay fishery who see it as a profitable operation tend to place themselves in a situation such that their application will be selected by the Minister for a concession. Perhaps the two major methods of attempting this are:

(i) by a fisherman using his boat to explore waters outside the limited entry areas and thus establishing a history of prawn exploratory work; and (ii) by a fisherman who does not own a vessel endeavouring to seek finance to build one to undertake fishing outside the limitation areas. This second method has an extremely high risk element attaching to it and has, over the years, caused the Department considerable concern. However, such high risk activity is likely to be associated with early days of prawn fishing in a specified region rather than as a continuous process.

Unlike the rock lobster fishery, the prawn fishery has a two part system of authorisation allocations: those to the land-based processing establishment, and those to independent operators. In the rock lobster fishery, where some 830 boats are operating, the land-based processing establishments are able to attract sufficient vessels to supply their throughput. However, in outlying areas such as Carnarvon and centres further north it has been seen desirable to ensure that the decentralised land-based establishment be guaranteed minimum throughput by allocation of a percentage of the authorisations to that land-based company. There are thus two groups of fishing boat skippers, those who are skipper-owners or part owners, and those who are skippers within a fleet of company-owned vessels. These skippers join with those who do not hold authorisations in applying for new authorisations when they become available. However, the skippers do not own vessels on their own account and, therefore, the granting of an authorisation to a person in this category would mean that the successful applicant would then have an authorisation without a boat, such a situation could give rise to the direct marketing of an authorisation. The allocation of new authorisations to a person without a vessel in thus unlikely.

Those boat owners who have a prawn authorisation or a rock lobster concession are seen by fishermen outside these two industries as having a preferred position within the fishing industry and, with some justification, object when these authorised or concession vessels move into unlimited entry fisheries from time to time. However, this problem is not of a serious nature, because most of those fishermen outside the limited entry policy are either geographically separated from the limited entry fishermen or are operating on species which are not operated upon by the limited entry fishermen.

(b) Economic

The Department does not possess information of a precise nature in relation to the value of a prawn authorisation over and above the intrinsic value of the vessel. However, there is no doubt that a substantial value does exist and figures of about $100 000 have been quoted. It is with the knowledge that there is a substantial value placed on the possession of an authorisation that the Government has decided to increase the number of authorisations for the 1975–77 triennium by three. This again has an effect on the financial return of those owners who have recently bought interests in a prawning vessel and is another of the factors which such a person needs to take into account when making a business decision on whether or not to invest in the prawn industry and to what degree.

DISCUSSION

The use of licence limitation regulations as a fisheries management tool does provide a method of partially controlling the exploitation rate and capital input. For fisheries such as that on the western rock lobster and Shark Bay prawns it has been of benefit to the State and to the industry. However, its implementation requires close contact between industry, the scientist and the administrator.

If successfully operated, the measure provides economic security and high profitability, but it also impinges on personal liberties and freedom of choice of fishermen. The manager has to ensure that biological, economic and administrative understanding is at a level which ensures that the fisheries involved are fully developed, monopolies are not created, both Government and industry benefits financially, and that if new licences or authorisations are granted the system of selection is one which is accepted by those interested in obtaining entry into the limited fishery.

LITERATURE CITED

CRUTCHFIELD JAMES A. (1965). *The Fisheries: Problems in Resource Management.* University of Washington Press, Seattle.

GULLAND, J. A. (1972). *Some Introductory Guidelines to Management of Shrimp Fisheries.* IOFC/DEV/72/24, FAO, IIOFSDP, Rome, 12pp.

HANCOCK, D. A. (1973). The basis for management of Western Australian Prawn Fisheries. (This seminar)

DISCUSSION

Kirkegaard. I would offer a comment and ask whether Dr Hancock would comment in turn. On one of the apparent effects of licence limitation in W.A., there appears to be a fairly high level of profitability. What people in the fishing industry seem to do with their profits is put them back into the fishing industry. What appears to me to be happening is that, because of the situation in which you are ensuring high profitability, the extra profits are being put into other fishing units which, because W.A. is now fairly well covered with or will shortly be covered with limited entry fisheries, these extra fishing units are being put into other areas to fish. In the situation we are in this probably does not worry us at the present time, but I am wondering if this isn't one way of perhaps enforcing licence limitation on adjoining States or adjoining control areas. Two reasons are one, there is no access within your control system for vessels from elsewhere, and two, you are possibly producing extra fishing effort which can only now be exported.

Hancock. I will take your last sentence first, about producing extra fishing effort. I would think, from the point of view of the prawn fishery licence limitation has been responsible for curbing fishing effort to a great extent, but the real problem is that there are fishermen who have a licence but who want to get an even greater profitability out of that licence. So far there has been no limitation on the size of the boat, and some of the 24 m boats are not able to maintain what they consider profitability within the limited licence fishery, and therefore they work there for a period of months and then they shoot off to the Gulf. This is well known. That, correspondingly is of course, having the effect of increasing the effort in the licence limited fishery beyond the level that was thought about in the first instance because, for example, in Exmouth where the boats started off as a series of converted rock lobster vessels, you now have bigger more efficient vessels and one wonders how far that sort of development can go. If you start cutting off the safety valve, of course, that puts a greater responsibility on those States with limited entry to make sure they are doing their homework right and that they are getting the proper economic understanding on which they will base their numbers of licences and the profitability of the boats remaining within those fisheries. Because, let's face it, there isn't at present a lot of alternatives for boats in W.A. for other fisheries outside the limited entry ones.

Ryan. The paper indicates that the Department is required to approve the transfer of the licence, could you indicate the criteria by which you grant such approval, if you have not granted approval for transfer of a licence and the circumstances in which such approval would not have been granted.

Hancock. Transfer of a licence itself is not really a difficult thing provided someone is a *bona fide* fisherman. I think the actual granting of new licences is more the matter for concern. After a licence has been first isued, it becomes an economically adjusted unit which passes from hand to hand. It does obviously have an inflatory value which is usually to the advantage of the fisherman to whom the licence was first issued. I suppose this is the first time we have thought in terms of provisional licences which may be non-renewable. With no obligation to renew them this gives an opportunity during those three years to see the problems associated with making them into permanent licences. I think probably I am not fully armed with the individual criteria. I have not seen them written down to be quite honest. Everyone is judged on his merits and all of them have to be approved by the Director of Fisheries in W.A.

GENERAL DISCUSSION

CHAIRMAN: DR R. A. NEAL

Neal. Looking back over the program of this Seminar, I certainly would evaluate it as a productive one and a thorough one. The papers presented and the resulting discussions have been, I think, a meaningful contribution to our understanding of the prawn on all five of our subject areas here—descriptive biology, population dynamics, prawn culture, commercial fishery and management. I do want to open the floor at this point for any comments, observations, any summary of statements on the topics I've covered or anything related to the conference, so we're open for discussion here.

Harrison. There are two points I'd like to raise. First of all, in connection with the Moreton Bay permit system, both of these are in the management section. When we first introduced the permit system in Moreton Bay, the permits were issued not to the boats but to the individual fishermen and the permits were not transferable. This overcame all the problems associated with artificial barriers placed on the permits. The system was based on the concept that a fisherman earned a right to fish in that closed fishery through his own experience in the fishery and a new entry could earn the right to fish in that fishery after having worked in it as an employee for a number of years. This system was changed to the present one in which the permit became attached to the boat and was transferable. The other comment I'd like to make is in relation to the Gulf of Carpentaria prawn fishery and our present thinking in regard to management on this is that we would not at this stage consider it advisable to introduce a licence limitation system applying to the boats. We consider that there's still an exploratory fishery in the Gulf and that we shouldn't put any limitation at the moment on the size of the fleet operating there. What we do want to do, however, is to control the rate of capitalisation in the area and so what we have done is to agree with Australian Government on a licensing of the processing plants on shore. By processing plants we mean, not only the actual processing plant, but the depots at which the prawns are landed and the facilities for landing them, including carrier vessels and so forth. The idea is when the appropriate legislation has been brought into effect—this has been announced publicly—licences will be available only to the existing operators. I think there are about ten in number, no additional licences beyond those ten will be issued pending further investigations into the state of the resource.

Young. As far as the Moreton Bay fishery is concerned, just one or two background comments I'd like to make, as a result of some of the research we've been doing in that area. Essentially the king prawn fishery in Moreton Bay is purely for juvenile prawns. The offshore fishery is for mature king prawns and we have recruitment to the offshore fishery from other estuaries on the east coast of Australia other than Moreton Bay. It seems to me that when you're considering any restriction of the fishing effort in Moreton Bay, it is not necessary to take into account the effect of this fishing on the size of adult stocks. The amount of recruitment in Moreton Bay is not influenced in any way by the amount of fishing that is done there and also that the amount of fishing in Moreton Bay may well have very little effect upon the size of the offshore stocks subsequently.

Neal. Any other comments on this particular fishery? If not, do we have comments on any other topics we've mentioned here?

Hancock. At the risk of labouring the question, you did say that there was a considerable difference of opinion over the implementation of the licence limitation system, and yet when you look around the States, one gets the feeling that two years ago there was a hardening against licence limitation but there seems to have been a changeover from people who are outright against it, you get a sort of grudging acceptance about 'well, it's alright for the western rock lobster, then it's alright for the western prawn' and so on. I think it would be worth inquiring whether there is this antipathy to the system; we know that it has its problems, we know that people are concerned about this transfer value of vessels but that apart, there's the system of management. I think it's worth discussion.

Neal. I think we have some differences of opinion here. Would anyone taking an opposing view like to comment, or a similar view?

Gorman. There is a tremendous fluctuation in catches in prawns. Now an administrator sets licences and restricts entry, at what level does he restrict any entry? Does he in fact aim at maximum number of boats to take advantage of the peaks or does he try to organise it so it's sort of average level, or does he try to organise it down at the lowest level? If he does it maximum level, it means in lean years there'll be a large proportion of boats going to miss out. If you do this at the mean level, you get a similar effect but it's not going to be quite as serious. You are on the other hand going to get a quite considerable wastage of your resource. If you set it at the lowest level, you're going to get considerable wastage of your resource but you're not going to impose any hardship or you're going to impose a minimum amount of hardship on the people who are in it. I'd just like to hear from the people who are responsible for setting these levels of boat licences, their view on this situation and how they actually tackle it.

Neal. Does anybody want to interest himself with this?

Sanders. In answering the question raised here and by the invitation made by Dr Neal, I see that licence limitation in those fisheries for which it's applicable and this especially applies to those where an annual catch will be more-or-less constant. The future lies in estimating the optimum number of operators and this is where things get rather difficult, but if in this special situation where the annual catch is constant, then you can use the method of growth-yield analysis and divide this optimum catch by that catch required for the vessels to break even and that will give you the optimum number of operators. In determining the catch to break even, you have the parameters such as the price of the product, the cost, catch rates, numbers of hours fishing and a few others depending on the sophistication of your equations and you can adjust the few depending on the values of those various parameters. In theory, you can adjust the number of operators. As I said originally, there are social consequences to annual adjustment of numbers of boats and so it's probably a method that's not very acceptable for those types of fisheries which annual catch fluctuates widely. For those where the catch doesn't fluctuate widely then by use of provisional probationary licences and by limiting the number of probationary licences to a relatively small number of the total licences, one can then get control, not only by way of increasing the boat numbers, but by actually reducing them, that is, by not renewing the licence after the probationary period is over. That's the direction I see licence limitation going for those fisheries.

Harrison. In the very near future fishing boat crews and skippers will have to have approved certificates. This implies training because as soon as the certificates become mandatory then training must also take place. So, I think the standard of fishing boat crews must improve after this comes into effect. On the other aspect, should we have management or should we have a free go for everybody—I have little doubt on this that the fishing industry, because it's hunting for a wild stock which has no owner, has built into it an automatic mechanism which almost forces overcapitalisation to take place. I think it's the responsibility of fisheries management to do, or the fisheries administration, to try to ensure that the resources available to the community near the shore of our country are exploited to the best good of the community as a whole. Now, whether these are exploited for the best yield or for the highest catch value or for the biggest total employment or for any other purpose is a matter for the Government to determine as a policy. If government determines which objectives they want to achieve then the fisheries administrator has to introduce regulations accordingly. If we're aiming at maximum employment in an area, we possibly do it by regulations which have the effect of reducing efficiency. If, on the other hand, we want the maximum yield in terms of high quality export prawns, we may go the other way and use licence limitation as the best approach.

Zed. I'd like to ask a question on the licence limitation issue and if we are to be concerned at all with preservation of this stock, it seems to me that there are the three alternatives of either licence limitation, the restriction of gear usage or to impose closed seasons. Closed seasons may be a possibility but I think the gear restrictions to reduce efficiency aren't a viable proposition because as we've heard from some other speakers they can be got around, some fishermen we've heard shove bags into their codends and do all sorts of things like this so it's going to be a very hard thing to police the actual usage of the gear and the efficiency.

Allen. I'd like to go back to what Geoff Harrison said a few minutes ago. He put his finger then on a very important point which is underlining a lot of the uncertainties in this kind of discussion and that is the variety of different objectives which a government can have in managing a fishery. Whether it's purely for the financial ones, maximation of financial return, maximation of gross national product to maximation of yield, maximation of exports or to maximation of employment. If I may say so in this company, I think a lot of the difficulty comes from the fact that governments themselves, possibly even their advisers, don't really realise which objective they are striving to achieve. I think this is a very important thing that we should all try to bear in mind is what we're really trying to do in managing fisheries—what do we want to get out of the fishery—this is the point that I want to emphasise.

Temperley. I liked Mr Haysom's logging deal his morning because I know a bit more about logging than I do about prawning, but I think it's worth recognising that the purpose of forestry management on Crown land is very similar and in the days when I had a bit to do with it, there were Crown licences which were very old, which had a lot of privileges and which were transferable at very high rates. There was the other type of provisional licence, but by and large, the purpose of the deal was to secure the resources, to harvest them at the rate at which they could be replenished, and also to provide a reasonable return to the logger and to the sawmiller, but they got by on the royalty basis that was equated back to this reasonable profit but there are a number of other methods that we used and I think they're very important. One was that payment of royalty derived from this profit was payable at the start. In other words, if somebody trawled some prawns and then dumped them in the ocean, he paid a royalty for the privilege. There are many other similar principles in the forestry going that I think are applicable in the prawning industry.

Pane. Could I ask something which may be a little out of order but I'll ask it anyway. It seems to me from the papers that have been presented at this Seminar that the interests of everybody start when the prawn lays its eggs and stops when the fisherman hauls it into his net. It seems to me that the whole purpose of the prawn fishery is to provide a product for human consumption and it seems that there has been not very much spoken about what happens after the prawn hits the boat. Do the people that are concerned consider that their obligations stop at that point, and if not, why haven't we heard a little more about what happens beyond that point?

Austin. As a member of the general public, I understand that the prawn resources belong, at least in part, to me, and consequently, it worries me that, to a large extent, financially I'm in competition with Japanese and American publics for high price prawns. It seems to me that one way of overcoming this would be to build into the licensing system, where it applies, some provision whereby prawns, or some proportion of export prawns, should come to the Australian market at a reasonable price, whatever that means, but something lower than what the Japanese or Americans pay for them.

Ruello. I'd like to make a comment based on someone who's studied the quality of the prawns and, at the same time, a housewife's point of view. I agree with Robin Austin, I think one of the tragedies that has happened with the prawns, particularly in N.S.W., is that they're so expensive that when you want to go to have a plate of fried rice, you get these horrible little prawns from India, that are tasteless, odourless and almost colourless. This is where I almost agree with Robin that we should have subsidised prawns for Australia because we all like to eat them.

Young. I'd just like to make one general comment on research in the fishing industry generally. It seems that in most industries, industry itself tends to contribute largely to the research that is going on in that industry. It's a feature of the fishing industries, not only in Australia but also over the world, that they tend to be very loath to engage in research. I think this is partly because of the common resource idea—after all, why should I put money into finding better gear when someone else is going to pinch it and use it—but I think this could partly explain the question why so much emphasis is put on the resource before it reaches the boat. Once it gets on your boat, it's then no longer common property. It then belongs to the person who caught it, and I suppose subconsciously, one tends to think that it's up to him to do his research, find out the best ways to look after what is now his product.

Hancock. I seem to be taking up three lines of discussion all at once. I feel sure somebody from CSIRO or Food Preservation or somebody ought to take issue on the fact that there isn't any work done after prawns reach the deck, however I leave that to them. The other thing I think is that Judy was lucky that her Indian prawns were odourless and tasteless. The third thing was I'd like to ask what is really wrong with the fishermen having a more or less guaranteed income. There seems to be a sort of innovation really in terms of a fisherman who really has all the hazards to cope with and here we're suddenly making him respectable. I guess this can't really be achieved unless you do something to preserve the stock and make sure it's not overexploited and that really is the reason why research is undertaken. I think the real problem is where you choose the level of income of those fishermen while to make it possible for them while still making sure there are enough licenses in that fishery so that the resource is exploited properly.

Thomson. The fact that I'm a critic of limited licences does not mean I disapprove of them. My own criticism is that I don't think they should be applied until need has been demonstrated and I feel that in the prawn fisheries this has not been demonstrated when they were applied. Like Russell a year ago, he criticised this type of approach to fisheries management as wasteful and I think it is. It means for those years while you're adjusting your licences upwards, you are wasting your resources. I don't think it's a bad thing to guarantee fishermen an income. What I do object to is governments and fisheries administrators doing this but justifying their actions on the grounds that they are protecting a resource—that is what I object to. I don't think that they're being honest to the public. Also, if I may say, looking into the future, as you asked us to do, I think that this type of approach is going to disappear just as our oil resources are disappearing. The demand for protein is bound to increase and it will become a matter of management by governments to produce the greatest possible sustainable yield and not produce the greatest possible sustainable income.

Ruello. I'd just like to make a coment on what Don Hancock said. I should remind you all that a little bit of work is done on prawns once they reach the deck. Also, point out to you that this work is only temporary, only work from a three year grant from the Fishing Industry Research Council, which shows you the emphasis given by the Government to this. It's also important to note that the present Department of Primary Industry regulations which are set out by the Australian Government aren't being implemented anywhere in Australia because they're not doing any testing. These things are a bit farcical. The industry really doesn't have any guidance as to what sort of quality they should be producing. They're only interested in getting the prawns out of the profit, the larger the prawn I think the more profitable they are, but Mr Pane could probably correct me on that.

Pane. Just to answer that quickly. In the past the larger prawn has been the more profitable, however the Japanese, being the fickle people they are, are now changing their minds just when we conned the fishermen into believing he should be catching a large prawn, the Japanese are now refusing to buy it. In answer to the two people who said they would like to have Australian prawns exported to Sydney or other places, the Australian housewife has been, I think, conditioned herself to believe that if she pays $1.87 kg for a whole cooked greasy she's getting a real good deal. Ask her to pay $2.20 kg for beautiful export green kings and she'll think you're crazy.

Ruello. A housewife comments—'You give me your beautiful export product and I'll pay for it'.

Gorman. One of the real problems with prawns, I'm talking about domestic consumption of prawns in Australia, has been the fact that traditionally the average person here knows a prawn only as a red freshly boiled, or reasonably freshly boiled, thing that comes out of the local fish shop. They're quite happy to go in and buy cutlets at a Chinese restaurant, but if you give them the green prawn tails and say go away and eat those, the first thing they say is 'what do we do with it', they don't know how to handle them. Industry has done a terrible job of promoting the produce in Australia. I've had this out with industry quite a bit. I think industry should make a much more forceful attempt to find a market in Australia for its products and cease to depend on overseas to the extent that it does.

Austin. I think in America the industry employed a firm specifically to promote prawns with the general public, didn't it Dr Neal?

Neal. Yes, that's right. This was after the Pope's decision that Roman Catholics were not required to abstain from meat on Friday. There was considerable concern by the fishing industry that the sales of fishery products would decrease and, as a result of this, the National Fisheries Institute, which is an industry group, supported by dues from processing firms, launched a campaign to promote fishery products and a large portion of the effort went toward promotion of shrimp. It has been a very successful program and I feel certain it has played a major role in the increase in per capita consumption and the increase in the relative price of prawns in the U.S.

Thomson. I wondered when we were getting around to prawn farming. I wasn't here yesterday so the point I want to make may have been raised, and I apologise if it was, but in the discussion on the prawn farming on Friday, it rather struck me that no one mentioned looking at the existing prawn culture—the indigenous Indo-Pacific prawn culture that one has in the Ganges Delta, Singapore, the Philippines or Indonesia—surely by looking at them some reasonable hints could be obtained. I know it's perhaps nicer to start off your own experiments but some of those prawn fisheries, not consistantly but sometimes, do produce very good yields indeed. Have any of the would-be prawn farmers looked at these to try to sort out what are the significant factors?

Neal. The topic was touched on I think in our discussions but the point is very well taken. Are there some comments?

Temperley. I think these areas are well worth looking at if only because they have been at it for a long time and also they are farming species that we're interested in. I agree with Prof. Thomson that this has got to be looked at a lot closer than I for one have been able to look at it yet.

Shannahan. I reject it. I am in favour of the more intensive scheme. I'm more in favour of capital intensive schemes than labour intensive schemes.

Harrison. Yesterday in the discussion on prawn culture, I raised one point which didn't attract any comment. I'll try it again in case there is any comment today. I think I made the point that prawn culture or fish culture generally, unless it's the intensive variety, is going to be a large user of the valuable estuarine productive lands on which a lot of our coastal species of fish depend. How are we going to deal with the possible conflict for the use of this land between the aquaculture people who want to retain the productivity of that land for their own use and the need for the continued productivity of that land to maintain the resources that are needed by the rest of the community?

Smith. The land is certainly one question. The remoteness of the areas which would be suitable for natural raising of prawns on a large scale, where we have the high temperatures required by the generally tropical penaeids, is something which prevented early development in Australia. The method of stocking has been found to be unreliable in the countries which are using this traditional method, although they do have a high total production it is patchy and people that have tried to reliably obtain a high yield from these ponds so far haven't been successful. The so-called underdeveloped countries that are using these methods are now looking quite closely at hatchery methods to stock them so that the vaguaries of stocking from a natural resource are not encountered and we have a big problem in construction of these type of impoundments. The people in Thailand, for instance, hand dig their ponds using a bamboo spade and it takes a lot of sweat. I don't think we're prepared to pay for that or could possibly put it into capital investment. We apparently don't have the mechanical means to construct ponds cheaply in the softer terrains that are thought to be suitable. It may be possible somehow to raise this terrain to a high level but then you encounter high pumping costs so there's another economic problem there.

Shannahan. Professor Thomson for your information. Fujinaga in Japan, who has the classical type of large pond, if I recall, mentioned that he was getting a yield of something like 0.5 kg per sq. m. He also said that others were down as low as 0.3. On the more intensive methods of farming, users of the method claim they are getting somewhere near 2 kg per sq m or better and I think that Galveston also is achieving something of a similar figure.

Thomson. As usual I think I might not have made myself clear. I was not advocating indigenous farming as compared to intensive farming, but suggesting that if you looked at their past practices you may well get leads as to the ways and means of doing it, which would make a better success of your experiments. That's what I was intending to imply.

Walker. Taking the discussion off on another track, recently overseas quite a number of eminent fisheries biologists have been worried that the classical methods of fish population analysis don't provide administrators with sufficient data quickly enough for them to make realistic decisions about the management of a fishery in real time. Stan Hynd pointed this out that, especially in prawn fisheries, this is a serious consideration. I was wondering if anyone here would like to comment on that proposition? They do, of course, suggest that there should be other more rapid methods that could be applied more rapidly to assess this stage of a population should be developed. There are a number of suggestions for this, for instance larval surveys and such like.

Temperley. I think this problem is common in all industrial management situations where data is available so long after the event that management is only going through the motions of trying to prevent a horse from bolting.

Osbourne. Could I just attempt to answer Mr Harrison's question a moment ago concerning the justification for commercial exploitation of a given area in relation to natural exploitation. I think this is going to have to go back to the government for them to decide what is the best way to exploit this resource, whether it might be intensive culturing by a commercial firm or in fact predation by humans in the sea.

Zed. In relation to the point about the land that could be taken up for the less intensive types of ponds, I think it must be remembered that you're going into prawn culturing one species and I think it's becoming increasingly more well known that the estuarine mangrove type areas that could be utilised as ponds are feeding areas for not only prawns but also other species that have commercial importance. What probably is a better proposition is that there are certain places in mangrove areas that have already been alienated, such as salt pans, and these may be able to be converted to take up a dual use as salt evaporating pans and as prawn culture ponds.

Neal. I think we need an economic evaluation or some economic measure of the value of these natural estuarine areas before we can really make a decision as to whether or not we want to replace them with an aquaculture operation.

Temperley. One thing worth throwing into the arena is that capital intensive prawn farming operations are also energy intensive. I don't know whether people have done their sums on some of these energy costs involved, but I suspect that they could be a lot higher than was thought. As I said yesterday, my feeling is that in the foreseeable future if there is any room for aquaculture, it will probably be a compromise between the intensive and extensive, and the capital and labour intensive situations.

Saenger. In terms of placing an economic value on mangroves, the only figure that I've seen has been an American figure where they value mangroves at approximately $70 per tree. So perhaps we should go in for mangrove farming.

Neal. To summarise the Seminar, we have had contributions on all five of its aspects.

The descriptive biology is of course the basic foundation for further work on many other aspects of culture, population dynamics and management. Particular contributions of note on the descriptive biology are those on the movements of the prawns, the basic ecological studies underway, and the location of food I think was a particularly good effort.

I believe that we have not resolved some questions regarding the role of currents in moving larvae or postlarvae into the estuaries. We've not resolved the question of the mortalities during the larval or postlarval stages of the life cycle. I would like to ask for your comments on these topics. Also, I think we have a standing question on the relative importance of plant and animal foods in the diets of the prawns. Perhaps some of you have some additional comments you'd like to make on this topic.

In the field of population dynamics, a legitimate question has been raised. It's one that's been frequently raised for marine fisheries—do we really need to worry about over fishing or do we really need to worry about the correct size to harvest? We've heard much more in the way of difficulties in trying to resolve these problems than we have of successes in finding a suitable solution. Is this research really needed? I think the problem of whether or not to protect the small shrimps is a particularly pressing one, several people have indicated concern about this problem. The suggestion that we had, that mortality rates may be lower than previously thought, that is the natural mortality rates, would indicate that there is possibly a definite advantage in protecting these smaller shrimp.

On the topic of shrimp culture, we heard many opinions. We reviewed some of the efforts, particularly those outside Australia. I think we have a consensus of opinion that shrimp farming will become an economic reality. I don't think we have a consensus at all on how this will be done. This will be your last chance to comment on that topic during this Seminar at least.

I've been particularly impressed with the opportunities that exist for expansion of your fisheries. I've also seen that the high costs of harvesting are limiting this expansion and probably will continue to limit it in the future. I'd like to hear from some of you, projections on expected expansion of the fisheries considering these factors. On a related topic, we've heard about methods for improving the quality of the product and again the problems related to implementing these methods.

Finally, on the topic of management, we've considered today a number of different aspects and a number of unresolved questions still exist.

I think one is the value and the need for economic analysis especially concerning factors such as harvesting costs. We seem to have considerable disagreement on the subject of the philosophy of licence limitation. I see here emerging some management systems that look particularly good to me and particularly good in light of the kind of systems that are being used elsewhere.

APPENDIX I

AUSTRALIAN PRAWN FISHERIES

BY R. H. WALKER
Department of Agriculture, Canberra, A.C.T. 2600

ABSTRACT

The biology of seven commercially important species of Australian penaeid prawns is summarised.

The Australian prawn catch has increased from 5.5 million kg worth $4 797 000 in 1964–65 to17.5 million kg worth $19 374 000 in 1971–72. This has been a result of the discovery of new fishing grounds off northern Australia and South Australia. The operation of five 'unit fisheries' which make up the Australian prawn fishery is described.

INTRODUCTION

Biological Affinities

Most commercial prawns of Australia are members of the section Penaeidea which is part of the Class Crustacea, Order Decapoda. This order contains those animals which are familiar to most people as crustaceans, i.e. shrimps, prawns, crabs, lobsters, hermit crabs, etc. Members of the Penaeidae may be distinguished from other prawns and shrimps by two main features:

(i) the front edge of the shell of the second abdominal (tail) segment is over-lapped by the shell of the first segment; and
(ii) the first three pairs of walking legs bear pincers (chelae) and are of similar thickness.

Most other shrimps are in the superfamily Caridae and are distinguished by these features:

(i) the front edge of the shell of second abdominal segment overlaps the shell of the first segment; and
(ii) the third pair of walking legs never have chelae and the first and second pairs of legs are often dissimilar in thickness.

Furthermore, penaeid prawns are the only decapod crustaceans which shed their eggs into the sea immediately after fertilisation. All other decapods carry their eggs until their larvae hatch from the eggs.

The family Penaeidae contains the majority of Australian commercial prawns and all of these at the present time are contained in the sub-family Penaeinae. For a taxonomic definition of the family Penaeidae and the subfamily Penaeinae readers should consult Dall (1957).

Morphological description of the Penaeidae

The body of a typical penaeid prawn is divided into two main portions, the cephalothorax (head) and the abdomen (tail). The cephalothorax is covered by the carapace which is extended at the front into a prominent toothed rostrum (head spike). The abdomen is divided into six segments each of which is covered by its own shell plate (tergite). The sixth segment bears on its rear edge a triangular projection (telson).

A pair of stalked eyes arise beneath the carapace on either side of the rostrum. Behind the eyes the animal bears pairs of appendages on the lower surface of the body. Each of these pairs of appendages marks the position of an evolutionarily primitive segment. In the cephalothorax the primitive head and the first fourteen primitive segments have fused but the pairs of appendages attached to the segments are still apparent. They are antennules, antennae (feelers); mandibles, maxillae I and II (mouthparts); maxillipeds I to III (feeding legs which transfer food to the mouthparts); pereiopods I to V (walking legs, pereiopods I to III have pincer-like chelae). In females the sternite (base) of the segment bearing pereiopod V is modified into a thelycum (external genitalia).

In the abdomen, the individual segments are evident. The sterna of the first five abdominal segments carry pleopods (swimming legs) and the sixth abdominal segment bears uropods (tail fan) on its rear edge. In the male the first pair of pleopods carry the petasma (external genitalia), each of the second pair of pleopods carry an appendix masculina.

The life cycle of a typical prawn

The 'classical' life cycle of a prawn is divided into two phases, a marine phase and

Table 1. Generalised prawn life cycle

Stage	*Duration*	*No. of moults*	*Approximate total length*	*Remarks*
Eggs	12 hours		Less than	Demersal
Nauplius	24-48 hours	8 approx.	1 mm	Demersal
Protozoea	7 days	3	3 mm	Planktonic marine phase
Mysis	7 days	3-4	4-10 mm	Planktonic
Postlarva	1 month	10	1-2 cms	Enters nursery area Gradual change to juveline form
Juvenile	3-4 months	Many	2-10 cms	Males are often mature as they leave nursery area Estuarine phase
Adult	8 months	Many	10-30 cms	Females mature at sea and spawn after fertilisation Marine phase

an estuarine phase. Females spawn in the open sea. The eggs are demersal (sink to the sea bed) and after about 24 hours hatch into the first larval stage, the nauplius. This stage is small (about 1 mm) and pear-shaped with three appendages. After going through about eight moults the nauplius metamorphoses into a protozoea. In this stage the anterior region is covered by a carapace and the thoracic region and abdomen are differentiated. The telson is forked. This stage has limited mobility but may undertake vertical diurnal migrations which could aid its dispersal.

After three moults the protozoea metamorphoses to a mysis. The general appearance of this stage is reminiscent of an adult prawn. The entire cephalothorax is covered by a carapace and the abdominal segments now bear uniramous (unbranched) pleopods. This stage is still wholly planktonic.

After three moults the mysis metamorphoses to a post-larva. In this stage the pereiopods assume a form suitable for walking and the pleopods are biramous (have two branches). The postlarva is the stage which reaches the nursery areas on the coast. They are able to leave the water column and cling to the bottom.

In the nursery areas the settled postlarvae gradually change to juvenile prawns as they moult. The juveniles feed and grow in the nursery grounds for three to four months and then as adolescents migrate to sea. At sea the prawns become sexually mature, mate and the females spawn. It is generally accepted that the life cycle of a typical prawn takes about eight to twelve months to complete. Table 1 is a summary of the 'classical' life cycle.

Australian commercial species

There are more than 35 species of Panaeinae recorded from Australian waters. Members of the genera *Penaeus, Metapenaeus, Trachypenaeus* (Hardback prawns), *Parapenaeopsis* (Coral prawns), and *Metapenaeopsis* (New Guinea prawns) are all exploited to some degree. The seven most important commercial species are listed below. These seven species supply most of the Australian prawn catch.

Banana prawn	*Penaeus merguiensis*
Brown tiger prawn	*Penaeus esculentus*
Eastern king prawn	*Penaeus plebejus*
Western king prawn	*Penaeus latisulcatus*
Endeavour prawn	*Metapenaeus endeavouri*
School prawn	*Metapenaeus macleayi*
Greentail prawn	*Metapenaeus bennettae*

BIOLOGY

Description

A description which will enable the identification of the prawns which are discussed in this document is given below. Because these prawns are superficially similar, the features which distinguish them are not readily apparent. A complete technical description of Australian members of the genus *Penaeus* and a key to the Indo-Pacific members of the genus is given by Dall (1957). Technical descriptions and a key to the members of the genus *Metapenaeus* are given by Racek and Dall (1965). Both these publications give technical descriptions of other prawns encountered in Australian waters.

Banana prawn

Carapace without a pair of deep grooves on either side of the rostrum reaching almost to the rear edge of the carapace. Rostrum almost straight with a high triangular blade in mature prawns. There is no hepatic ridge on the carapace. The dactyl (lst segment) of the third maxilliped of the male is half the length of the propodus (previous segment). In the male there is a tuft of hairs at the end of the propodus which reaches half the length of the dactyl.

Body cream to yellow, tail fan red tipped with yellow. Body sometimes pink to red. Swimming and walking legs yellow but sometimes pink or red.

Tiger prawn

Carapace without a pair of deep grooves on either side of the rostrum reaching almost to the rear edge of the carapace. Rostrum slightly 'S' shaped. No groove in the ridge directly behind the rostrum. With an hepatic ridge. Dactyl (last segment) of third maxilliped ⅔ length of propodus (next segment) in males and females. There is a tuft of hairs on the propodus of the male which reaches the length of dactyl.

The body is striped with alternating bands of buff and brown or yellow and orange. The tail fan is brown or orange with yellow edges.

Eastern king prawn

Carapace with a pair of deep grooves on either side of the rostrum reaching almost to the rear edge of the carapace. There is a further small groove on either side of the rostrum running forward from the rearmost tooth of the rostrum. A pair of short grooves ⅙ the length of the carapace on either side of the rostrum at the front of the carapace have the rear ends divided into three.

The body is yellow to light brown. In large prawns from deep water it may be pinkish. Legs are yellow. The tail fan is edged with blue. The sides of the abdomen have short vertical brown stripes on each segment.

Western king prawn

Carapace with a pair of deep grooves on either side of the rostrum reaching almost to the rear edge of the carapace. The rostrum is without the small grooves which occur in the eastern king prawn. A pair of short grooves ⅙ length of the carapace on either side of the rostrum at the front of the carapace have the rear ends divided into two.

The body is yellow to light brown. The tail fan is edged with dark blue. The first five segments of the abdomen have a short vertical brown stripe on the side. The walking legs are generally blue at the top with yellow ends.

Endeavour prawn

No teeth on the lower edge of rostrum. The body and carapace are covered with irregular patches of short hairs which feel greasy. The rostrum is straight and triangular. The tail spike (telson) has three pairs of large movable spines.

The body is generally light brown. The antennae are bright red. The tail fan is blue at the edges grading through yellow green to brown at the base. The walking legs are yellow toward the base and white or pink at the ends. They are not striped.

School prawn

No teeth on the lower edge of the rostrum. The body and the carapace are smooth. The front half of the rostrum has no teeth on its upper edge and curves upwards. The tail has four large spines on the sides.

The body is colourless with scattered green spots when the prawn is alive. The edges of the tail fan are blue.

Greentail prawn

No teeth on the lower edge of the rostrum. The body and carapace are covered with irregular patches of short hairs which feel greasy. The rostrum has a slight upward curve and has teeth all along the upper edge. The tail spike has no large spines on its edge.

The body is almost transparent and speckled with dark brown. The tips of the tail fan and swimming legs are green.

Distribution

TOTAL AREA

The general distribution of each species is briefly discussed below. The Australian distribution of each species is summarised in Table 2.

Banana prawn

This prawn occurs in the Indo-Pacific region between 67°E. and 166°E. longitude and ranges in latitude from 25°N. to 29°S.

Brown tiger prawn

This prawn is found in the warmer waters of Australia from Sydney on the east coast, around the north coast of the continent and down the west coast to Shark Bay in Western Australia. It has been recorded from South Kalamitan.

Western king prawn

This prawn has a scattered distribution in

Table 2. Geographical occurrence of 7 species of Australian commercial prawns

Prawn	*State*						
	N.S.W	*Qld.*	*N.T.*	*W.A.*	*S.A.*	*Vic.*	*Tas.*
Banana	—	+	+	+	—	—	—
Brown tiger	+	+	+	+	—	—	—
Eastern king	+	+	—	—	—	+	?
Western king	—	+	+	+	+	—	—
Endeavour	+	+	+	+	—	—	—
School	+	+	—	—	—	+	—
Greentail	+	+	—	—	—	—	—

the Indo-Pacific region from the Red Sea, through Malaysia and Moluccas to Korea and Japan. In the Australian region it ranges from Kangaroo Island, S.A., around Western Australia, Northern Territory, northern Queensland, Thursday Island to New Guinea and scattered down the eastern Australian coast to New South Wales.

Endeavour prawn

This prawn is found only in Australian waters. It occurs around the northern coast of the continent from Shark Bay in Western Australia through the Northern Territory and Queensland to Ballina in northern New South Wales.

School prawn

This species is found on the east coast of Australia between north-eastern Victoria and the Mary River in Queensland.

Greentail prawn

This species is found on the east coast of Australia from Coila Lake in southern New South Wales to Cooktown, north Queensland.

Bionomics and life history

SEXUALITY

All prawns discussed in this document are heterosexual (i.e. there are distinct sexes) and males can be distinguished externally from females. Mature females are larger than mature males. Males have a petasma which is an organ situated between the first pair of swimming legs. They also carry spermatophores (sperm sacs) inside the bases of the fifth pair of walking legs. The spermatophores are extruded through small tubes at the base of the fifth legs.

Females have a thelycum. This is situated between the last two pairs of walking legs on the underside of the prawn. There are two types of thelycum. The members of the genus *Penaeus* discussed in this document have a closed thelycum. Members of the genus *Metapenaeus* discussed in this document have an open thelycum. The closed thelycum is generally a circular organ with a slit running from front to rear which gives access to a chamber inside which the sperm sac is held after mating. There is a small boss-like plate at the front end of the slit. The open thelycum is made of a series of sculptured and raised bars to which the sperm sac is stuck. Females liberate eggs through two microscopic holes at the bases of the third pair of walking legs.

The sperm of male prawns is generated in the testes which are white tubular organs found in the cephalothorax (head). The ovaries are much larger organs and have six or seven lobes which extend throughout the head and along the tail of the prawn immediately above the gut. The ovaries of ripe females can be distinguished as a broad green or orange stripe running the length of the upper surface of the abdomen.

MATING

The male uses the petasma to transfer the sperm sacs to the female's thelycum. A female with a closed thelycum must be soft-shelled before she can mate because the sperm sac is placed in the thelycal chamber by the male. The lips of the thelycum can only be parted while they are soft. Females with an open thelycum are presumably capable of mating at any time.

As yet no Australian prawn has had its mating behaviour described in detail.

MATING AND SPAWNING AREAS AND SEASONS

Banana prawn

In the southern Gulf of Carpentaria most impregnated females have been found in waters deeper than 14 m. Tuma (1967) found that in the populations he studied the greatest number of impregnated females occurred between the months of March and September.

In the south-eastern Gulf of Carpentaria Munro (1974) found that banana prawns mate during the winter and that the main spawning season is during late winter and early summer.

Further surveys made by CSIRO since 1969 indicate that nursery areas in the Gulf occur along the eastern and southern shore between Weipa and Roper River. Rivers at the extremities of the distribution have juveniles present during the winter. During the summer juveniles occur in rivers at the centre of the distribution. Thus banana prawns in the Gulf of Carpentaria appear to spawn throughout the year.

Brown tiger prawn

Racek (1959) says that on the New South Wales and Queensland coast tiger prawns become sexually mature as they move from the nursery areas towards a depth of 50 m and that fertilised females are found beyond that depth. Presumably spawning also occurs in depths greater than 50 m.

Eastern king prawn

Racek (1959) says that the breeding grounds of the king prawn are located in depths of 100 to 150 m off the New South Wales and southern Queensland coasts.

School prawn

Racek (1959) says that the breeding grounds of the school prawn are located in depths greater than 60 m off the New South Wales and southern Queensland coasts.

Greentail prawn

According to Dall (1958) the greentail prawn spawns between late October and May in depths of about 14 m. This prawn can complete its lifecycle in enclosed coastal lagoons (Morris and Bennett, 1952) but if it can gain access to the sea it will mate and spawn there (Dall, 1958).

Western king prawn

Slack-Smith (1969) says that recruitment of this prawn to nursery areas in Shark Bay occurs throughout the year. However, it is greatest in summer so presumably mating and spawning occurs during spring and summer outside Shark Bay.

Western king prawns in Exmouth Gulf spawn during October-November. It is unlikely that females spawn more than once during a season.

Endeavour prawn

There is no information published on the mating and spawning habits of the endeavour prawn.

While discussing the sexual maturity of prawns, Racek (1959) indicates that prawns in colder waters become capable of spawning somewhat later than those in warmer (more northerly) waters. Spawning seasons are longer in warmer waters.

Mating and spawning of eastern king, school and greentail prawns occurs during the full moon quarter (Racek, 1959). Spawning of the western king prawn in Shark Bay is probably related to lunar periodicity (Slack-Smith, 1969).

Eggs and larvae

EGGS

According to Racek (1959) the eastern king prawn produces about 400 000 eggs, the School prawn produces about 350 000 eggs and the greentail prawn produces 200 000 eggs. Tuma (1967) says that a female banana prawn produces about 100 000 eggs. Hancock (1974) reports that western king prawns contain more than 400 000 eggs at the time of spawning.

Table 3 is modified from Racek (1959).

LARVAE

With the exception of the greentail prawn all prawns dealt with in this document probably have life cycles which conform to the 'classical' life cycle set out in Table 1.

No larval stages of the western king, brown tiger or endeavour prawn have yet been scientifically described.

Various larval stages of the banana prawn, the eastern king prawn, the school prawn and the greentail prawn have been described or observed.

Banana prawn

Kirkegaard, Tuma and Walker (1970) show a drawing of a post larva of this prawn from the Norman River in Queensland.

Eastern king prawn

Dakin (1938) described the postlarval stage and a protozoea and mysis he attributed to the eastern king prawn. In 1940 Dakin described another protozoea and mysis which he attributed to the eastern king prawn. In the 1940 paper he indicated the larvae he had described in 1938 probably belonged to another species.

Racek (1959) observed but did not describe in detail some nauplii, the third protozoeal stage and a first and second mysis stage and postlarvae. He was doubtful about the specific identity of the protozoeal and mysis stages.

Barber and Lie (1974) found that eastern king prawn postlarvae enter estuaries on the flood tide during both day and night and that more enter during the first quarter of the moon. They suggest that it is possible that daylight and full moon depress the numbers of postlarvae entering an estuary.

Table 3. Eggs of some New South Wales prawns

Prawn	*Diameter*	*Colour*	*Where found*
Greentail	0.23 mm	pink	mud bottom
School	0.26 mm	yellow	mud bottom
Probable eastern king	0.28 mm	blue	10-14 m above bottom

School prawn

Racek (1959) observed but did not describe in detail the naupliar stages, three protozoeal stages, two mysis stages and the postlarval stages of the school prawn.

Greentail prawn

Morris and Bennett (1952) studied the development of this prawn through four nauplius stages (they suggest there are actually eight stages) followed by three protozoea stages, then three mysis stages and six postlarval stages. The time taken for development from egg to late mysis was 10 to 11 days. Racek (1959) observed but did not describe in detail most of the larval stages of this species.

Racek (1959) makes some remarks about the behaviour of larval prawns. The first stage nauplius is generally found near the bottom. However nauplii are strongly attracted to the light and they soon rise to the surface. The early protozoea are also attracted to light and remain in the surface waters but older protozoea and early mysis prefer light of a lower intensity. They are found on the surface at night and in deeper waters during the day. The postlarvae are capable of clinging to the bottom and apparently only enter the water column during favourable tides.

JUVENILES

Juveniles of the banana, eastern king, brown tiger, school and greentail prawns have all been found in estuarine areas in eastern Australia. In the southern Gulf of Carpentaria banana prawns are the only prawn mentioned in this paper which appears in estuarine areas. Tiger prawns, western king prawns and endeavour prawns are also found in the southern Gulf as adults but juveniles of these species are mostly found outside river mouths. In Exmouth Gulf and Shark Bay juvenile western king and tiger prawns are found on the extensive areas of gently sloping tidal flats which surround these bays. In Nickol Bay, Western Australia, banana prawn juveniles are found in the small tidal creeks which open into the bay. These juveniles are found in the creeks during summer when the water is often hypersaline. In contrast, some juvenile banana prawns have been found in freshwater in the Norman River which runs into the Gulf of Carpentaria.

Juveniles of the greentail prawns have been found in the Brisbane River in salinities ranging from freshwater to that of the open sea.

Young (1974) found that recruitment of young king prawns to Moreton Bay occurs throughout the year with peaks of recruitment occurring around February, June and October-November. The main nursery areas are sea grass beds. Postlarval prawns settle in the shallowest parts of these beds and move to deeper water as they grow older.

Thus it appears that the juveniles of many species of prawns can tolerate wide variations in salinity in their natural habitat. However it is generally accepted that juvenile prawns which inhabit estuaries normally leave during floods. Juveniles of the eastern king, brown tiger, school and greentail prawns return to the estuaries when salinities return to normal after the flood has subsided.

Ruello (1974) has shown the need to prevent the destruction of juvenile prawn habitats by industrial or commercial users of estuarine areas.

ADULTS

Prawn spawn within their first year of life. The smaller prawns (e.g. school and greentail prawns) probably live for only one year. Many of the larger species are capable of entering a second year of life and some may enter a third.

The greentail prawn can reach sexual maturity in enclosed brackish lagoons but all adults of the other prawns mentioned cannot tolerate reduced salinities and require oceanic conditions for spawning.

Prawns are palatable animals which are preyed upon by many of the larger carnivorous fish.

Both banana and king prawns are parasitised by an isopod. This results in parasitic castration of males, i.e. males with the parasite never develop functional genitalia.

Specimens of king prawns have been found with large irregular patches of dark blue pigment on their shells. They are often mistaken for marked prawns.

Nutrition and growth

Dall (1968) investigated feeding of tiger, banana, eastern king, and greentail prawns. He concluded that there were no important differences between these species in food preferences, feeding or digestive tract function. He agrees with other authors' descriptions of prawns as 'omnivorous scavengers' or 'detritus feeders' which feed on dead and dying animals of all sizes, plant tissue and smaller animals. He also points out that prawns are capable of browsing on colonies of algae, bacteria and microscopic animals which grow on the surface of the sea bed and that this grazing may provide a considerable portion of the food intake of the prawn.

Prawns have few reserves of energy stored in their bodies and utilise food very rapidly. This means that they must eat frequently. This requirement for a regular food intake may be one of the reasons why prawns are found in regions where the productivity of the bottom is high.

Hindley (1974) has found that the banana prawn is stimulated to swim against a current by low concentrations of amino acids. This is probably the most important mechanism by which the prawn locates food. Chemotaxis may be important in the final location of food.

Greentail prawns moult about once a fortnight and increase their carapace length by about 2 mm a month (Dall 1958).

Tuma (unpublished data) kept banana prawns in a cage in the Norman River for 120 days. In that period male prawns increased their carapace length by about 17 mm and females increased their carapace length by 19.5 mm. At the end of the experiment the modal carapace length of males was 26.97 mm for males and that of females was 29.38 mm.

Somers (1947) found that the pattern of growth of the eastern king prawn in south-eastern Queensland indicated that juvenile animals in Moreton Bay grew in a fashion which indicated that their respiration rate is proportional to their weight. Adults, on the other hand, grow at a rate which indicates that their respiration is proportional to their surface area. The mathematical description of the growth of this species is complicated because its rate of growth is temperature sensitive.

Dall (1964, 1965a, 1965b, 1965c, 1965d) has investigated aspects of the moulting physiology of the greentail prawn in considerable detail. Interested readers are referred to his papers.

Behaviour

MIGRATIONS

All prawns undertake a migration from their nursery area to their mating and spawning grounds in the sea in order to complete their life cycle. The only exception is the greentail prawn which can complete its life cycle in enclosed coastal lagoons, but even this species will migrate to sea if this is possible.

The seaward migrations of the eastern king and school prawns show a pronounced lunar periodicity (Racek, 1959). School prawns begin their outward migration on the third night after full moon and king prawns begin their move one or two nights later. The migration of school prawns reaches its peak on the 12th night after full moon and that of king prawns peaks 16 nights after the full moon. The migration of school prawns is completed on the 19th day after full moon. The king prawn migration is completed on the 21st day after full moon.

After their migration school prawns remain in depths of less than 64 m. The king prawn moves to water 90-146 m deep where it mates and spawns. These migrations take place during the summer months. Greentail and banana prawns also migrate from their nursery grounds during summer.

On the east coast king prawns from New South Wales migrate northwards as they grow older. Prawns tagged at Newcastle have been recovered off Moreton Island about one year after they have been tagged.

School prawns do not appear to participate in extensive migrations. It is possible that each river supports a discrete population.

Marking experiments carried out by Potter (1974) indicate that eastern king prawns leaving Moreton Bay by Amity Passage, Jumpinpin and Southport Bar contribute to the fishery in deep water off Moreton Bay. Prawns which leave the bay through the northern entrance continue to move north and contribute to the fishery off Mooloolabah.

Recruitment of western king prawns and brown tiger prawns to the Shark Bay fishery takes place in waves which are probably related to a lunar periodicity in spawning and migration from the nursery areas (Slack-Smith, 1968).

IRREGULAR MOVEMENTS

Not all movements of prawns are clearly distinguishable as migration and there are other irregular movements of prawn stocks in inside and ocean waters. Not all commercial species are affected by such irregular movements and 'consistent' and 'inconsistent' forms may be distinguished.

Consistent prawns prefer a certain habitat in a well-defined area, which may be, however, very extensive and may cover a wide range of depths. These species do not form pronounced age-groups, except during mating and spawning, and stocks are to be found, year by year, in only slightly varying abundances on the same grounds. The eastern and western king prawn, the common tiger prawn and endeavour prawn belong to this group.

Inconsistent prawn species are always on the move and show a preference for turbid waters and soft muddy grounds. They form pronounced age-groups and dense schools and may occur in enormous quantities on inner littoral grounds. Their optimal habitats are defined by a limited range of depths and they usually do not occur beyond the 64 m line. They are essentially associated with rivers and their abundance may be linked with the occurrence of river floods, as well as with certain conditions of weather and sea. Owing to their extensive schooling habits these species are often caught in great quantities. The school prawn and banana prawn are typical inconsistent prawn species.

The migratory movements are caused by many factors. River floods, drought conditions, salinity, sudden changes of currents, strong wind and other surface conditions naturally result in major environmental changes particularly in shallow waters. The immediate reaction of prawn stocks to sudden changes in environment is always pronounced, although the resulting behaviour varies with different species. For example, strong to gale force winds have been found to cause a type of irregular movement. Consistent prawns react to wind by travelling against the direction of the wind, inconsistent prawns travel with it.

RHYTHMS IN ACTIVITY

Penaeid prawns display many types of rhythmic activity.

Diurnal rhythms in availability to a fishery are well known. King, tiger and endeavour prawns are generally caught at night whereas banana and school prawns form the basis of daylight fisheries.

Diurnal rhythms in activity have been reported for many penaeid prawns.

Racek (1959) has reported lunar rhythms in moulting, mating and migrations from nursery areas. Both White (1974) and Racek (1959) have reported lunar rhythms in abundance. It seems likely that these rhythms are a direct result of lunar activity although it has been suggested that lunar rhythms in penaeids could be a response to rhythm induced in part of the prawns environment.

White (1974) has found an annual cycle in tiger prawn availability in Exmouth Gulf. The catch per unit of effort in the fishery varies with temperature. It is at a maximum at the beginning of the fishery season (March) when water temperature is high, falls to a minimum in July or August and rises slightly as water temperature rise in later winter and spring.

Populations

There is little data on the structure and dynamics of Australian prawn populations. However, both State and Australian fisheries agencies are developing models of prawn populations in the waters near New South Wales, Queensland, Western Australia, South Australia and the Northern Territory.

Because prawns have complex life cycles it is difficult to predict the size of populations from year to year. There are many factors which affect the success of spawning, the recruitment of larvae to nursery areas and the recruitment of juveniles to populations of adults. This complex of influences means that the numbers of juveniles recruited to an adult population does not necessarily bear any relationship to the size of population which originally spawned these young prawns.

Furthermore, because few prawns live more than one year there is no reserve of older animals to maintain the population at relatively constant level. So because of their biological peculiarities the numbers of prawns in a population fluctuate widely, and to a large extent, unpredictably from year to year. However it appears likely that a knowledge of the numbers of juveniles leaving a nursery area will provide a short-term prediction of the likely size of an adult population.

It does seem clear from such studies as have been carried out that many prawns die without either spawning or being caught by fishermen.

Table 4. Australian prawn production

Quantity (lb × 10^3) and value (\$ × 10^3)

State or Territory	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72
New South Wales	6 623	6 107	4 501	4 016	3 780	5 343	3 602	4 202	4 691	5 562
Victoria	4	25	8	11	10	5	4	2	1	31
Queensland	4 971	5 118	5 737	6 034	5 934	10 572	10 032	8 217	18 740	18 212
South Australia						295	1 579	2 872	2 675	3 360
Western Australia	1 017	2 118	1 829	2 485	3 898	3 862	3 823	5 492	6 179	5 553
Northern Territory	1	1		1	1	23	2 375	8 682	9 905	5 797
Australia	**12 616**	**13 369**	**12 075**	**12 547**	**13 624**	**20 101**	**21 414**	**29 467**	**42 190**	**38 514**
Total Value Australia	n.a.	n.a.	4 797	5 018	6 179	8 062	9 443	13 960	18 029	19 374

THE FISHERY

This section deals with the Australian prawning industry as it is carried on at the present time. The Australian prawning industry has become steadily more important during the last ten years. Both the quantity of prawns caught and their value has increased greatly. This is clearly shown in Table 4. The industry as a whole is considered to be composed of a number of 'unit fisheries' which employ similar gear and methods. This approach has been taken because during its life a prawn passes through many different habitats. The gear used to catch prawns varies with the habitat in which the gear operates rather than the species of prawns it captures. There are five unit fisheries for prawns distinguishable in the Australian fishing industry.

1. East Coast Trawl
2. Northern Trawl
3. Western Trawl
4. Southern Trawl
5. East Coast estuarine

A brief description of each of these fisheries follows.

EAST COAST TRAWL

Species fished and fishing ground

Eastern king prawn

Stockton Bight, New South Wales, to Frazer Island, Queensland.

Tiger prawn

Central New South Wales to Bowen, Queensland.

Banana prawn

Hervey Bay, Queensland, to Bowen, Queensland.

Endeavour prawn

Northern New South Wales to Bowen, Queensland.

School prawn

Lakes Entrance, Victoria, to Noosa Heads, Queensland.

Greentail prawn

Batemans Bay, New South Wales, to Moreton Bay, Queensland.

Fishing seasons

Eastern king prawn

Pre-spawning adults: February to May on the southern part of their range. February to July on the north coast on New South Wales and in Southern Queensland.

Mature adults: May to September.

Tiger prawn

South of Bowen, Queensland, November to April.

Banana prawn

March to July occasionally to September.

Endeavour prawn

As for tigers.

School prawn

December to July.

Greentail prawn

Central and southern New South Wales, November to April. Northern New South Wales and Southern Queensland, November to June.

Fishing units

BOATS

Boats range from about 8 m (25 ft) to 21 m (70 ft) long. The wheelhouse is generally forward. The winch, which is driven hydraulically or mechanically, is immediately aft of the wheelhouse. Trawl wire is lead from the winch to an overhead A-frame in the case of boats which tow one net (single-rig) or to a goalpost rig in the case of boats which tow two nets (double-rig). Double-rigged boats tow their nets from booms rigged outboard of the goalpost. Very few boats are rigged in the American fashion with their booms pivoting on the mast.

There is a sorting tray aft of the trawling gantry. This is generally the lid of an insulated box mounted on deck in which the catch is stored either in ice brine or refrigerated brine. Larger boats often have refrigerated storage below deck, especially in Queensland where boats may stay out of port for more than 24 hours. Most boats are equipped with two-way radios and echo-sounders. Many boats have automatic pilots and some boats carry radar.

Gear

Trawls are made of synthetic twine. There are many designs of trawl but generally flat trawls are used for king and tiger prawns. Trawls with a high floating headline are used for prawns such as banana which form dense schools. When a shot is finished the otter boards are winched to the gallows head or boom. This may take some time in the deep water king prawn fishery where depths of 180-220 m are trawled. The codend is brought aboard by means of a lazy line and emptied out on the sorting tray. The gear is then reshot and the catch is sorted. Trash is discarded and the prawns are sorted into baskets, washed and stored in ice brine or RSW.

Trawls vary considerably in distance and duration. When large dense schools of banana or school prawns are being fished the shot only lasts the length of time it takes for the net to pass through the school. When king and tiger prawns are being fished shots are from 1 to 2 hours in duration. In the deep-water king prawn fishery shots last for 3 to 4 hours.

Because fishermen are willing to travel considerable distances to exploit promising prawn concentrations the fishing effort on various grounds of the fishery fluctuates widely. There are about 230 trawlers in New South Wales and about 500 in Queensland.

Fishing operations

The fishing for king, tiger and endeavour prawns is carried out at night. South of Yeppoon, Queensland, fishing trips are from one to six nights long. Shallow water (less than 90 m) is generally worked on a basis of nightly trips. Trips to grounds in deeper water generally last for three to six nights. North of Yeppoon, in the more remote fisheries, boats may be away from port for more than a fortnight.

The school and banana prawns fisheries are daylight operations. Greentail prawns are also caught during the day on occasions. Because the catch rates in these fisheries are high they are generally undertaken on a day-trip basis, but if catch rates fall trips of a week or more may be undertaken, especially in north Queensland.

Prawn trawlers operate from most ports between Terrigal and Bowen. A few small trawlers operate from Sydney and ports on the south coast of New South Wales.

There are no published catch and effort data on the east coast trawl fishery. But extensive log book programs are being carried out at present by CSIRO Division of Fisheries and Oceanography and the Queensland Department of Primary Industries and should rectify this gap in the knowledge of the fishery.

Catch

About 2.7 million kg (6 million lb) of prawns per year are caught off eastern Australia but it is difficult to obtain statistics on the size and composition of catches in this fishery. New South Wales does not record its prawn catch by species and some of the species caught in Queensland are also caught in large quantities in the Gulf of Carpentaria and form part of the catch of the Northern prawn fishery. Furthermore, records of catches in both States do not distinguish between prawns caught in the estuarine fisheries and the offshore trawl fisheries.

Economics

The economics of this fishery have not yet been studied.

Legislation

In Queensland otter trawls used in ocean waters must have a minimum mesh size of 38 mm and maximum headrope length of 36.6 m. If two nets are used their total headrope length must not exceed 36.6 m.

All boats which fish within State waters (within 4.8 km) must hold a State licence. All Australian boats which fish within proclaimed waters (approximately 320 km) must have an Australian Government licence. Australia has a declared fishing zone 19 km wide in which fishing by other countries is forbidden. All fish landed in Queensland for resale within the State must be sold through the Queensland Fish Board.

In New South Wales otter trawls for prawns must have a minimum mesh size of 38 mm. Some specific commercial fish taken in prawn trawls south of South West Rocks may not be retained by prawn fishermen but they may retain legal sized speciments of these fish if they are caught north of South West Rocks. This is to protect the trawl fishery for fish off the south coast of New South Wales.

Boats must hold a N.S.W. State licence to catch fish in New South Wales waters and to land fish in New South Wales. Fish for direct human consumption must be sold through the N.S.W. Fish Marketing Authority or through recognised co-operative societies.

Development

Present prawn fisheries south of Yeppoon appear to be exploited fairly fully. However recent surveys on the continental slope off New South Wales by the New South Wales Fisheries Department indicate that a sizeable resource of penaeid and carid prawns is present between 275 and 900 m.

Grounds on the continental shelf between Yeppoon and Bowen have still to be fully explored.

NORTHERN TRAWL

Species fished and fishing grounds

Western king prawn

From Bowen to Torres Strait, around the coast to Bathurst Island.

Banana prawn

From Bowen to Trinity Bay, Weipa to Limmen Bight, north of the Coburg Peninsula and Bathurst and Melville Islands.

Tiger prawn

From Bowen to Bathurst Island.

Endeavour prawn

From Bowen to Torres Strait, Weipa around the coast to Bathurst Island.

Fishing seasons

Banana prawn

The main season lasts from late March to early June, but significant catches are made until September and October.

Other species

From May to November or early December.

Fishing units

Boats range from about 9 m (30 feet) to 40 m (130 feet) in length, but most are between 13.5 m (45 feet) and 26 m (85 feet) long. Table 5 gives the percentage size distribution of boats which fished in the Gulf of Carpentaria for more than five months in 1969–70.

Table 5. Length distribution of vessels in the northern prawn fishery

Length	*%age in population*
45′ and under	13
46′ – 55′	46
56′ – 65′	30
Over 65′	11

Because of sea conditions, the nature of the banana prawn fishery and the geographic extent of both this fishery and the tiger prawn fishery, boats designed for use in the northern prawn fishery tend to be larger than those used for other fisheries. This can be inferred from Table 6.

Most boats engaged in the northern prawn fishery are double-rigged. Booms are generally mounted on a goal-post gantry and are carried outboard in the operating position with paravane type stabilisers suspended in springs, while the boat is steaming or trawling. The winch is generally mounted beneath the goal-post. The drum axes may be athwartships or fore-and-aft. A few large boats have a separate winch for each boom. Most company owned boats carry Stroudsberg type, three-drum winches with winch axes fore-and-aft.

Some boats carry try nets which they use for monitoring catch rates while fishing for tiger prawns.

There are many designs of nets in use, but generally nets with a high mouth opening are used for banana prawns and flat nets are used for king and tiger prawns.

Many boats enter the northern prawn fishery solely to take part in the banana prawn season. Hence, the number of boats engaged in the fishery varies from month to month. Table 7 shows the number of boats engaged in the fishery during each month since January 1970.

Because techniques used for catching banana prawns differ from those used for catching tiger prawns, the operations of each fishery will be described separately.

Banana prawns form schools and are generally caught during the day. When the boats arrive at the fishing grounds, an echo-sounder search for prawn schools is begun.

Table 6. Age of Australian Vessels in the northern prawn fishery as % of age distribution in boat length categories

Hull age (years)	*Length*				
	45′ and under	*46′–55′*	*55′–65′*	*over 65′*	*All vessels*
less than 3	—	11%	42%	29%	17%
3 to 5	—	19%	25%	—	14%
5 to 10	67%	59%	33%	14%	50%
10 to 15	8%	—	—	—	2%
15 to 20	8%	4%	—	29%	7%
20 and over	17%	7%	—	28%	10%

Table 7. Number of boats operating in the northern prawn fishery by month 1970–72

Month	*Australian boats*			*Foreign boats*			*All boats*		
	1970	*1971*	*1972*	*1970*	*1971*	*1972*	*1970*	*1971*	*1972*
January	18	21	30	14	14	10	32	35	40
February	34	29	34	17	12	5	51	41	39
March	86	66	51	16	15	9	102	81	60
April	131	141	168	11	22	13	142	163	181
May	137	181	185	18	21	9	155	202	194
June	135	166	170	21	17	6	156	183	176
July	139	182	185	22	15	12	161	197	197
August	143	164	183	22	15	12	175	179	195
September	127	134	154	22	15	11	149	149	165
October	105	100	130	18	11	11	123	111	141
November	69	66	81	22	13	9	91	79	90
December	36	58	41	21	13	9	57	71	50
Total	**228**	**270**	**306**	**24**	**22**	**15**	**252**	**292**	**331**

On some grounds where the water is shallow, this may be aided by an aircraft search for 'mud boils'. These muddy patches at the surface of the sea often mark the position of prawn schools. When a school is located, the position is marked with a dahn buoy and the net is shot away. The net is dragged through the school until it is judged that enough prawns have been caught. This may only take one or two minutes if the school is very dense. The net is then hauled to the surface. The codend is brought aboard and before it is opened the quantity of trash in the catch is estimated. If this is not too great, the catch is dumped directly in the hold or ice box which is filled with refrigerated brine and ice. If there is too much trash, the catch must be sorted and the codend is opened onto the sorting table.

Boats which do not process their catch at sea are at an advantage in this fishery, as they can fill their storage space with as many banana prawns as they can carry and unload them to a shore base or factory ship. Boats which process their catch generally have their catch rate limited by the rate at which they can process prawns. These boats generally store their catch in dry refrigeration, and to obtain an acceptable product must quick-freeze their catch before storing it.

Tiger, king and endeavour prawns are mostly caught at night. They do not form schools so the high catch rates which are a feature of the banana prawn fishery are not encountered. Because catch rates are relatively low, shots are much longer. The average trawl takes from 1½ to 2 hours to complete, but shots may be from one to four hours long depending on the amount of trash mixed with prawns. Other conditions may also limit the length of the shot.

In this fishery, a try net is often used to help find the best concentration of prawns. The try net is shot about once every 15 minutes and the boat alters course depending on the catch rates of prawns and trash.

The lower catch rates (22.5 to 45 kg/hr) in this fishery mean that boats which process

Table 8. Annual catches of boats engaged in the northern prawn fishery

Catch range	*Percentage of total boats*			*Percentage of total catch*		
× 10^3 *pounds*	*1970*	*1971*	*1972*	*1970*	*1971*	*1972*
0-20	48.4	49.0	50.8	6.0	5.3	5.5
20-40	10.7	9.9	11.5	5.4	4.0	6.8
40-60	13.1	6.5	4.7	11.1	4.6	5.0
60-80	9.0	6.2	6.9	10.8	5.8	9.2
80-100	3.6	2.4	6.6	5.4	3.1	11.6
100-120	2.0	4.1	5.0	3.8	6.1	9.8
120-140	1.2	3.8	3.4	2.8	6.8	9.4
140-160	0.8	2.1	2.8	2.0	4.3	8.1
160-180	—	2.1	2.5	—	4.9	7.3
180-200	1.6	3.0	—	5.4	7.9	—
200-220	—	1.0	—	—	3.2	10.1
220-240	0.8	2.7	0.9	3.3	8.6	4.1
240-260	2.0	0.7	1.2	8.6	2.4	6.0
260-280	2.4	0.7	0.6	11.1	2.5	3.2
280-300	1.2	1.4	0.3	6.0	5.5	1.8
over 300	3.2	4.4	0.3	18.3	25.0	2.1

Table 9. Vessel operating time in the northern prawn fishery

Number of months operating	*Number of Australian boats*			*Number of Foreign boats*			*Total number of boats*		
	1970	*1971*	*1972*	*1970*	*1971*	*1972*	*1970*	*1971*	*1972*
1	228	270	304	24	22	15	252	292	321
2	203	231	237	4	22	13	227	251	252
3	181	205	209	22	22	13	203	227	224
4	154	181	179	22	22	13	176	203	194
5	126	143	151	22	18	13	148	161	166
6	105	105	122	22	16	11	127	121	135
7	77	74	91	22	15	1	99	89	104
8	51	46	53	21	15	9	72	61	64
9	30	28	32	17	12	9	47	38	43
10	13	18	11	15	7	6	28	25	18
11	2	6	4	8	5	3	10	11	7
12	1	44	—	4	5	—	5	9	—

prawns at sea are not at a disadvantage. In fact, the dry storage of prawns in plastic bags may give a better product than brine storage.

Larger trawlers (21-26 m) may stay at sea for four to six weeks. Small trawlers, if they are supported by a carrier boat or mothership, may also be absent from port for similar periods, but if they are not supplied with fuel and stores at sea, their endurance is generally no more than a week.

Echo-sounders are used for the initial location of suitable grounds and for avoiding obstacles but, as was stated previously, try nets are used to find and stay in areas of where prawns are concentrated.

There are no detailed catch and effort data available for the northern prawn fishery, but some conclusions can be drawn from general data available from monthly processors returns. Table 8 shows that there is wide variation in the efficiency of boats with only 15% of boats delivering over half the total receivals, while almost half the boats delivered only 5% of the total catch.

Many boats enter the northern fishery only to take advantage of the banana prawn season. Table 9 shows that only about half the Australian boats engaged in the fishery stay for more than five months, whereas over half the foreign boats, which are based in the north, remain in this fishery for eight to nine months.

Table 10 shows that foreign boats catch prawns at a higher rate and more consistently than Australian boats. There are a number of reasons for this. Firstly, foreign boats are larger and hence have better sea keeping

Table 10. Northern prawn fishery monthly average catch 1970–71 (lb × 10³)

Month	*Australian boats*			*Foreign boats*			*All boats*		
	1970	*1971*	*1972*	*1970*	*1971*	*1972*	*1970*	*1971*	*1972*
January	3 726	6 993	4 436	11 559	13 227	14 888	7 153	9 487	7 015
February	5 070	4 110	3 498	10 539	11 100	20 077	6 893	6 156	5 256
March	15 298	13 616	3 400	3 653	21 815	18 507	13 471	15 134	5 800
April	10 930	26 566	29 352	25 960	20 616	25 877	12 094	25 763	28 702
May	6 929	18 226	20 756	30 956	19 237	23 802	9 724	18 331	20 907
June	4 306	24 660	6 592	36 884	31 754	22 210	8 691	25 146	7 392
July	5 584	14 288	4 176	35 241	25 966	23 440	9 639	15 045	5 355
August	6 004	8 859	3 592	33 841	33 925	34 059	9 508	10 959	7 256
September	6 038	6 339	4 314	39 748	39 258	13 497	11 015	6 218	4 988
October	5 507	5 039	464	55 833	26 641	32 938	12 872	7 180	7 121
November	6 268	41 971	4 201	25 323	21 642	19 384	10 875	7 670	5 644
December	5 828	3 478	4 049	14 428	18 324	14 343	8 364	6 197	5 901
Average Annual Catch	35 805	66 200	43 357	261 567	187 960	177 429	57 305	75 374	51 922

Table 11. Northern prawn fishery total annual receivals by processing establishments (lb × 10³)

Month	*1968*	*1969*	*1970*	*1971*	*1972*
January	2 046	132	229	332	281
February		10	358	252	205
March		674	1 372	1 226	348
April		1 228	1 705	4 199	5 376
May		741	1 503	3 703	4 056
June		874	1 370	4 602	1 301
July	1 304	1 264	1 593	2 964	1 055
August	749	1 183	1 699	1 962	1 415
September	404	1 672	1 797	927	823
October	202	1 541	1 627	797	1 004
November	172	957	1 099	606	508
December	125	663	531	440	295
Total	**5 001**	**10 940**	**14 882**	**22 009**	**16 667**

qualities than most Australian boats. Secondly, foreign boats have larger crews and are able to fish 24 hours a day. Thirdly, foreign boats operate as a fleet and co-operate with each other during fishing and searching operations. Australian boats on the other hand operate individually and if they find a productive area, they tend to remain secretive about it until they have gained maximum benefit from it.

However, foreign crewed boats have now been phased out of the northern prawn fishery in accordance with Australian Government policy.

Catch

The northern prawn fishery is the most important prawn fishery in Australia.

Table 11 sets out the landings from the fishery since detailed landing figures were first collected in 1968.

Table 12 shows the composition of the northern Australian prawn catch since 1970. From this table, it appears the catch of banana prawns has fluctuated widely in total quantity but the relative importance of the banana prawn fishery has remained fairly constant. In contrast, both the total catch and relative importance of the tiger prawn fishery has increased steadily.

In 1972 the main banana season was considerably shorter than it had been previously. There are two reasons for this, firstly in 1971 and 1972 the main banana grounds in the Gulf of Carpentaria were closed to fishing until the end of March and in 1972 the grounds of West Irian were closed to Australian boats by the Indonesian govern-

Table 12. Species composition of the northern prawn catch 1970–1972. Composition is expressed as % composition of monthly or annual catch

Species	*Year*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*% of Annual Catch*	*Total Catch (lb × 10³)*
Banana															
	1970	40	60	93	88	87	73	60	52	56	63	48	15	67	9 945
	1971	2.4	2.7	73.7	92.5	88.9	85.7	86.4	56.9	19.2	32.6	16.3	4.6	74.1	16 190
	1972	5.3	11.7	34.3	96.7	94.1	61.0	19.2	22.5	21.5	13.0	24.8	10.2	65.7	10 952
King															
	1970	—	—	—	1	—	1	2	—	—	1	1	2	1	148
	1971	0.6	2.4	0.2					0.2	0.8	0.3	0.2	1.1	0.1	28
	1972	1.8	—	2.9	0.1	—	—	0.7	1.4	—	0.1	0.4	—	0.3	52
Tiger															
	1970	31	13	4	8	10	17	27	25	28	24	22	58	19	2 417
	1971	82.2	78.7	18.0	4.5	7.0	5.8	10.6	8.1	33.1	45.8	57.9	63.3	14.5	3 163
	1972	69.4	76.6	56.2	2.2	4.7	32.7	57.4	51.2	52.4	60.5	47.3	65.4	24.5	4 085
Endeavour															
	1970	24	11	1	2	3	5	7	10	11	6	13	19	7	1 039
	1971	13	13.3	2.4	1.1	1.8	1.1	1.9	4.3	13.4	10.3	23.3	29.2	4	872
	1972	21.4	19.7	4.3	0.9	1.1	5.7	1.1	5.7	16.0	18.2	19.8	21.6	7.5	1 241
Mixed															
	1970	5	15	2	1	—	4	4	13	5	6	16	6	6	891
	1971	1.2	2.9	5.7	1.9	2.3	7.4	1.1	30.5	33.5	11.0	2.3	1.8	7.3	1 589
	1972	2.1	1.0	2.3	0.1	0.1	0.6	6.7	6.6	6.3	4.8	5.1	4.7	2.0	337

ment. Historically, boats moved to this fishery after the end of the season in the Gulf of Carpentaria. The lack of access to this fishery presumably contributed to the increased tiger prawn catch in the latter half of 1972. There may, of course, be biological reasons for changes in total catch and catch composition.

Economics

The Department of Primary Industry has investigated the economics of prawn catching in the Gulf of Carpentaria. The results of this study indicate that an annual catch of about 9 million kg is required for the present fleet of 200 to 300 boats to operate economically. A catch of less thn 6.8 million kg means that many fishermen would not make a profit.

The report indicates that because of the seasonal occurrence of the banana prawn fishery and the fluctuations in abundance of that species, it is desirable that the fishing fleet should be sufficiently mobile to allow maximum exploitation of banana prawn stocks. But the fleet should also be able to move freely within the Gulf or out of the Gulf if the season is poor. This would allow a total catch compatible with the net economic yield of the fishery and encourage efficient distribution of resources within the prawning industry in northern Australia.

The survey indicated that owner-skippers were more efficient than employed skippers. In the three years 1968–69 to 1970–71 owner-skippers returned an average of 12.8% on capital, whereas employed skippers returned an average of 6.9%.

Legislation

There are a few regulations governing the activities of Australian boats in the northern prawn fishery. Boats must hold a Queensland or Northern Territory licence to fish within the waters of the State or the Territory and must hold an Australian Government licence to operate within the exclusive fishing zone and within proclaimed waters.

In Queensland, nets must have a minimum mesh size of 38mm and a maximum headrope length of 36.6 m.

On the eastern side of the Gulf of Carpentaria there is a closed season prior to the opening of the banana prawn season. The date of opening and the extent of the closure is determined by consultation between industry and government. The season generally opens in late March or early April.

There are three Japanese-Australian joint venture companies operating in the northern prawn fishery. These companies are bound by agreements with the State and Australian Governments to phase out participation by Japanese boats and crews before July 1973.

In the Northern Territory, there are no limits on the size of trawls or the meshes of trawls. Limits on the size of meshes of nets which can be used in rivers in the Northern Territory effectively ban trawls from rivers there.

Trawling for prawns is forbidden in Queensland rivers which flow into the Gulf of Carpentaria.

Management

The major management measures in use in the northern prawn fishery is the closure of areas in the eastern Gulf of Carpentaria prior to the banana prawn season. The extent of the closures and the date of the opening of the season is determined by consultation between industry and the State and Australian Governments.

These closures are applied for socio-economic reasons. The northern prawn fishery is based on the export of prawns. To be acceptable for export, these prawns must be about 20-25 tails to the pound. Most prawns on the fishing grounds are at this size in the middle of March. This is when the close season generally opens.

In Queensland and Northern Territory, juvenile prawn populations are protected by various restrictions on fishing in nursery areas.

Development

The northern prawn fishery will further develop by exploration of the coast of northern Australia.

The coast of the Northern Territory between Elcho Island and Joseph Bonaparte Gulf has not yet been fully explored and it is probable that other grounds will be discovered on the east coast of Queensland and in the Gulf of Carpentaria.

WEST COAST TRAWL

Species fished and fishing ground

Western king prawn

Cockburn Sound, Shark Bay, Exmouth Gulf.

Tiger prawn

Shark Bay, Exmouth Gulf, Nickol Bay, Admiralty Gulf, Vansittart Bay, Napier Broome Bay.

Banana prawn

Nickol Bay, Admiralty Gulf, Vansittart Bay, Napier, Broome Bay.

Fishing seasons

Shark Bay—March to September.
Exmouth Gulf—March to September.
Nickol Bay—March to September.
Montague Sound, Admiralty Gulf, Vansittart Bay—not defined.

Fishing unit

At the beginning of the fishery, boats were often converted to prawn trawling from cray-fishing, but now boats are designed as prawn trawlers. They are generally double-rigged and follow the pattern explained in discussion of the trawl fisheries of the east coast and northern Australia.

The Western Australian Government had adopted a policy of limited entry to prawn fisheries in that State. Licences to fish prawns are given for a limited period and area, and the number of licences issued depends on the condition of prawn stocks. In general, groups of licences are allocated to boats supplying particular processing factories which serve the fishery and the remaining licences are allocated to independent operators. Boats which hold licences for a restricted prawning area are not allowed to fish in any other prawning area and must fish for a minimum period in the area for which they hold a licence. There are 32 licences issued for Shark Bay, 23 for Exmouth Gulf and 13 for Nickol Bay.

In 1971 after extensive surveys by the Western Australian Department of Fisheries and Fauna, a private company, Seafarer International Pty Ltd, began an exploratory fishing operation in the Western Australian waters of Montague Sound, Admiralty Gulf and Vansittart Bay. This has been successful and the Western Australian Government has announced that it will issue 30 licences to prawn in this area.

A large portion of the prawn grounds in Cockburn Sound is in use as an experimental area.

To encourage exploration and development of new prawn fishing grounds, there are no licence limitations on grounds outside the recognised trawling areas.

Fishing operations

Because of the confined nature of Western Australia prawning areas, boats at present are not required to make long trips. Boats are seldom absent from port for more than three days. The Shark Bay and Exmouth Gulf fisheries are night fisheries for tiger and king prawns. In Exmouth Gulf, banana prawns were caught during the day during 1964–66. Nickol Bay is a daylight fishery for banana prawns and the fishery in the Kimberleys will probably be similar.

The main ports for Shark Bay are Carnarvon and Denham, for Exmouth Gulf the port is Learmonth and Point Samson is the port for Nickol Bay.

Catch and effort data for Exmouth Gulf

Table 13. Western Australian prawn catch—quantity (lb × 10³) and value ($ × 10³)

Species	*Year*			
	1968–69	*1969–70*	*1970–71*	*1971–72*
Brown tiger	1 625	2 942	2 570	1 851
Banana	187	260	321	183
Endeavour	81	258	597	327
Western king	1 862	1 875	2 637	3 135
Greentail	69	157	53	57
Total catch	3 823	5 492	2 986	2 915
Value	1 802	2 697	2 986	2 915

indicate that the fishery is close to its maximum yield. In Shark Bay there are indications that the total catch could be increased by an increase in effort. Catches in Nickol Bay fluctuate widely.

In 1972, Hancock published graphs of catch and effort in Shark Bay. Tiger prawns demonstrate the typical gradual decline expected of a unit stock with increasing exploitation. King prawns show a steep decline from 1964 to 1966 continuing to 1967 and then increasing to 1970–71. This is possibly because of poor recruitment during the period 1964–67 followed by a recovery in 1968. It will be necessary to arrest the decline in catch per unit effort of tiger prawns before individual boats' catches become uneconomic.

Recent catches in the Western Australian prawn fishery are set out in Table 13.

Economics

There have been no recent studies of the economics of the Western Australian prawn fisheries. In 1966–68 the Department of Primary Industry surveyed the economics of prawn trawling in the Exmouth Gulf and Shark Bay fisheries. This survey came to the conclusion that there was a good return on capital invested by a boat owner in both fisheries.

In Shark Bay the annual return from prawn fishing was about 19% and in Exmouth Gulf the return on capital was about 30%. Some boats in Shark Bay also hold rock lobster licences and their annual returns on capital were about 30%.

Legislation

Apart from licence limitations referred to previously, there are few regulations governing prawn trawling in Western Australia. In Shark Bay and Exmouth Gulf there are a number of juvenile nursery areas closed to trawling. Nickol Bay is closed to trawling from January to mid-March.

Management

Recognised fishing areas in Western Australia are carefully managed. The number of boats which are involved in any one fishery is carefully limited. Catch and effort are monitored by means of a comprehensive log book program which enables careful consideration to be given to increased fishing power of boats and fluctuations in the availability of the resource.

Development

The Western Australian Government has surveyed most of the area between Cape Londonderry and Exmouth Gulf to a depth of about 55 m. Further development could take place in deeper water on the continental shelf and east of Cape Londonderry in Joseph Bonaparte Gulf.

SOUTHERN TRAWL

Species fished and fishing grounds

Western king prawn

St Vincent Gulf, Spencer Gulf, Great Australian Bight off Coffin Bay and Venus Bay.

Fishing unit

Trawlers range in length from 12 to 26 m. Many of the larger vessels are converted tuna vessels and operated in both the tuna and prawn fisheries. The number of boats allowed to use double gear is limited. At present, there are 45 boats engaged in the fishery.

Fishing operations

The operation of boats and gear is similar to that already described for other fisheries. Because of the limited geographic extent of the fisheries and the limited carrying capacity of the smaller boats fishing voyages are seldom more than one or two nights long.

Catch

Table 14 sets out the catch in the South Australian fishery since it began.

Table 14. South Australian prawn catch quantity (lb × 10^3) and value ($ × 10^3)

Species	*1967–68*	*1968–69*	*1969–70*	*1970–71*	*1971–72*
Western king prawn	295	1 579	2 872	2 675	3 360
Value	148	789	1 637	1 551	2 283

Legislation and management

The South Australian fishery is a limited entry fishery and boats must be licensed to trawl for prawns. Areas at the northern end of Spencer Gulf are closed to trawling. The minimum mesh size of a prawn trawl is 50 mm (1.9 in).

Development

The South Australian prawn fishery exploits a limited stock of prawns and the best prospects for further increasing the production of prawns in the State are provided by prawn culture. A large culture operation with access to Japanese technology is in fact being established on the north-eastern shore of Spencer Gulf. The South Australian Government plans to license more trawlers in the near future.

EAST COAST INSHORE

Species fished and fishing grounds

Eastern king prawn

Estuaries, coastal lakes, and inshore waters between Lakes Entrance, Victoria and Moreton Bay, Queensland.

Greentail prawn

Estuaries, coastal lakes and inshore waters between Batemans Bay, New South Wales and Moreton Bay, Queensland.

Tiger prawn

Estuaries, coastal lakes and inshore waters between central New South Wales and Bowen, Queensland.

School prawn

Estuaries, coastal lakes and inshore waters between Eden, New South Wales and Noosa Lakes, Queensland.

Bay prawn

This is a mixture of small hardback, New Guinea, go home, and greentail prawns caught in southern Queensland.

Fishing seasons

This fishery is most active and attains its highest catches during the spring and summer between September and May.

Fishing unit

A wide variety of gear and boats are used in this fishery. Small trawlers are used in near coastal waters, lakes and rivers. In New South Wales there are generally otter trawlers but in southern Queensland, particularly in the Noosa Lakes, beam trawls are used.

Various kinds of set nets are used in rivers and lakes to capture juvenile prawns as they migrate seaward.

Hauling nets (seines), scissor nets and scoop nets are also used to take prawns but the latter gear is generally used by amateurs.

Fishing operations

Otter and beam trawls are set in the usual manner from small boats which are often open or half-decked.

Set nets are staked or anchored in channels or against the banks of rivers during favourable moon and tide periods and the pocket or bunt is regularly tended and emptied by means of a small boat. Seines or hauling nets are operated from the bank or a small boat in the conventional manner.

Catch

As statistics are not collected separately for this fishery catch figures are difficult to obtain. However, in New South Wales the estuarine fishery contributes about 0.9 million kg (2 million lbs) to that State's annual prawn catch. In Queensland the Moreton Bay fishery contributes about 1.36 million kg (3 million lbs) annually to the Queensland prawn catch.

Legislation

In New South Wales trawling is permitted in Jervis Bay, Botany Bay, Sydney Harbour, and the Hunter, Hawkesbury and Clarence Rivers. In other waters of that State various set nets and seines may be used. These nets have a minimum mesh size of 32 mm and vary in length from 5.5 to 137 m depending on the design and location of the net. Otter trawls may not have a headrope longer than 11 m and the mesh of the codend must be between 38 and 44 mm. The mesh of other portions of the net should be between 38 and 57 mm.

In estuarine waters otter trawls may not have more than 128 m of warp attached to them.

In Queensland, otter trawls used in Moreton Bay, Port Curtis, Keppel Bay, Edgecumbe Bay and Cleveland Bay have a maximum headrope length of 14.6 m and a minimum mesh of 38 mm.

In Queensland rivers a beam trawl with a beam no longer than 4.5 m and a minimum mesh size of 25 mm may be used. In Noosa Lakes a beam trawl with a beam 4.5 m long or an otter trawl with a headrope no longer than 7.3 m may be used. In the case of both areas the minimum mesh size is 29 mm.

Set nets of various sorts may be used in some Queensland rivers.

Management

There are various close areas in force in both Queensland and New South Wales estuaries and coastal lakes. The number of boats which can fish in Moreton Bay is limited. Trawling is permitted in the Hunter and Clarence Rivers only between 1 December and 31 May. Port Jackson and Botany Bay are closed during the winter and the Hawkesbury River and Jervis Bay have no closed season.

Development

It seems certain that culture operations will begin in the estuarine waters of eastern Australia in the next few years. The New South Wales Government has a laboratory at Port Stevens which is investigating prawn culture and there are a number of experimental culture establishments in the Moreton Bay area.

LITERATURE CITED

DAKIN, W. J. (1938). 'The habits and life history of a penaeid prawn (*Penaeus plebejus* Hess).' *Proc. zool. Soc. Lond.*, 108A, pp. 163-183.

DALL, W. (1957). 'A revision of the Australian species of Penaeinae (Crustacea : Decapoda : Penaeidae).' *Aust. J. mar. Freshwat. Res.*, 8, pp. 136-231.

—— (1958). 'Observations on the biology of the greentail prawn, *Metapenaeus mastersii* (Haswell) (Crustacea : Decapoda : Penaedae).' *Aust. J. mar. Freshwat. Res.*, 9(1) pp. 111-134.

—— (1964). Studies on the physiology of a shrimp, *Metapenaeus mastersii* (Haswell) (Crustacea : Decapoda : Penaeidae). I. Blood constituents.' *Aust. J. mar. Freshwat. Res.*, 15(2), pp. 145-161.

—— (1965a). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). II. Endocrines and control of moulting.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 1-12.

—— (1965b). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). III. Composition and structure of the integument.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 13-23.

—— (1965c). 'Studies on a physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). IV. Carbohydrate metabolism.' *Aust. J. mar. Freshwat. Res.*, 16(2), pp. 163-180.

—— (1965d). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). V. Calcium metabolism.' *Aust. J. mar. Freshwat. Res.*, 16(2), pp. 181-203.

—— (1968). 'Food and feeding of some Australian penaeid shrimps.' *FAO Fish. Rep.*, 57(2), pp. 251-258.

DEPARTMENT OF PRIMARY INDUSTRY (1970. 'An economic survey of the Shark Bay and Exmouth Gulf prawn fisheries 1966–67 and 1967–68.' Fisheries Report No. 6, Canberra, 46 pp.

DEPARTMENT OF PRIMARY INDUSTRY (1973). 'An economic investigation of the northern prawn fishery. Costs and earnings of trawlers.' Fisheries Report No. 8, Canberra, 62 pp.

HANCOCK, D. A. (1974). 'The basis for management of West Australian prawn fisheries.' Proceedings Australian National Prawn Seminar, 10.1–10.28.

—— (1972). 'Shark Bay prawn fishery—Consideration of a closed season proposal.' *F.I.N.S.*, 5(2), pp. 33-35, 43.

HINDLEY, J. P. R. (1974). 'Location of food by *Penaeus menguiensis.*' Proceedings National Prawn Seminar, 3.1–3.12.

KIRKEGAARD, I., TUMA, D. J., AND WALKER, R. H. (1970). 'Synopsis of biological data on the banana prawn, *Penaeus merguiensis* de Man, 1888.' *CSIRO Fish. Synopsis* 8.

MORRIS, MURIEL, C., AND BENNETT, ISOBEL (1951). 'The life history of a penaeid prawn (*Metapenaeus*), breeding in a coastal lake (Tuggerah, New South Wales).' *Proc. Linn. Soc. N.S.W.*, 76, pp. 164-82.

MUNRO, I. S. R. (1974). 'Biology of the banana prawn (*Penaeus merguiensis*) in the southeast corner of the Gulf of Carpentaria.' Proceedings National Prawn Seminar, 21.1–21.23.

POTTER, M. A. (1974). 'Movements of the eastern king prawn, *Penaeus plebejus*, in southern Queensland waters.' Proceedings National Prawn Seminar, 15.1–15.11.

RACEK, A. A. (1955). 'Littoral Penaeinae from New South Wales and adjacent Queensland waters.' *Aust. J. mar. Freshwat. Res.*, 6(2), pp. 209-241.

—— (1959). 'Prawn investigations in eastern Australia.' *Res. Bull. St. Fish. N.S.W.*, 6, pp. 1-57.

—— and DALL, W. (1965). 'Littoral Penaeinae (Crustacea : Decapoda) from northern Australia, New Guinea and adjacent waters.' *Verh. Akad. Wet. Amst.*, (b) 56(3), pp. 1-119.

RUELLO, N. V. (1974). 'Biological research and the management of prawn fisheries in New South Wales.' Proceedings National Prawn Seminar, 7.1–7.17.

SLACK SMITH, R. J. (1969). 'The prawn fishery of Shark Bay, Western Australia.' *FAO Fish. Rep.*, 57(3), pp. 717-734.

SOMERS. I. (1974). 'Growth of eastern king prawns (*Penaeus plebejus*).' Proceedings National Prawn Seminar, 17.1–17.12.

WHITE, T. (1974). 'Factors affecting the catchability of a penaeid shrimp, *Penaeus esculentus*.' Proceedings National Prawn Seminar, 6.1–6.37.

YOUNG, P. C. (1974). 'Preliminary observations and biology of juvenile king prawns (*P. plebejus*) in Moreton Bay, Queensland.' Proceedings National Prawn Seminar, 20.1–20.29.

To A. A. Racek
biologist and teacher *par excellence.*
In recognition of his outstanding contributions
to the Australian prawning industry
and to our knowledge of prawns.

Dr Racek at work in his field laboratory—the garage behind the Ballina Fisheries Inspector's residence (*c.* 1953).

Mrs Racek helping Tuggerah Lakes fishermen cook prawns (*c.* 1953). She was often her husband's only assistant on field work.

APPENDIX II

AN HISTORICAL REVIEW AND ANNOTATED BIBLIOGRAPHY OF PRAWNS AND THE PRAWNING INDUSTRY IN AUSTRALIA

BY N. V. RUELLO
New South Wales State Fisheries
211 Kent Street, Sydney, NSW 2000

ABSTRACT

This paper gives an account of the history and growth of the Australian prawning industry from its beginnings in Sydney in the early 1800s to its present position as one of the nation's most valuable, highly decentralised and fastest growing primary industries.

The east coast fisheries have a long history and have been documented more fully than the others and are therefore discussed at considerable length despite a recent decline in relative importance. Research on prawns and the prawning industry is traced from the Chevert *and the* Challenger *expeditions and the subsequent taxonomic studies of the late 1800s to Dannevig's (1904) pioneer investigation of an Australian prawn fishery (in Port Jackson, Sydney) and up to the current costly biological, economic and technological studies encompassing several States and species. Current prawn research programs of Australian universities and State and Australian Government departments are listed in an appendix.*

The second part of the paper is an annotated bibliography on Australian prawns and all aspects of the prawning industry.

PART 1.

HISTORICAL REVIEW OF THE PRAWNING INDUSTRY AND PRAWN RESEARCH IN AUSTRALIA

INTRODUCTION

Earlier writers have recorded the history and development of particular fisheries (Department of Fisheries and Fauna, W.A. 1967, Ruello 1969, Department of Fisheries, S.A. 1972, Walker MS), but this paper presents the first detailed discussion of the development of the country's major prawn fisheries and the only review of 'prawn research' in Australia.

Although the Australian prawning industry started about 150 years ago, it has only attained national importance and attracted general interest in the past decade following the development of several new fisheries and the expansion of the export trade. The omission of the prawning industry from the early editions of T. C. Roughley's 'best selling' book, *Fish and Fisheries of Australia*, and the brief mention of prawns and the prawning industry in earlier Australian books are examples of the early widespread ignorance of this valuable fishing industry.

The prawning industry grew rapidly in the 1950s following the development of offshore prawning in New South Wales and Queensland, and *Australian Fisheries Newsletter* devoted its February 1956 issue to articles on this important subject. Twelve years later, after the development of new fisheries in the Gulf of Carpentaria (Fig. 1), Western Australia and South Australia, the January issue was a special edition dealing with prawns and this new era in the prawning industry. Today, prawns are the most important sector in the Australian fishing industry in terms of total landings and the value of the prawn catch is exceeded only by the rock lobster industry.

In addition to its valuable commercial fisheries, Australia has several well-known amateur fisheries—in Tuggerah Lakes and

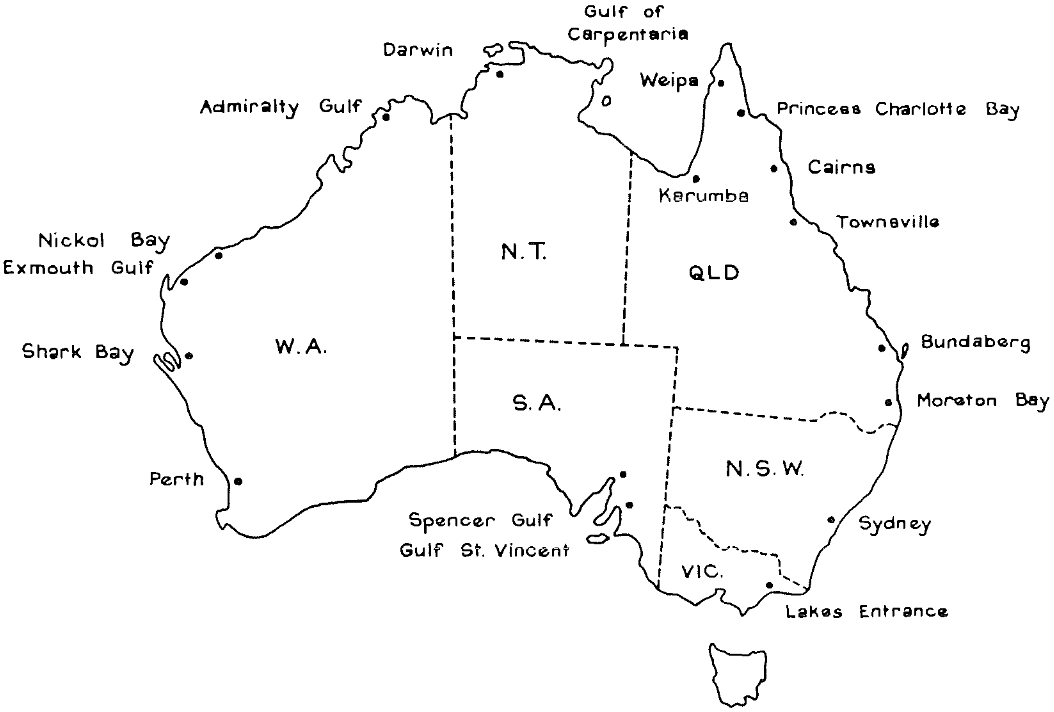


Fig. 1. Map of the principal prawn fishing areas in Australia.

Lake Illawarra, N.S.W. (Fig. 2), in Queensland's Noosa Lakes, in Mallacoota Inlet and the Gippsland Lakes, Victoria, and in Peel Inlet and the Swan River, W.A. Of these the Tuggerah Lakes fishery is probably the richest and several hundred 6 m seine nets and a thousand scoop nets are commonly in use each night during the Christmas season. The 1967 amateur catch in Tuggerah Lakes was estimated at approximately 450,000 kg and this probably exceeded the commercial catch.

Australia's prawn fisheries are currently confined to the estuarine environment and the continental shelf while the deep water and inland prawns remain virtually untouched, although they are many in numbers and species.

Procedures

A paper on the history of the Australian prawning industry (together with an annotated bibliography) was being planned early this year, when details of the National Prawn Seminar were announced. The paper was originally planned for completion in 1974, however it was felt that a provisional edition would be a useful background document for the forthcoming seminar. The preparation of this paper was therefore hastened and while the author accepts responsibility for its contents he would appreciate notification of any errors. This edition will be revised by the author and published as a Technical Report by N.S.W. State Fisheries.

For the purposes of this paper, the word *prawn* refers to the larger members of the Section Penaeidea and Caridea (Sub-Order Natantia) which have real or potential commercial value.

Part II. the bibliography section has been arranged so that it can be used independently of Part I of this paper.

The key words in the title (and the dominant theme of the paper) are *historical review*. For this reason, *people* and *events* are discussed in order of *time* and the contemporary situation is generally omitted from the following discussion. Fishing methods, gear, catch handling and processing, and fisheries management are discussed in depth only when it is necessary to demonstrate a point of historical interest; furthermore, detailed discussion of these subjects is unwarranted here because extensive accounts are readily available elsewhere (see Bibliography).

Much attention was given to historical

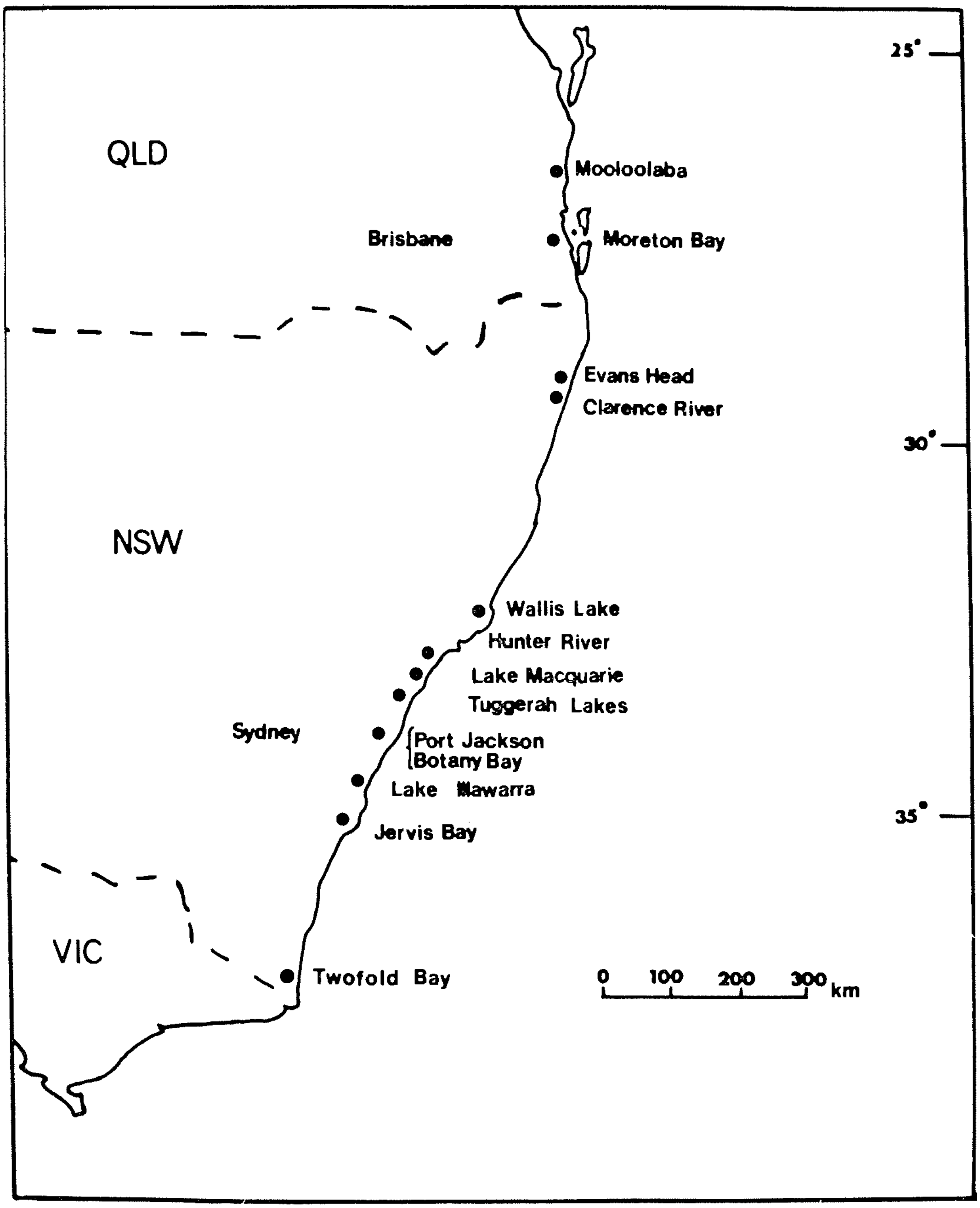


Fig. 2. Map of the principal prawn fishing areas in south-eastern Australia.

accuracy, and whenever possible original (primary) reference sources were consulted and secondary reference material was used only when necessary. This added effort and attention to seemingly minor details was rewarded (and in fact was necessary) because it brought to light many hitherto unknown or 'obscure' facts. Some of the information discovered contradicts material in more recent publications (including those of the present author) which presumably were less thoroughly researched than the present paper.

Prawns of commercial importance

Penaeus monodon
Panda, leader or giant tiger prawn
Penaeus esculentes
(brown) tiger prawn
Penaeus latisulcatus
western or blue-leg king prawn
Penaeus merguiensis
banana prawn
Penaeus plebejus
eastern king prawn
Metapenaeus ensis
offshore greasyback prawn
Metapenaeus insolitus
northern greentail prawn
Metapenaeus dalli
school prawn (Western Australia)
Metapenaeus bennettae
greasyback or greentail prawn
Metapenaeus endeavouri
Endeavour prawn
Metapenaeus eboracensis
York prawn
Metapenaeus macleayi
school prawn (Eastern Australia)
Parapenaeopsis sculptilis
rainbow prawn
Parapenaeus australiensis
Racek (or red) prawn
Trachypenaeus curvirostris
southern rough prawn
Trachypenaeus anchoralis
northern rough prawn

CHRONOLOGY

1800
(?) Prawn fishery starts in Sydney.
1820
1840 (?) Fishery starts in Brisbane River.
(?) Hunter River fishery starts.
1850
(?) Fishery starts in Port Curtis (Gladstone, Qld).
1860
1865 W. Hess describes *Penaeus plebejus* n. sp.
1879 First Australian publication on prawns—by W. A. Haswell.
1880 (?) Start of fishery in Fitzroy River (Qld).
1886 100 boats prawning in Port Jackson.
1889 Newcastle fishermen start prawn fishery in Clarence River.
1895 18 men engaged in prawn fishing in the Brisbane River.
1898 *Thetis* finds king and school prawns at sea.
1902 *Ostrea* finds prawns in Moreton Bay.
1903 H. C. Dannevig conducts first study of an Australian prawn fishery.
1904 *Rip* engaged in exploratory fishing in Western Australia.
1906 *Woy-Woy* finds *Hymenopenaeus sibogae* off Sydney.
1909
Endeavour finds prawns off South Australia and off eastern Australia.
1914
1926 Start of otter trawl fishery (in Port Jackson).
1932 Start of pocket net fisheries in N.S.W. lakes.
1938 Publication of first major study of prawn biology by W. J. Dakin.
1947 Prawns found in Stockton Bight—start of offshore fishery.
1950 N.S.W. vessels start a trawl fishery in Moreton Bay. N.S.W. offshore catch exceeds estuarine production. Experimental consignment of prawns to the U.S.A.
1952 *Lancelin* engaged in exploratory fishing in W.A.
1954 Exploratory fishing of Gulf of Carpentaria by *Nanango*. Start of banana prawn fishery at Bundaberg.
1955 Commencement of export trade.
1957 *Challenge* records large catches of prawns off Fraser Island.
Weerutta engaged in exploratory fishing in South Australia.
Abortive start to Shark Bay fishery.
1958 First attempt at prawn farming in Australia.
1959 Publication of Racek's study on Australian fisheries.
1960 Exploitation of Cape Moreton ground after *Challenge* survey.
Introduction of double-rig trawling.
1962 Shark Bay fishery successfully started.
1963 Commencement of Gulf of Carpentaria prawn survey.
1965 Beginning of Exmouth Gulf fishery (W.A.).
1966 Start of the Gulf of Carpentaria fishery.
1967 Fishery starts in Nickol Bay (W.A.).
Start of the Spencer Gulf fishery (S.A.).

1968	Commencement of prawning industry in the Northern Territory. Beginning of St Vincent Gulf (S.A.) fishery. *Van Gogh* visit to Gulf of Carpentaria.
1969	Fishery develops in Venus Bay (S.A.).
1971	N.S.W. State Fisheries Brackish Water Fish Culture Research Station completed. Deep water prawn survey by *Kapala.*
1973	Survey of deeper waters off Fraser Island by Qld Dept Primary Industries.

THE FISHERIES

New South Wales

Penaeid prawns were almost certainly caught by the early settlers (in the 1790s) fishing the shallow waters of the Lane Cove, the Parramatta River and the shores of Port Jackson (Sydney) with scoop or hauling nets, but a special fishery for prawns probably did not start until the population increased substantially in the first or second decade of the 19th century. Commercial fishing (for prawns and fish) developed slowly in the Colony but it gradually spread to Botany Bay, Narrabeen Lakes, Pittwater, Tuggerah Lakes, and the Hunter River as road and sea transportation improved. Dannevig (1904) noted that 'A climax was reached about 1886, when approximately 100 boats are said to have been at work, prawning in Port Jackson.'

McNeill (1958) has suggested that the prawn fishery was originally started by experienced Welsh, English and Scottish migrants around Botany Bay. The nationality of the first prawn fishermen is uncertain however, because the Report of the Royal Commission on the Fisheries of New South Wales (1880) records (with some displeasure) the large number of Italian fishermen in Port Jackson. Dannevig (1904) also noted the dominant role played by Italian fishermen in Port Jackson.

Ogilby (1893) reported that the sand prawn *Penaeus canaliculatus* (now known as the king prawn *Penaeus plebejus*) was the common species in the sandy bays around Sydney (and elsewhere) while the smaller, mud or river prawn *Penaeus macleayi* (the school prawn *Metapenaeus macleayi*) was the dominant species in the rivers; the *Penaeus* sp. recorded by Ogilby is almost certainly the greasyback prawn *Metapenaeus bennettae* because Whitelegge (in Ogilby 1893) described it as having a hairy, sculptured carapace and as being abundant at certain seasons in the Sydney markets—*M. bennettae* best fits this description. Ogilby also noted that *Penaeus monodon*, the giant tiger prawn, 'is at times common in the Sydney market but is irregular in its appearance; during the summer and autumn of 1891-92 it was exceptionally plentiful, since which time but few specimens have been observed.' Although *P. monodon* is a widely distributed warm water species the records of the Australian Museum confirm Ogilby's observations of this species in Sydney.

The Hunter River (Newcastle) fishery was probably established by 1850 because of the earlier rapid growth of the coal mining and timber industries, and of the population, and the availability of a regular steam-boat service to Sydney. By 1889 Newcastle fishermen had explored waters as far as the Clarence River (Fig. 2) and had established a small fishery in this river. The Clarence River area is now the most important producer of school prawns, much of which are sold as bait.

The prawn fisheries of the 19th century were small and insignificant because ice was scarce or unavailable (Clarence River fishermen had to transport their ice from Sydney) and the poor distribution and transport facilities restricted trade. Hunter River prawns, for example, were taken by horse and cart to Newcastle where part of the catch was sold, principally to Chinese fish curers who dried prawns for sale on the domestic or overseas (Chinese) markets. A large part of the Hunter catch was taken by steam-boat to fish markets in Sydney; this entailed another trip by horse and cart from the Sydney waterside to the markets. Consequently, these prawns were often in poor condition when they were displayed at the Sydney markets and it was not unusual for large quantities to be condemned. It is noteworthy that at the close of the 19th century the crayfish (*Jasus*)[1] industry was far more important than the prawning industry (Stead 1908).

New South Wales' early exports were not confined to Asia or the 'Old World'. Phillipps (1925) noted that 'enormous numbers' of Sydney prawns were exported and sold in Wellington, New Zealand, fish shops in March and April (1924?). One firm, the N.Z. Trawling and Fish Supply Co., sold one ton during the above two months.

---

[1] Now called rock lobster.

The prawn fishery entered a new phase in 1926 after the controversial introduction of otter trawling in Port Jackson; the advent of trawling meant that fishermen could now seek prawns in the deeper waters away from the shores and thus greatly enlarge their potential fishing area. Beam trawling was also tried in Port Jackson but evidently it was not as popular in New South Wales as it was in Europe. For many years trawling was opposed by 'traditional' fishermen because it allegedly destroyed the weed beds and spawning areas along the sea bottom, and in Port Jackson it was a nuisance to commercial shipping; however, this mechanised fishing method gradually spread to other areas including Botany Bay, Hunter River and Clarence River, where it is still carried on.

Another type of fishery started in 1932 with the use of set pocket nets in the entrance to Lake Illawarra. The pocket net is essentially a trawl net, staked out across a fast flowing channel, to trap prawns moving out to sea in the nocturnal ebb tides during dark phases of the moon (Ruello 1967). The net must extend from the bottom to the surface because king prawns emigrate in the surface water while school prawns move in the bottom or mid-water. Pocket net fishing was started in Tuggerah Lakes the next year and gradually developed in most of the larger New South Wales lakes.

By the early 1940s, the State's annual catch fluctuated between 450 000 and 900 000 kg while the Queensland catch was only about 112 000 kg and the production from other States was almost negligible. At this time Australia's prawn production was exceeded only by that of the U.S.A. (McNeill 1944).

Prawn fishing was still confined to the estuarine waters of Australia until 1947 although adult prawns had been found at sea half-a-century earlier. In 1898 H.M.C.S. *Thetis* trawled king prawns from Shoalhaven Bight and the coastal waters off Newcastle; she also discovered school prawns in Shoalhaven Bight (Whitelegge 1900). A decade later the Commonwealth's F.I.S. *Endeavour* (Fig. 3) caught king prawns off the Queensland coast (Schmitt 1926). In addition, the large steam trawlers operating off the N.S.W. coast often caught large king prawns in the 1920s (McNeill 1950), and W. J. Dakin (1935, 1938, 1940) and N.S.W. State Fisheries, for many years, drew attention to the fact that king and school prawns were leaving the estuaries (in large numbers) to breed at sea.

The discovery of large numbers of school prawns in the coastal waters of Stockton Bight (Newcastle) in the summer of 1947-48 by Danish-seine trawlers marked the beginning of the ocean fishery in Australia and a new era in the country's prawning industry. New and promising trawling grounds were soon discovered off Evans Head and the Richmond River (Ballina), in northern N.S.W., and in Shoalhaven Bight, south of Sydney. N.S.W. fishermen also started to explore the adjacent Queensland waters. By 1950 the ocean fishery surpassed estuarine production and it has remained the more important fishery in the State.

The ocean fishery was at first confined to waters less than 55 m deep and trawling was generally restricted to daylight hours. In 1953 A. A. Racek commenced prawn investigations in N.S.W. and his trapping experiments (Fig. 4) demonstrated the abundance of large king and tiger prawns in the deeper offshore waters. Fishermen then trawled in progressively deeper waters and tried more night trawling with spectacular results—the king prawn catches rose markedly and by the end of the 1950s they exceeded the catch of school prawns. The extraordinarily high catches of large king prawns off the N.S.W. north coast (and southern Queensland) in the mid-fifties produced a 'gold rush' atmosphere which was developed further by contemporary news stories. Newspaper articles were commonly published under headings such as:

Prawn fortune off N.S.W. coast

The very large catches of school and king prawns off Evans Head and other northern N.S.W. grounds in 1953 and 1954 often exceeded the safe handling capacity of many vessels and their crews, and the Fishermen's Co-operatives (ashore) could not handle the peak catches. Many prawns were thus wasted and the problem was not helped by the poor distribution facilities and limited markets then available. The Australian public has traditionally been a consumer of boiled prawns and the export industry was then in an embryonic stage of development. The domestic and international markets gradually expanded in the late 1950s and they overtook the local supplies in the early sixties. More recently the growth of the domestic market has been accelerated by the enormous consumption of prawns at special 'Prawn Nights' in many sports and social clubs, particularly in N.S.W.

The N.S.W. ocean fishery recorded its

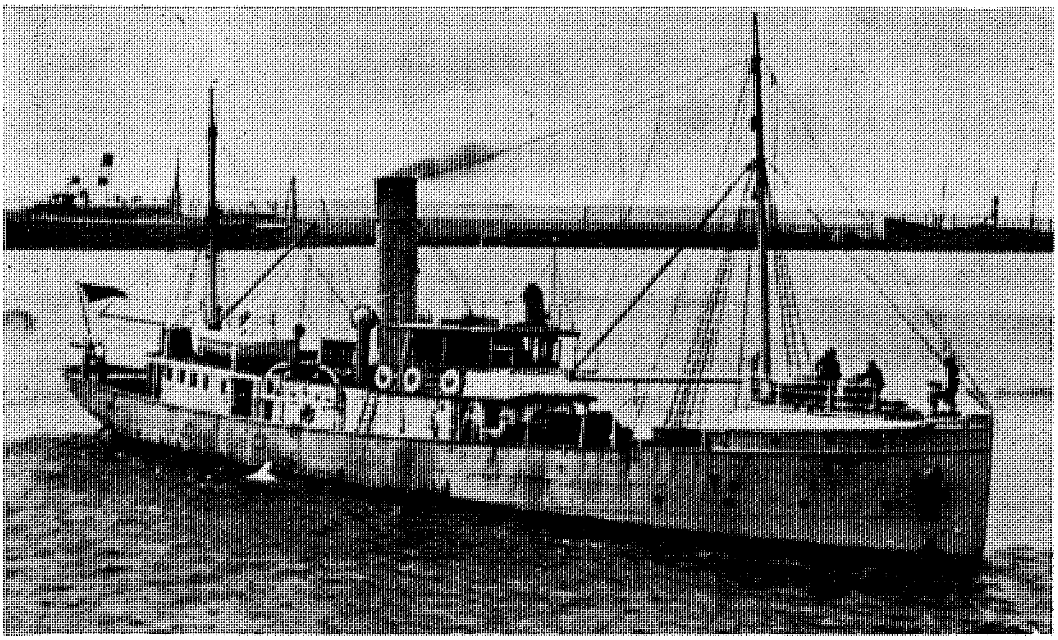


Fig. 3. Photograph of the F.I.S. *Endeavour* (1909-1914). (She was later lost at sea with all hands.)

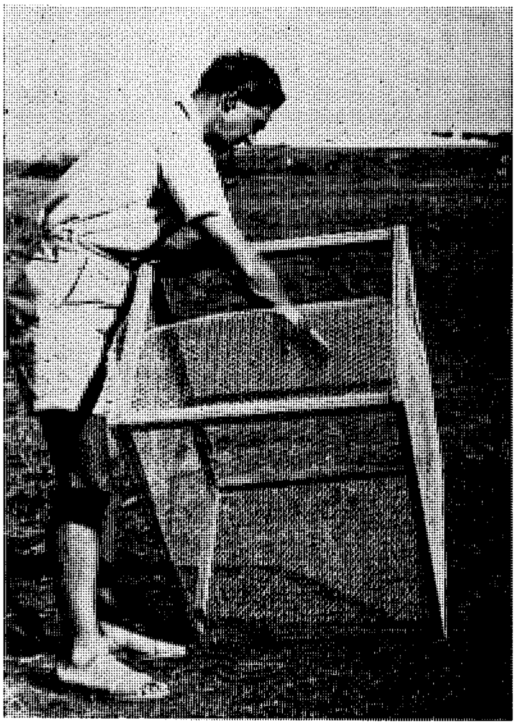


Fig. 4. A. A. Racek working on one of his simple but effective prawn traps which indirectly assisted the development of the offshore trawl fishery.

maximum catch in 1954–55 but production has fluctuated markedly from the inception of the fishery, presumably in response to environmental fluctuations. Today trawl fisheries exist along the coast from Tweed Heads to the sheltered waters of Twofold Bay.

In the mid-sixties two traditional prawn fishing methods were modified by N.S.W. fishermen. In 1965 Clarence River fishermen developed a novel fishing method in which the propellor wash from a stationary vessel (which is tied to the shore or mooring poles) is used to drive prawns into a pocket net staked out along the river bank. Two years later, Tuggerah Lakes fishermen used a modified hauling net, in the same way as a Danish-seine net is operated, to catch schools of greasyback prawns. The modified hauling net is now used in Lake Illawarra and Lake Macquarie and several other coastal lakes. Both of these new fishing methods have proven quite successful. For example, more than 225 000 kg of greasyback prawns were caught in Tuggerah Lakes in 1967–68 with modified hauling nets (N.S.W. State Fisheries unpublished data).

A notable feature of the N.S.W. prawning industry is its highly decentralised nature—

there are substantial fisheries at more than 20 localities on the coast. Other outstanding features are the evolution of a characteristic standard type of fishing vessel in many ports and the minor role of exports—the majority of the N.S.W. catch is sold within the State as boiled prawns or bait, and N.S.W. also imports prawns from Queensland (and elsewhere).

In 1971 the F.R.V. *Kapala* found large quantities of the deep water prawn *Hymenopenaeus sibogae* (royal red prawn) on the continental slope adjacent to Newcastle (275-550 m) (Gorman and Johnson 1971). This species was first trawled in 1906 off the coast of Sydney at a depth of 1 460 m by the *Woy Woy* expedition (McNeill, in Schmitt 1926), but its deep water habitat (*inter alia*) has inhibited any significant exploitation by Australian fishermen to the present day. Regrettably, these prawn stocks lie in 'international' waters and could therefore be exploited by foreign fishing fleets before Australian fishermen develop an active interest in them.

Last year Italian prawn fishermen in Port Jackson (Sydney Harbour) caught several thousand kg of the pelagic sergestid *Acetes australis.* These small (30-50 mm long) penaeid prawns were caught along the Harbour shores with fine meshed hauling nets (designed for anchovy fishing) and were readily sold in Sydney, which was experiencing the usual winter shortage of prawns. (These small prawns were used in fish cakes by Sydney's migrant community.) This gregarious species is commonly abundant in many of the N.S.W. estuaries (Colefax 1940, and personal observation) and could probably sustain a small winter fishery, when the larger penaeid species are not readily available.

Today, New South Wales is no longer the nation's leading prawn producing State. However, it has a long, rich and interesting history and it still has a most diverse industry—many species and many types of fisheries in a variety of habitats. The future is also promising; many tonnes of royal red prawns (and edible fish) await the more venturesome fisherman-entrepeneur while the currently unexploited adult king prawn stock south of Newcastle could provide a good living for a limited number of less venturesome fishermen.

Queensland

EAST COAST

Commercial prawn fishing probably commenced in the 1840s after the Moreton Bay (Redcliffe) settlement was abandoned in 1839 (Scott 1939) and a new settlement (Brisbane) started up along the Brisbane River. Fishermen in the Brisbane River (and elsewhere in Queensland) used a large bow-shaped hand scoop net, or scissors nets, to catch prawns along the river shores or from a drifting boat; hauling nets and other methods were apparently proscribed. The fishing industry soon spread to nearby rivers such as the Albert and the Logan River and to the Noosa Lakes district, the Mary River and the Fitzroy River, north of Brisbane. The principal commercial species in southern Queensland rivers were 'river' prawns—greasyback prawns *Metapenaeus bennettae* and school prawns *M. macleayi.* The fishery for juvenile banana prawns *Penaeus merguiensis* in the Fitzroy River (chiefly for the local bait market) started in the 1880s and continues to the present time (Walker MS). The town of Gladstone was founded on Port Curtis in 1853 (six years before the Colony of Queensland was proclaimed) and undoubtedly attracted fishermen to its sheltered waters.

Welsby's remarks on prawn fishing in the closing decades of the 19th Century are enlightening (and entertaining):

> "Prawn catching in the Brisbane River may be classed as one of the fine arts, for with a punt, either square ended or sharpie fashion, an amount of dexterity and cunning is required, more than the average amateur fisherman understands. Prawn catching also requires payment of one pound per year to the Queensland Government, otherwise Fred Baker or one or other of his satellites will have you."
>
> *and*
>
> "It is hard work, this prawn catching. The men generally engaged in the labour are Italians and Greeks, chiefly the latter, and every penny they get for the prawns they catch they richly deserve."
>
> (from Welsby 1967.)

The Queensland Marine Department's report for the year 1894–5 states that . . . 'about eighteen men are employed prawning in the river'. This contrasts poorly with the equivalent New South Wales situation—Port Jackson—where there were 100 vessels working in 1886 (Dannevig 1904). By 1905 there were still only 30 'prawners' in the Brisbane River. The arduous nature of the work (noted above by Welsby) and the limited catches of hand nets may account for the relatively slow development of the prawning industry in Brisbane, and Queensland generally. The absence of a metropolitan fish market also restricted development.

The Department's 1904–5 report noted that the prawning season in the Maryborough district (Mary River and Hervey Bay) extended from the beginning of April to the end of October and was producing up to 2 000 quarts (2 280 litres) of prawns per week which were being dispatched to all parts of the Commonwealth. Fifteen prawners were reputedly earning £40 weekly: large consignments of prawns were going to Sydney and Melbourne and these were fetching extra-high prices because of the usual winter shortage of prawns from the N.S.W. estuaries.

The fishery diversified and gradually developed in the 1900s: seine nets, stripe nets, pocket nets and finally beam trawls were used in the southern Queensland rivers. (Otter trawling was still prohibited before 1950 however.) In 1907 the Government established a fish market in Brisbane (and leased it to a private operator) and this undoubtedly stimulated the sale and distribution of sea foods. By 1941–42 the official annual catch was 101 275 pounds (45 938 kg) and it earned £6 511 for fishermen.

A somewhat puzzling aspect of the Queensland fishery is that the prawn stocks in Moreton Bay—the king prawn *Penaeus plebejus*, the banana prawn *P. merguiensis*, the tiger prawn *P. esculentes* and *Metapenaeus* spp.—remained virtually untouched until 1950 (Haysom 1953) when the N.S.W. trawlers *Nanango* and *Jo-Ean* experimented with otter trawls and were pleasantly surprised by the results. Large prawns were caught in the Bay as early as 1886 or 1887 by the steamer *Marwedel*, while dozens of large 'sea' prawns had been caught in a trawl with 63 mm meshes by a distinguished party (J. Stevens, Inspector of Fisheries, D. G. Stead, the well-known Sydney naturalist, and others) aboard the Marine Department's launch *Ostrea* in 1902 (Welsby 1967); furthermore, the F.I.S. *Endeavour* found prawns along the Queensland coast in 1909. The State's prohibition on otter trawling and the restrictions on the length and power of vessels engaged in beam trawling in the Brisbane River may account for the late development of trawling in the more open waters of Moreton Bay.

The Moreton Bay fishery grew rapidly once otter trawling was officially allowed in 1950. The 1952–53 official catch was 136 000 kg (56% tiger, 38% greasyback and 6% king) but fishermen experienced difficulties in selling the Bay greasybacks in competition with the higher quality Brisbane River greasybacks (the latter were of better quality because they were caught in smaller quantities and hence were better cared for) and large quantities were dumped. The next year's Bay catch was higher but greasybacks were most abundant, and contributed 56% of the total of 225 000 kg, whereas tigers only contributed 27%, and kings 17% (Annual Reports of Department of Harbours and Marine).

The development of offshore fishing in Queensland was slow in comparison to N.S.W. Small quantities of king prawns were taken off the coast south of Brisbane in the early 1950s but a regular fishery was not established until 1954–55 when the area between Jumpinpin and the N.S.W. border was thoroughly trawled and yielded good catches.

In June 1954, 22 000 kg of banana prawns were caught off Bundaberg (Hervey Bay) and this large catch quickly attracted many fishermen and considerable publicity. In 1954–55 about 100 trawlers participated in this new fishery and the annual production was an estimated 225 000 kg. As a result, the Brisbane and Sydney press produced their 'gold rush' type articles in their newspapers and thereby attracted even more fishermen. Unfortunately, the catch fell markedly the next year and history has since shown that erratic catches are a characteristic of the banana prawn fishery. Walker (MS) has traced the history of commercial prawn fishing in Bundaberg back to its tentative start in 1949.

An interesting result of the commencement of a prawn fishery in the Bundaberg area was the finding of large beds of scallops (*Amusium balloti*) and the subsequent development of a scallop fishery—which provides employment in the prawn off-season.

In 1955–56 Queensland's (and Australia's) export industry finally got off to a successful start when several large shipments of banana and king prawns, totalling 45 000 kg, were exported to the U.S.A. The first experimental consignments of prawns were made to New York, U.S.A., five years earlier (*Fisheries Newsletter*, February 1950). The export trade has since been extended to many countries and has grown rapidly in size and now takes the major part of the State's (and the country's) prawn production.

The Australian Government's *Challenge* survey (Fig. 5) of the prawn resources off the east coast of Australia played a significant role in the development of Queensland's offshore fishery. In July 1957, soon after the commencement of the survey, king prawns were found off Fraser Island to a depth of 64 m and a most profitable fishery was quickly established in this area. Offshore trawling was gradually extended up the coast and fisheries subsequently started at Gladstone, Keppel Bay, Sarina, Mackay, Proserpine, Bowen, Townsville, Cairns and Princess Charlotte Bay. Walker (MS) has discussed the development of the fisheries in these areas.

A point of historical interest is that A. A. Racek surveyed the area between Mackay and Proserpine in October 1954, with support from a private syndicate (Department of Harbours and Marine, *Annual Report for 1954–55*). Racek's survey was conducted with a small vessel without a winch but it nevertheless landed small catches, of king and banana prawns. An American member of the syndicate demonstrated the practice of spotting banana prawn 'boils' (schools) at sea (Racek personal communication).

The December 1959 issue of *Fisheries Newsletter* announced that the *Challenge* recorded good catches of king prawns in the area NNE. of Moreton Island, to a depth of 91 m, in the previous month, and that the estimated catch rate would be 27-45 kg/hour of prawns up to 254 mm long. The Queensland and N.S.W. fishermen who quickly adjusted their fishing gear for trawling in deep water were amply rewarded for their efforts. During the next few years this ground was extended east to a depth of 146 m and as far north as Mooloolaba. The Cape Moreton-Mooloolaba ground now extends to the edge of the continental shelf and is the country's premier king prawn fishery—it consistently yields good catches of large prawns. This valuable fishing area includes a long-established dumping ground for obsolete Army munitions and this presents an added danger to fishermen working these deep waters.

In 1960, the Queensland Government allowed the introduction of double-rig trawling and this practice was quickly adopted by most of the fishing skippers operating the larger trawlers. The deepwater grounds off Cape Moreton and Mooloolaba however are still worked with a single-trawl—most fishermen consider single rig stern trawling difficult enough in this area.

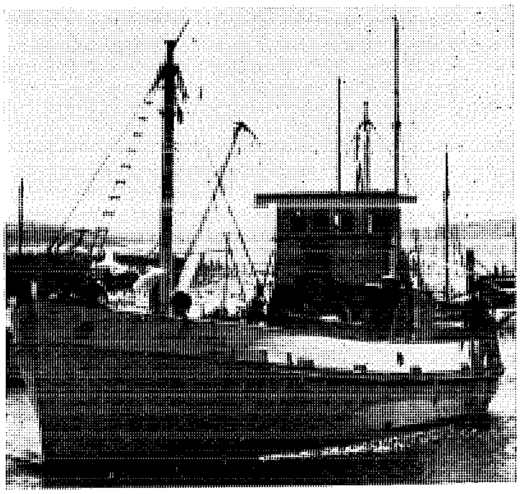


Fig. 5. The L.F.B. *Challenge*. The *Challenge* survey greatly assisted the development of the Queensland offshore fishery.

Recently, *Australian Fisheries* (September 1973) reported that the Queensland Fisheries Department was surveying the deeper waters off Fraser Island (adjacent to the area surveyed by the *Challenge*) and had recently found large quantities of king prawns and as a result a fleet of 60 trawlers quickly caught a total of 45 360 kg. M. A. Potter, the biologist in charge of the survey, has attributed the success of this survey to the availability of radar—the continental shelf off Fraser Island is extraordinarily wide and echo-sounders are not sufficient to locate a particular fishing site whereas radar enables more accurate position finding (Potter, personal communication).

This recent survey has shown that although the east coast of Queensland is widely believed to be heavily or over-exploited, there are still new prawn grounds to be discovered and fished.

GULF OF CARPENTARIA

The fishery in the Gulf developed as a result of a joint Government-Industry survey of the prawn resources of the SE. corner of the Gulf. Harrison (1965) discussed the circumstances and decisions leading up to the initiation of the survey while Walker (MS) has recorded the development of the fishery. This survey therefore need not be discussed at length here.

The *Nanango*, a New South Wales fishing vessel, trawled for prawns in the Karumba area in 1954 (Racek personal communication) and was apparently the first Australian vessel to search specifically for prawns in the Gulf. The *Nanango* and other trawlers which visited the Gulf in the following few years had some encouraging catches and these focused attention on the Gulf as a new area for prawn fishing. In 1959 the Australian Government was asked for assistance in surveying the Gulf but the question was not seriously discussed until 1962 when the firm of Craig Mostyn and Company Pty Ltd began planning a processing plant at Karumba. In April 1963 a formal agreement was reached between the Australian and Queensland Governments and the commercial interests on the funding and operation of a survey. J. M. Thomson was appointed Project Leader but resigned from CSIRO shortly after. At the end of July the survey team, led by I. S. R. Munro, commenced operations from the chartered vessel *Rama* from a base at Karumba (Harrison 1965).

By the end of 1963 more than a dozen commercial trawlers—including a fleet of seven Western Australian freezer-boats under charter to the AFEX company—had carried out exploratory trawling within the survey area.

The official survey finished in August 1965 after finding more than 20 species and demonstrating that there were good prospects for developing a fishery based principally on banana and tiger prawns. Other species of commercial importance recorded were the Endeavour prawn *Metapenaeus endeavouri* and the western or blue-leg king *Penaeus latisulcatus*. Charts showing depth contours and tables giving probable times when banana prawns can be caught in relation to tides were made available to fishermen in exchange for log book data on catches and fishing activity.

A commercial fishery quickly developed in the Karumba region and after some good catches in 1967 the fishery expanded markedly in the following year and it has now been established as one of Australia's richest. The success of the Karumba fishery stimulated the development of other areas of the Gulf and directed the attention of fishermen to the waters around the Northern Territory.

In July 1967 the South Seas Fishing Company began fishing banana prawns in the Weipa area with the mothership *Papuan Prince* and four trawlers. In 1968 two other companies entered the Gulf fishery with three motherships, while another company opened a processing plant at Thursday Island to process catches from Torres Straits and Weipa. Another processing plant was opened on Denham Island in 1969 to service the southern Gulf region (Walker MS). Markwell Fisheries established a receival depot at Karumba and a primary processing plant further up the Norman River at Normanton, in 1968, but final processing is (still) carried out at Tweed Heads, N.S.W. Other, smaller, processing facilities have since been established in the Gulf region.

The interest in the Gulf has not been confined to Australia. The Japanese newspaper *Minato Shimbun* recorded that a Japanese carrier vessel and a catcher vessel were averaging daily catches of 317 kg of prawns in the Gulf in June 1966 (*Australian Fisheries Newsletter* September 1966), and other Japanese vessels have also been sighted in the Gulf. The most publicised and best-known foreign visitor to the Gulf of Carpentaria was unquestionably the Soviet factory ship *Van Gogh*, under the command of Commodore Alexei Solyanik. This 103 m long (5 105 gross tonnes) vessel was fishing 56 km off Karumba in July 1968 and allegedly intimidated the dwarf-like Australian trawlers fishing nearby. The Prime Minister of the day, J. G. Gorton, duly ordered a RAN patrol vessel and RAAF reconnaissance aircraft into the Gulf to watch the interests of Australian fishermen and guard against incidents with foreign vessels (*Australian Fisheries Newsletter*, August 1968). The *Van Gogh* was accused of (*inter alia*) sucking up tons of prawns off the sea bottom with a large vacuum device, it was allegedly interfering with the activities of Australian vessels and rifle fire was reportedly exchanged.

The true story about the *Van Gogh*'s visit will probably never be recorded but the resulting publicity was unprecedented in Australian fisheries history and focused the nation's attention on the new rich fishery in this remote area—in a spectacular manner (Fig. 6). The *Van Gogh*'s visit also apparently made a lasting impression on the Federal Cabinet, because eleven months later funds were approved for a major research program on the prawn resources of northern Australia.

The Gulf fishery grew rapidly in the 1970s and in May-June 1972 a fleet of about 200 trawlers landed 4.08 M kg of prawns. The

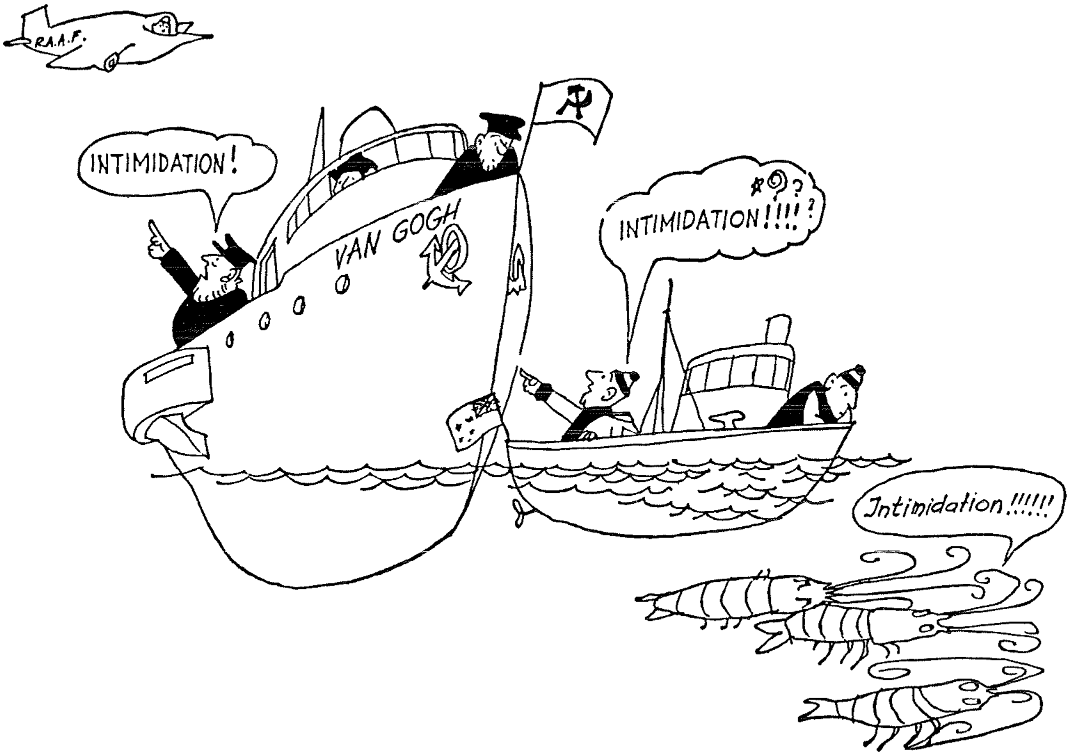


Fig. 6. The *Van Gogh* visit to the Gulf of Carpentaria—by the Sydney cartoonist G. Molnar. Cartoon by courtesy of Sydney Morning Herald.

start of the Gulf fishery was responsible for a number of changes in the Australian prawn fishing industry. Ice was inadequate for preserving the huge catches in the high ambient temperatures and was therefore replaced by high capacity refrigerated sea-water or dry freezing systems. Double-rig trawling invariably replaced single stern trawling while new vessels were designed specially for the tropical northern fishery. Light aeroplanes were chartered to spot banana prawn 'boils' and direct the fleet to these dense schools of prawns. 'Prawn spotting' itself however was not an innovation of the northern fishery because fishermen in N.S.W. lakes found schools of greasyback prawns by searching for muddy patches of water many years before the Gulf fishery started. Echo-sounders have also proved to be an essential part of the banana prawn fishermen's gear because they can be used to search for prawn 'boils'. A notable feature of the Gulf fishery (and the northern fishery generally) is that almost all of the catch is processed for export and only the smaller size groups (or species), and the large prawns which do not meet the high export standards, are usually held for the domestic market.

The history of the Gulf fishery clearly demonstrates how a thoroughly planned government survey carried out in consultation with industry and at an opportune time (i.e. in relation to technology and markets) can quickly lead to the development of a thriving industry.

It is interesting to note that John Lort Stokes, the commander of the sloop *Beagle*, called the Gulf country the Plains of Promise *in 1841* during an exploratory voyage in this area.

Northern Territory

The fishery in the Northern Territory is the youngest, least documented and largest prawn producer in Australia. Following the development of the fishery in the Gulf of Carpentaria and a rapidly growing interest in the potential of the seas around the Territory, the Minister for Territories, in November 1967, invited proposals for the development of the prawning industry. Six months later conditional approval was given to participation in the processing industry by the following companies:

(a) *Enterprises involving Australian ships and crews only:*
    Craig Mostyn and Co. Pty Ltd
    M. G. Kailis Gulf Fisheries Pty Ltd
    Northern Meat Exporters Pty Ltd
    Tipperary Land Corporation
(b) *Joint ventures:*
    Northern Research Pty Ltd
    William Angliss (Aust.) Pty Ltd
    Gollin Kyokuyo Fishing Co. Pty Ltd

(*Australian Fisheries Newsletter*, May 1968.)

Australian owner-operator fishing boats were, of course, allowed to fish in the waters of the Territory. *Australian Fisheries Newsletter* also noted that solely Australian enterprises would be assisted by allowing them first choice of possible sites for processing plants and restricting other shore processing plants and factory ships to certain distances from them; in addition, joint ventures would have to replace any foreign ships and crews with Australian ships and personnel after no more than five years, and their shore processing plants would have to be located in Darwin.

The growth of the industry in the Territory was unprecedented in Australia (and elsewhere?). The catch was almost negligible in 1967–68, it rose to 1.13 M kg the next year and then a record production of more than 3.85 M kg in 1969–70 (Northern Territory Administration, undated).

Prawn fishing is currently the Territory's second most important primary industry. The species and grounds worked by the Territory's fleet are variable. The Melville Island, Limmen Bight and Groote Eylandt grounds in the Gulf of Carpentaria produce both banana and tiger prawns and smaller quantities of Endeavour prawns, whereas the grounds in international waters between the Territory and West Irian are prime producers of banana prawns. Two-thirds of the 1969 and 1970 production (principally banana prawns) came from international waters but in 1971 this was reversed and the Gulf waters produced two-thirds of the catch while the international waters contributed the remaining third.

In May 1970 Northern Research Pty Ltd became the first of the three joint ventures to open a shore-based processing plant (at Dinah Beach, Darwin) and to introduce its own Australian-built and manned catcher boats. For the previous two seasons the company operated eight Japanese trawlers and processed the catch at sea aboard the mothership *Kashii Maru* (*Australian Fisheries*, June 1970). The widespread use of motherships during the initial years of the fishery in the Territory was one of the characteristic features of the industry; other notable features include the dominance of company-owned vessels and the growing participation of Aboriginals in all sectors of the industry. The nature of the fishing fleet is also remarkable because nearly all of the Australian vessels are of recent design, large, and specially equipped for long fishing trips—some of these vessels operate at a distance of 1 600 km from Darwin and stay at sea for several weeks.

The Territory's fleet is relatively small (50-80 vessels) but it is a valuable one—new vessels cost about $250 000 each and each vessel has a high seasonal catch rate, thus helping to make the Territory's industry Australia's biggest producer of prawns.

Western Australia

Before 1962 Western Australia's prawning industry was limited to small hand net fisheries in Peel Inlet (Mandurah) and the Swan River (Perth). These fisheries, which have a history of approximately 100 years, generally have a total annual production of less than 45 000 kg of one species, *Metapenaeus dalli*, the western school prawn. The State's modern prawning industry was born in 1962 at Shark Bay.

The first attempts to find prawns in the oceanic waters of Western Australia were made in 1904 when the State Government chartered the 90-ton ketch *Rip* to search for trawlable fish in the area between Cape Naturaliste and Shark Bay. Some moderately large catches of big prawns were taken in the vicinity of Bernier Island (Shark Bay) but the prawns remained unexploited for almost a half century until another survey was initiated (Department of Fisheries and Fauna, W.A., 1966). In 1952 the State Fisheries and Fauna Department and the CSIRO Division of Fisheries and Oceanography commenced a fish resources survey with the Department's patrol vessel *Lancelin.* This survey was conducted spasmodically from 1952 to 1956 and in 1955 the *Lancelin* was accompanied for several weeks by a refrigerated fishing vessel *Jon-Jim.* Potentially commercial quantities of prawns were found in Shark Bay and in Exmouth Gulf and there was a record trawl of 180 kg of banana prawns in a one-hour trawl in Exmouth Gulf.

Commercial trawling commenced in Shark Bay in 1957 with two vessels, but despite good catches this venture only lasted a year —apparently because of inadequate shore facilities. A fishery was successfully started in Shark Bay in 1962 following the establishment of processing facilities at Carnarvon by the Nor' West Whaling Company Ltd. Three vessels caught a total of 144 000 kg of western king and tiger prawns in 20 weeks. Most of this catch was processed and sold on the domestic market but small consignments were exported to test the overseas markets (Moore 1963). The experimental exports were favourably received and markets were quickly established and expanded and today Western Australia exports almost all of its catch.

The highly successful start of the Shark Bay fishery attracted the attention of fishermen throughout the country and this aroused fears of a large influx of interstate vessels (in the following season) and a dangerously high exploitation rate. The Fisheries and Fauna Department therefore decided to limit the number of prawning vessels in Shark Bay to 25, to ensure an acceptable economic return for pioneering fishermen and processors and to prevent over-exploitation of the prawn resources. The number of vessels licensed for Shark Bay prawning was increased to 30 in 1964 following the opening of a second processing plant at Denham. The processing companies received three-fifths of the licences issued while the remainder were allocated to individual fishermen, most of whom processed their catch on board the vessel (Department of Fisheries and Fauna, W.A., 1967).

The Exmouth Gulf fishery did not start until three years after Shark Bay was successfully fished: Gulf Fisheries Pty Ltd began exploratory commercial operations in Exmouth in 1964 and in the next year established a processing plant to take the catches of their nine vessels. A total of 17 trawlers was licensed to fish in Exmouth in 1965, four licences were held by independent operators and the remaining four belonged to a factory ship operated by Ross Fisheries (Australia). The Exmouth Gulf fishery, like the Shark Bay fishery, is based on the (nocturnal) king and tiger prawns; however, large catches of banana prawns (*Penaeus merguiensis*) were recorded in 1964 and 1965.

The number of vessels licensed to fish in Shark Bay and Exmouth Gulf has been increased slightly in recent years in line with the Fisheries and Fauna Department's policy of regular assessment of its licence limitation scheme. This licence limitation management policy, based on regular research and assessment, was a novel concept in Australian prawn fishery management, but a similar scheme now operates in South Australia.

A banana prawn fishery started in Nickol Bay in 1967 and a total of about 450 000 kg was caught in the Bay and off the Harding River between April and October that year (Walker MS). Subsequent catches have been considerably lower and Walker noted that the catch rates in Nickol Bay are low compared to those in the Gulf of Carpentaria.

Several fishing companies are currently examining the prawn resources in the region of Admiralty Gulf. This area was surveyed by the Fisheries and Fauna Department over the past six years; exploratory fishing operations were encouraging but the remoteness and strong tidal currents of the region are a hindrance to the development of a fishery.

South Australia

The blue-leg or western king prawn was trawled from South Australian waters, by the F.I.S. *Endeavour*.. (1909–1914) (Schmitt 1926). However, the first attempt at commercial prawn trawling was not made until 1948 —shortly after the discovery of large prawns in Stockton Bight, N.S.W.—when a N.S.W. Danish-seine trawler experimented in Spencer Gulf. The results were disappointing and the once hopeful pioneer returned to his home State (Department of Fisheries, South Australia, 1972).

The Department of Fisheries and Fauna Conservation carried out exploratory trawling from its vessel *Weerutta* in 1957 and continued this intermittently until 1964. The results were only moderately encouraging and Chief Inspector Moorhouse remarked that 22 kg was considered a good catch for a night's fishing (N.S.W. Chief Secretary's Department files). Various fishermen also searched for prawns during this time but without any better results.

The search for prawns in Spencer Gulf was continued in earnest in September 1967 by several local fishermen and a New South Welshman and this attempt was successful. Within months a new fishery was established and consistently large catches of the western king prawn *Penaeus latisulcatus* were made —some of the early catches of the twin rig trawlers were as high as 1 800 kg per night.

The Fisheries and Fauna Conservation Department closed South Australian waters to trawling in March 1968 and introduced a zone licence-limitation scheme to control fishing activities; the State's waters were zoned and each vessel was granted a permit to trawl in a particular zone. This zoning scheme was intended to encourage exploratory trawling and to reduce the fishing effort on the most favoured grounds. By August 1968, 40 permits had been issued for Spencer Gulf and St Vincent Gulf. In 1969 new stocks were found off Venus Bay on the west coast of South Australia and these now sustain a profitable fishery. In October that year a prawn fishermen's co-operative was formed and nine months later a modern processing plant was opened at Port Lincoln. By June 1971, 45 permits had been granted for prawn fishing in the five zones established by the Fisheries and Fauna Conservation Department.

The most notable feature of the South Australian industry is that all the fisheries are based on a single species, *Penaeus latisulcatus.* Other interesting characteristics are the consistently high catches of the Spencer Gulf fishery, the lengthy duration of fishing trips—up to four days, and the participation of large modified tuna clippers in the prawn fisheries.

A five-week joint Government-industry survey of possible prawn fishing areas in the south-east area of the State was carried out from March 1971. Prawns were not found and the sea bed was generally considered too rocky for successful trawling, and it appears that future developments must come from the far west coast of South Australia.

Victoria

Mallacoota Inlet and the Gippsland Lakes are the only Victorian localities with a significant prawn fishery. King and school prawns are taken in both estuaries with hand nets, while a stake net (i.e. pocket net) fishery is also conducted in the fast-flowing channels near the ocean entrance of the Gippsland Lakes. Moderate quantities of king prawns are occasionally trawled in the oceanic area off Lakes Entrance. Victoria's prawn production is small and usually totals less than 9 000 kg per year (Wharton 1967).

The Victorian Fisheries and Wildlife Department has expressed interest in conducting a new prawn resources survey—the area off Gippsland Lakes was surveyed by the *Challenge* in the late 1950s—and the recent development of the prawn fishery in Twofold Bay, southern N.S.W. (for king and school prawns) suggests that sizeable prawn stocks may also be found in the more easterly waters of Victoria.

COMMERCIAL PRAWN FARMING AND CULTURE

In November 1958 B. Wilsher collected 300 pairs of greasyback prawns from Lake Macquarie (N.S.W.) and released them into a pond 23 × 12 × 1.5 m, which he had excavated manually from part of a mangrove swamp at Taren Point (on the southern shore of Botany Bay), Sydney. Other members of this venture were R. Austin, an enthusiastic amateur biologist, and A. A. Racek from N.S.W. State Fisheries (and shortly after, Sydney University) who acted as scientific adviser (Anonymous 1962). The prawns spawned successfully in the pond and progeny from later spawning experiments were subsequently reared to the juvenile stage, some up to four months old. Unfortunately, the prawns were killed by water pollutants from nearby industrial sources (Racek 1970) and the project was abandoned in 1961 for various reasons. This pioneering work clearly showed that greasyback prawns would mate and spawn in ponds without any artificial inducement and that prawn farming had definite commercial potential.

This modest Sydney venture opened up a new dimension in the Australian prawning industry which is still virtually unexplored today, exactly 15 years later.

It should be noted that a distinction is made in this paper between farming and culture, the former entails the natural mating and spawning of captive prawns collected from wild stock whereas the latter involves the rearing of progeny arising from the 'artificial' spawning of fertilised females taken from wild stocks (after Racek 1970).

Almost a decade after the Sydney prawn farm closed, another small farm was opened at Port Roper (on Roper River) on the western shore of the Gulf of Carpentaria (in 1970) by Shrimp Exporters Pty Ltd; this company constructed five ponds, 15 × 7.6 m, and stocked them with young adult tiger, banana and greasyback prawns and later with greasyback prawn larvae (Australian Fisheries, September 1971). An interesting point about this farming venture is that the Japanese Fujinaga family (who pioneered prawn culture) were engaged as consultants by Shrimp Exporters Pty Ltd. Despite the early reports of encouraging results (Australian Fisheries) this company also closed within two years of its start.

Another three companies (private and public) recently entered the field of commercial prawn culture—two in the Moreton Bay (Queensland) area and the other in northern Australia. This last company, Aquaculture International (Aust.) Ltd, reported that its headquarters would be in South Australia and that it would be 'farming' prawns in the north of Australia 'using company technology developed in the U.S.A.' (advertisement for biologists in *Australian Fisheries*, March 1973). All of these current ventures are backed by considerable financial resources and thus contrast greatly with Australia's first farming operation.

Another common, but paradoxical, feature of recent and proposed aquaculture businesses is the conspicuous absence of experienced crustacean or culture biologists on their staff. This is undoubtedly a reflection of the paucity of such people, but it is also a consequence of the recent history of employment of biologists in Australia; biologists have traditionally worked in government or university departments, where tenure of employment is invariably secure and often permanent. Therefore commercial prawn culture, which is still a high risk enterprise in this country, can only expect to attract the less conservative and most venturesome of biologists and evidently there are few of these. The heavy reliance on overseas technology has obviously resulted from necessity, and is easily understood, but the apparently poor communication and co-operation between Australian prawn culturists appears counter-productive.

Although there have been no official, truly encouraging reports from companies engaged in prawn culture in Australia, and despite the apparent shortage of knowledgeable and experienced personnel and the obvious economic risks involved, there is no shortage of individuals or companies willing to embark upon such an enterprise. Prawn culture undoubtedly has unlimited potential *if* prawns can be reared at competitive prices. This question will almost certainly be resolved by the end of this decade.

RESEARCH

Biological studies

The first notable work on an Australian prawn was carried out by the Austrian W. Hess (1865) who described a new species *Penaeus plebejus* from specimens he apparently obtained at a fish market in Sydney. The current common name for this species, king prawn, was first recorded by Stead (1905) and presumably refers to the large adult size of the species. Surprisingly, it contradicts the Latin name (*plebejus*) assigned to the species by Hess (because of its frequent abundance in Sydney?) because *plebejus* means common.

Racek (personal communication) has noted that the French corvette *Coquille* surveyed the seas around northern Australia in the 1820s, and collected penaeid prawns, but the author was not able to examine the literature needed to elucidate this point.

Professor W. A. Haswell, at Sydney University, was the author of the first major study of Australian prawns. Haswell (1879, 1882) examined the specimens collected by the *Chevert* expedition, but the most important parts of these works were his descriptions of two new species, *Penaeus esculentes* (tiger prawn) and *Penaeus macleayi* (school prawn) which were found in Port Jackson, Sydney. Haswell almost certainly named the school prawn after Sir William Macleay, a well-known contemporary naturalist (and generous benefactor of the N.S.W. Linnean Society); this species was later assigned to the genus *Metapenaeus*.

The voyage of H.M.S. *Challenger* provided the material for the next notable study. Spence Bate (1888) examined this material and added to our knowledge of the Australian distribution of several non-endemic species. Several Australian writers commented on the nomenclature of individual prawn species in later years (Ogilby 1893, Stead 1908) and a number of overseas workers have recorded the presence of many non-endemic species in Australian waters. Despite these small but significant contributions the taxonomy of our prawn fauna was badly confused until it was thoroughly examined almost half-a-century later.

Schmitt (1926) reported upon the prawns collected by the F.I.S. *Endeavour* (1909-1914) and he also examined the species of *Penaeus* described by Haswell and held at the Macleay Museum at Sydney University.

He described two new species from the *Endeavour* collection: *Penaeus maccullochi* and *Penaeopsis endeavouri* (apparently named after his contemporary, A. R. MacCulloch, and the investigation ship respectively), and he recorded the presence of *Penaeus latisulcatus* in Australian waters—from Queensland and Kangaroo Island (South Australia). A year later Hale (1927) recorded the species *Penaeopsis novae-guineae* in South Australia.

Although prawn taxonomy attracted the attention of the early naturalists, the Australian prawn fisheries were not studied until 1903 when H. C. Dannevig, the N.S.W. Superintendent of Fisheries Investigation, examined the alleged slaughter of immature fish in Port Jackson by prawn nets. Dannevig (1904) found that the destruction of small fish was not excessive, nor dangerous, and probably no greater than that produced by conventional fishing nets and he concluded that prawn fishing was not objectionable in view of its economic value.

Another three decades passed before the biology of an Australian prawn was examined in detail. Professor W. J. Dakin, from Sydney University, outlined the early results of his research on the life history of the king prawn, in the 1934 R. M. Johnston Memorial Lecture to the Tasmanian Royal Society (Dakin 1935). He continued the study of the life history and habits of this species (Dakin 1938, 1940, Dakin and Colefax 1940) and later he and other members of his staff investigated the life history of the greasyback prawn (Dakin 1946, Morris and Bennett 1951). Several biologists from State and Australian Government Fisheries Departments carried out brief studies on various species, and fisheries, in the period 1900-1950 but the results of these studies were never published.

In 1951, J. C. Wharton commenced prawn investigations for the N.S.W. Fisheries Department—but he resigned shortly after to take up an appointment in the Victorian Fisheries and Wildlife Department. In 1953 A. A. Racek was appointed to carry out special prawn investigations in N.S.W. Racek initiated studies on the taxonomy of the penaeid fauna and soon found many formerly unknown species (Racek 1955, 1957a). At about the same time W. Dall at Queensland University was also conducting taxonomic research (Dall 1957) and later he collaborated with Racek to produce a major revision of the littoral Penaeinae from northern Australian waters (Racek and Dall 1965). While employed by N.S.W. State Fisheries, Racek investigated the biology, ecology and fishery of the commercial species in N.S.W. and adjoining Queensland waters (Racek 1957b, 1959) and his 1959 paper has since served as the 'essential text' for most new 'prawn biologists' in this country; he also provided other State departments with advice on prawn taxonomy and biology. His 1957a paper was produced as a result of such co-operative efforts.

Racek resigned from State Fisheries in 1959 to accept an appointment at Sydney University, but he lost none of his enthusiasm for prawns after he left the Fisheries Department (he was originally a sponge 'expert'). At Sydney University Racek supervised Australia's pioneer prawn farm, continued his taxonomic studies on littoral penaeids (Racek and Dall 1965, Racek 1968, 1970 and Racek and Yaldwyn 1971) and initiated research on the taxonomy of deep water prawns from the *Dana* and *Galathea* expeditions. Racek's contribution to fisheries management is discussed in another paper by the author (Ruello 1973b).

In Queensland, N. M. Haysom carried out prawn investigations for the Department of Harbours and Marine (Haysom 1953). W. Dall (at Queensland University) investigated the ecology, growth and behaviour of greasyback prawns from the Brisbane River (1958) and later carried out extensive studies on the physiology of this species (Dall 1964, 1965, 1967). Dall's physiological studies are outstanding contributions in this field and have provided a wealth of information on the greasyback prawn. Dall's papers on the greasyback prawn have served as an excellent starting point for biologists currently examining the economic feasibility of farming this species (see below). The CSIRO Division of Fisheries and Oceanography carried out prawn research in the 1950s in Queensland, and J. M. Thomson (1956) contributed a paper on 'Fluctuations in Australian prawn catch' to the 1955 Indo-Pacific Fisheries Council prawn symposium in Tokyo.

The 1960s witnessed an enormous increase in the number of scientists engaged in prawn research. This upsurge in research effort was brought about by the development of several new fisheries and by a renewed interest in the older fisheries of eastern Australia. R. J. Slack-Smith was the first of the new generation of 'prawn biologists' to be engaged by State and

Australian Government departments and before the close of the decade he was joined, in Western Australia, by J. W. Penn.

In 1963, I. Kirkegaard (Queensland Department of Harbours and Marine) joined I. S. R. Munro and his colleagues from CSIRO in the Gulf of Carpentaria prawn survey and associated studies. In N.S.W., I. R. Smith was engaged by State Fisheries in 1966 to examine the economic feasibility of farming (or culturing) the greasyback prawn, while later that year the author was appointed to study the natural prawn stocks and fisheries.

Slack-Smith (1969a, b) discussed the Shark Bay fishery and his mathematical model of this fishery at the 1967 World Conference on Prawns in Mexico City. At this meeting he also outlined the procedures used in the automatic processing of fishermen's log book data (Slack-Smith and Stark 1968). The Western Australian Department of Fisheries and Fauna now has an impressive collection of catch-effort data on the Shark Bay fishery as a result of the original efforts of Slack-Smith and A. E. Stark. Details of Slack-Smith's work and the results of Penn's studies on prawn reproduction are recorded in the documents prepared for the Western Fisheries Research Committee meetings in Perth.

Munro (1966) discussed the background, operating difficulties and early results of the Gulf survey. Later, Munro contributed several articles to the 1968 Australian Fisheries special edition on prawns, based on his studies in the Gulf of Carpentaria. Munro's (1972) introductory paper on the Gulf studies was recently issued, and another paper in the series (Kirkegaard 1972) describes the prawn larvae collected in this survey. D. Tuma (from the CSIRO) investigated, and reported upon, the sexual development of the banana prawn (1967) and he also prepared a guide to the genitalia of four commercial species (Tuma MS). Kirkegaard and his co-workers (1969, 1970) from the Gulf survey prepared synopses of biological data on six commercial species while Kirkegaard also reported upon a rare sergestid larva found in the Gulf (1969). Papers dealing with aspects of the biology of *Penaeus merguiensis* and several other species are being prepared by Munro.

At the conclusion of the Gulf survey Kirkegaard, Tuma and R. Walker transferred to Scarborough (Brisbane) to the East Coast Prawn Project, under the leadership of A. J. Bruce (1967), to participate in a study of the distribution and abundance of the king prawn (and its fishery) in Moreton Bay and adjacent oceanic waters. They were later joined by J. Brundritt (1968) and then by C. Lucas (1969). In 1969–70 there were further staff changes: Bruce resigned as Project Leader and was replaced by P. C. Young, Tuma and Walker transferred to the new Northern Prawns Research Project while I. Kirkegaard moved to an appointment with the Northern Territory Administration, Fisheries Division. Kirkegaard's (1970) paper on the larvae of *Trachypenaeus fulvus*, Lucas' *et al.* (1972) report on the mortality rates of marked king prawns and Lucas' manuscript on the population dynamics of the king prawn stocks of south-east Queensland are products of the East Coast Prawn Project. W. Barber, H. Kirkman, C. Lee, M. A. Potter and I. Somers were appointed to the East Coast Project over the past two years.

A notable feature of the East Coast Project was the initiation of special hydrological research to provide data for a study of the movement of larval and juvenile prawns across Moreton Bay (Newell 1971a, b). Special hydrological studies were also undertaken as part of the Northern Prawn Project (Cresswell 1971, Newel 1973).

In July 1969 the CSIRO Division of Fisheries and Oceanography initiated the Northern Prawn Project to investigate the population dynamics of the banana prawn, and for a general study of the prawn resources of Northern Australia. The ultimate goals of this project are to assess the effects of fishing on the stocks, and to provide a basis for formulation of management measures for the fishery. This project is operated from the Division's Cronulla laboratory under the leadership of J. S. Hynd. The size of the professional and technical staff, the cost of the project, the area of operations (southern Queensland to Nickol Bay, W.A.) and the number of species encountered are all remarkably high. This investigation started with a comprehensive river sampling program for juvenile prawns, a log book program and several tagging studies to determine distribution and migration of the prawn stocks and early results were recently summarised by Austin (1972).

N.S.W. State Fisheries commenced its investigation of prawn culture in 1966 as a result of the widespread interest in aquaculture, and of prawns in particular. Racek (1959) drew attention to the special suitability of the greasyback prawn for farming because of its estuarine breeding habits. Thus when the Brackish Water Fish Culture Research Station was completed at the end of 1971 this species was the first to be used in spawning experiments conducted by I. Smith. As expected, this species readily spawned in an aquarium but the rearing of larval stages was not so easily accomplished; however, recent attempts have proven successful, and eastern and western king prawn larvae have also been reared. Current research is directed to developing methods for mass rearing of larvae. Earlier this year G. Maguire was appointed to develop methods for the large-scale rearing of juvenile prawns and thereby assist in the execution of the prawn culture program.

The author's research on the school prawn stock and fishery in the Hunter region, and on the migration and geographical distribution of the king prawn, was recently summarised in a paper presented at the National Prawn Seminar (Ruello 1973b) and full details are available in several other papers (Ruello 1970, 1973a, c, MS.).

In 1970, the South Australian Fisheries Department appointed J. Bradbury to conduct research on new fisheries in Spencer Gulf and St Vincent Gulf. Bradbury resigned from the South Australian Department (to take up an appointment in Tasmania) after a year's work and was replaced by M. King. The results of South Australia's research are not yet available.

A notable point is the recent prawn research by post-graduate university students in Queensland and Western Australia. T. White (1973) investigated the population dynamics of the tiger prawns in Exmouth Gulf for his Ph.D. degree from the University of W.A. while P. Hindley (1972), at the James Cook University of North Queensland was studying the feeding biology of banana prawns for his Ph.D. degree.

FRESHWATER AND INLAND PRAWNS

The freshwater and inland prawns of Australia have received little attention from zoologists and the literature is limited to about a dozen papers, principally on *Macrobrachium*. Riek (1951) investigated the distribution of *Macrobrachium* and presented a key for their identification; he later (1953, 1967) described two corallanid isopods parasitic on these prawns. Fielder's (1970) study of the larval development of *M. australiense*, Williamson's (1972) study of *M. intermedium*, and the account of the reproductive behaviour of captive *Macrobrachium* prawns by Ruello *et al.* (1973) have some economic implication and are mentioned here.

Studies of fishing craft and gear

FISHING CRAFT

Australian vessels engaged in prawn fishing were critically reviewed by the country's leading naval architects, and by Jan-Olof Traung, the Chief of FAO's Fishing Vessel Section, at the 1966 Technical Meeting on Fishing Boats (at Broadbeach, Queensland). W. J. Hood, a Sydney architect, investigated the design of prawn trawlers and their performance in crossing bar harbours (many trawlers have capsized while crossing the sand bars at the entrance to many northern N.S.W. rivers). He reported that a vessel is likely to broach under bad sea conditions when the relationship between the sea wave length and the length of a vessel is approximately 2 : 1 and he presented two new designs for prawn trawlers for areas with bar harbours (Hood 1966).

R. T. Wright (1966), a Brisbane architect, reviewed the history and evolution of the contemporary (i.e. 'east coast') prawn trawlers and their deck gear and layout and noted that what was most unusual about these vessels was not their form (many were converted Danish-seine and similar vessels) but the type and layout of the deck equipment and gallows. Wright also discussed the advantages and disadvantages of double-rig trawling.

After two tours of the Australian fishing scene, Traung (1967) reported that the Australian winches are practical and inexpensive but noted that they could be simplified further with some additional engineering and planning. He suggested that a large net drum could be used advantageously for hauling the trawl; he also suggested that the small prawn trawlers in Sydney and Newcastle 'were generally sub-standard'.

The recent spectacular development of prawn fisheries in western, southern and northern Australia has led to the design and construction of large, steel, double-rig, refrigerated trawlers, and standardisation of vessels by large fleet owners. Full details of various classes of modern Australian prawn trawlers have been given in many issues of *Australian Fisheries* over the past few years; this journal has also recorded many other news items on fishing vessels and their gear. Despite the need, and widespread requests for special research on the design and per-

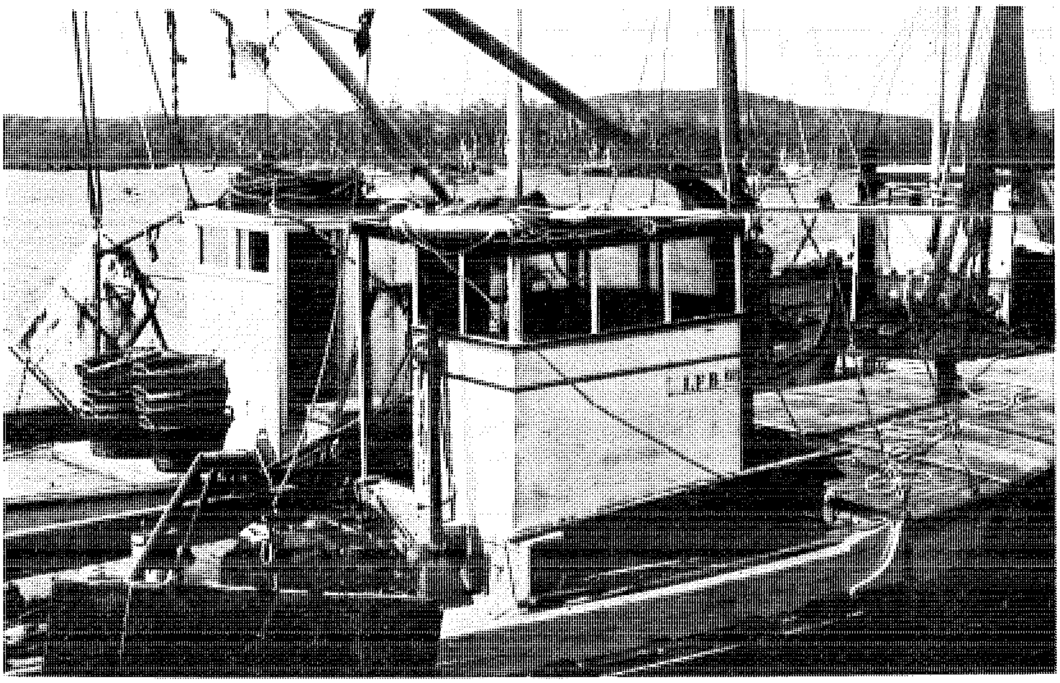


Fig. 7. Photograph of prawn trawlers at Evans Head (c. 1953). Note the small light winches and trawling gear and the simple open decks. (Photo by A. A. Racek).

formance of prawn trawlers (see discussions following Hood's 1966 paper) little has been forthcoming. T. B. Gorman and co-workers from N.S.W. State Fisheries have described their studies on warp loads and power requirements in the *Kapala* cruise reports, and Gorman will present the results of his statistical study of prawning vessels and gear usage at the National Prawn Seminar.

FISHING GEAR

The earliest published study of Australian prawn fishing gear was conducted by A. O'Grady, a Technical Adviser with the Commonwealth Fisheries Office (Department of Primary Industry). He described the fishing vessels and the various types of net and otter boards, and their methods of construction in a paper prepared for the 1955 Indo-Pacific Fisheries Council meeting in Tokyo (O'Grady 1957).

A decade later T. B. Gorman also described the otter boards and trawls used by Australian prawn trawlers (1966a, b). In 1967 P. D. Lorimer, from the Fisheries Division of the Department of Primary Industry, briefly reviewed the fishing craft, gear and nets used in the Australian fisheries in a paper presented at the Fisheries Development Conference. In 1969 Lorimer and his colleague, W. J. Innes, discussed the history and salient characteristics of the more popular trawls in their excellent publication on the construction and operation of prawn trawls, winches, and otter boards. Three years later Gorman (1972) carried out a comparative study of the design and operation of two small prawn trawls. W. D. Hughes (1972) from the Department of Primary Industry, Fisheries Division, described the vessels, gear and methods used in the northern prawn fishery.

The few papers cited above do not represent all of the prawn gear research carried out in this country. Regrettably, other studies have not been completed or published and considerable data is stored in departmental or personal files. The mesh selectivity of prawn trawl codends has been investigated on more than one occasion in N.S.W. and Queensland but the results of these important studies have not yet been published. There is considerable information on Australian fishing gear in various issues of *Australian Fisheries*, and several Australian papers have details on the fishing gear in particular regions. (Racek 1957b, Department of Primary Industry 1959, Ruello 1969b).

Despite the enthusiasm created by the formation of a Gear Research Committee (of the Commonwealth-State Fisheries Conference) in 1964 and the discussions arising from the 1966 meetings on Fishing Boats, the development of fishing craft and gear technology in Australia has been tardy and inadequate.

Prawn preservation and processing

A serious outbreak of food poisoning in the Newcastle area (N.S.W.) in the summer of 1947–48, allegedly due to the consumption of prawns from Myall Lakes and the Tuggerah Lakes, led to the commencement of scientific studies of prawn quality in Australia. W. J. Scott, a bacteriologist from the Council for Scientific and Industrial Research (CSIR, now CSIRO) Homebush laboratory of the Division of Food Preservation and Transport, investigated the reported food poisoning, the bacteriology of prawns and the changes which occur during handling and marketing, following a request from the Director General of Public Health in N.S.W. Scott (1948) found no proof of the cause of the food poisoning but he concluded that the methods used in handling prawns were such that bacterial food poisoning could readily occur during warm weather.

It is noteworthy that an outbreak of food poisoning brought about by the improper handling of large catches of school and greasyback prawns in Tuggerah Lakes in 1945 led to the prohibition of daytime prawn fishing in these lakes for more than a decade.

In 1950 the CSIRO Division of Food Preservation and Transport commenced a study of the nature and cause of 'black staining' (black spot) in cooked prawns, at the request of the Evans Head Fishermen's Co-operative. R. Allan visited the Evans Head area in July to observe the conditions of catching, handling, processing and distribution of prawns from the newly discovered, rich oceanic fishing grounds. Allan found that the facilities at the Co-operative's factory were totally inadequate for the large catches commonly taken—a daily catch of 450 kg per vessel was not uncommon and there was a fleet of about 20 vessels. It must be noted that the small trawlers then in use (Fig. 7) had no facilities for storing or cooking prawns and that the factory personnel had had little experience in cooking large quantities in a short period of time. In an unpublished report on this visit Allan (1950) presented a number of recommendations on how the catch should be handled on board fishing vessels and how it should be cooked, refrigerated and transported to Sydney and other distant markets.

The cooking and transport of prawns from the northern N.S.W. fisheries apparently improved during the next few years, but in April 1953 the extraordinarily large catches of prawns at Ballina, Evans Head and Tweed Heads were followed by the condemnation of hundreds of boxes (18-23 kg each) of prawns at the Sydney Fish Market because the prawns had unsightly black or brown heads, and a further study on prawn cooking and transport. This time the request to the CSIRO came from the N.S.W. State Fisheries Department.

Allan and his co-workers from the Homebush laboratory carried out comprehensive field and laboratory investigations and submitted a detailed report on their findings. Allan (1953) noted that 0.5% of 15 741 boxes of prawns received at the Sydney market from November 1952 to June 1953 were condemned because of poor quality. He reported that the brown head condition developed during the cooking procedure and hence was not an indicator of poor quality, whereas the black head condition was due to '. . . enzymic action on the blood of undercooked prawns' and was frequently associated with bacteriological spoilage. Bacteriological condemnations and depreciation were at a high level in frozen cooked prawns, particularly those from Ballina, because the prawns were not cooled sufficiently after cooking and because of the inadequate freezing facilities at the Co-operatives. Empey (1954) discussed this study and presented recommendations for improving prawn quality.

The Division continued research on melanosis in prawns for several years but its Annual Report for 1957–58 noted that 'Investigations have been commenced on the post-mortem changes in prawn flesh and their effects on glycogen depletion and ultimate pH . . . studies have been made on the susceptibility of canned prawn flesh to grey and black discoloration'. Prawn research was apparently discontinued during the following decade but the 1967–68 Report from the Division of Food Preservation, North Ryde laboratory (the name and address had changed) reported that prawn studies had been initiated, by W. A. Montgomery, with emphasis on quality assessment, development of melanosis and freezing techniques. Montgomery and Sidhu subsequently prepared two articles (1968a, b) on prawn preservation and processing for the *Australian Fisheries Newsletter*. The prawn research program was gradually expanded under the leadership of A. R. Johnson and several more papers on prawn processing and quality were produced by Montgomery and co-workers (1970a, 1970b, 1972).

In November 1971, J. H. Ruello commenced investigations on the processing and quality of prawns from the northern Australian fisheries; this work is being carried out from the Ryde laboratory of the Division of Food Research (another change of name) with a grant provided by the Fishing Industry Research Committee. The early results of studies on the storage of prawns in refrigerated sea water are presented in a paper prepared for the National Prawn Seminar. Ruello and McBride (1973) recently conducted a study of the consumer acceptability of the royal red prawn, for N.S.W. State Fisheries, and found that this species was readily accepted as a prawn cutlet but was rejected when boiled. The higher temperature generated during the cooking of the cutlet apparently expelled the unpleasant taste component which is commonly found in the boiled prawn.

Although the study of prawn preservation and processing has long been dominated by the Australian Government's Division of Food Research (and its predecessors), this field has recently attracted the attention of State departments in N.S.W. and Queensland. The N.S.W. Health Department (Government Analyst Laboratory) has, since 1966, examined imported and local prawns to determine their microbiological status and Proudford (1972) recently summarised the findings of these studies. The sampling and examination of prawns from Sydney fish shops (Proudford 1972) are continuing and are being supplemented with a comprehensive microbiological survey of the N.S.W. prawn industry, initiated this year by A. Fordham (of the Government Analyst Laboratory of Lidcombe) and the present author.

In Queensland, B. I. Brown has been investigating prawn processing and quality at the Sandy Trout Food Preservation Research Laboratory since 1968 and a brief summary of his work may be found in the annual reports issued by the Laboratory. Brown has been examining several methods of controlling melanosis in green king prawn tails and the Laboratory's 1970–71 Report recorded that sodium sulphite was more effective and economical than ascorbic acid in inhibiting black spot. Brown and his colleagues are continuing their studies on melanosis and they will also be investigating the effects of prolonged storage of prawns in salt brine, in 1973–74 (personal communication).

Socio-economic studies

There have only been two comprehensive studies of the economic aspects of Australian prawn fisheries (Department of Primary Industry 1970, 1973). The first was an economic investigation of the Shark Bay and Exmouth Gulf fisheries in 1966–67 and 1967–68 while the second dealt with the northern prawn fishery (from Bowen, Queensland to Darwin, N.T.). These outstanding studies obtained a large amount of valuable data on the operating costs and earnings of various types of fishing vessels operating under different conditions, and no attempt will be made here to discuss this work. These reports are strongly recommended to the interested reader.

In addition to the above studies on the primary sector of the industry, the Fisheries Branch (now Division) of the Department of Primary Industry has periodically examined the overseas markets for Australian prawns. Kearns (1956) briefly discussed the overseas markets and the likely prospects for Australian exports. The Department later carried out detailed studies of the United States market for prawns (1966) and then the Japanese market for prawns (1969). These two papers are also useful contributions to our knowledge of the Australian prawning industry and will not be discussed at length here, apart from a brief note on the abundance of valuable data they contain. Meany (1967) discussed the marketing of Australian imports and exports of prawns at the Australian Fisheries Development Conference in Canberra, and Breiner (1972) discussed Australia's prawn production in relation to world markets.

The sociological aspects of the Australian fishing industry (fish and crustaceans) have attracted even less interest than the economics of the industry, and the author does not know of any past or current work dealing specifically with the prawning industry. One notable general study relevant to this paper was carried out by the Department of Labour and National Service (1967)—this dealt with 'The Manpower Situation in the Fishing

Industry' and the paper has a large appendix on 'Labour Aspects of Selected Fisheries'.

In addition to the above studies, there are further data and information available in the Australian literature but they are scattered throughout the documents and papers produced for National Management or Development Conferences and in the many issues of *Australian Fisheries* (and its predecessors).

The general neglect of socio-economic research of Australian fisheries is surprising in view of the obvious need for such data in determining management practices. The limited funds available for research have probably contributed greatly to the apparently low priority on socio-economic studies in Australian Fisheries Departments. Valuable data could be obtained at a reduced price by providing moderate grants for post-graduate research students at universities or other research institutions. This scheme has an added benefit in that the post-graduate students may adopt a more independent and less parochial outlook than is commonly found in departments responsible for fisheries management or development.

Acknowledgments

It is a pleasure to acknowledge the assistance provided by many people, in particular I would like to thank Messrs N. Haysom, I. Kirkegaard, J. Penn, M. A. Potter, Dr A. A. Racek, and especially Mrs T. Holstein who had the arduous task of typing the manuscript.

LITERATURE CITED

COLEFAX, A. N. (1940). 'An Australian species of *Acetes* (Crustacea Macrura, Sergestidae), with remarks on the distribution and literature of the genus.' *Rec. Aust. Mus.*, 20(5), pp. 341-352.

CRESSWELL, G. R. (1971). 'Current measurements in the Gulf of Carpentaria. *CSIRO Aust. Div. Fish. Oceanogr. Rep.*, 50.

NEWELL, B. S. (1971a). 'Chlorinity and temperature distribution in Deception Bay, Queensland, 1968–69. *CSIRO Aust. Div. Fish. Oceanogr. Rep.*, 49.

—— (1971b). 'The hydrological environment of Moreton Bay, Queensland, 1967-68.' *CSIRO Aust. Div. Fish. Oceanogr. Tech. Pap.*, 30.

—— (1973). Hydrology of the Gulf of Carpentaria, 1970-71. *CSIRO Aust. Div. Fish. Oceanogr. Tech. Pap.*, 35.

SCOTT, E. (1939). *A short history of Australia.* Oxford University Press, 398 pp.

Other references cited in the text may be found in Bibliography (Part II).

APPENDIX

CURRENT PRAWN RESEARCH

1. **CSIRO Division of Fisheries & Oceanography**, Cronulla, N.S.W.
   (a) Northern prawn project
   J. S. *HYND*, Project Leader
   River sampling of juvenile prawns, tagging studies and log book programs in northern Australia. Principally on *Penaeus merguiensis.*
   (b) Gulf of Carpentaria prawn study.
   I. S. R. MUNRO is 'writing up' results of his Gulf work.
2. **CSIRO and Queensland Department of Primary Industries.** Fisheries Research Station, Deception Bay, Queensland
   East coast prawn project—study of biology and fishery of *Penaeus plebejus.*
   CSIRO: P. C. YOUNG (Distribution of juveniles) Project Leader
   W. BARBER (Adult biology/postlarvae)
   H. KIRKMAN (Botanist)
   C. LUCAS (Population dynamics)
   S. SMART (Statistician)
   I. SOMERS (Mathematician)
   QDPI: M. POTTER (Migration and population studies)
   C. LEE (Studies on postlarvae)
3. **N.S.W. State Fisheries**, Sydney, N.S.W.
   N. V. RUELLO
   (a) Hunter region prawn stocks—completion of 'writing up'
   (b) Impact of Munmorah Power Station on Tuggerah Lakes prawns
   (c) Ecology and reproductive biology of freshwater *Macrobrachium* (long term part-time study)
   (d) Microbiological status of N.S.W. prawning industry
   Project (d) is a joint study with the N.S.W. Government Analyst Laboratory. A. FORDHAM and N. V. RUELLO.
   (e) Potential of commercial prawn culture
   I. R. SMITH Breeding and spawning experiments, and rearing of larvae
   G. MAGUIRE Mass rearing of juveniles
4. **Northern Territory Administration,** Fisheries Branch, Darwin, N.T.
   I. KIRKEGAARD and D. GREY
   Studies on *Macrobrachium* culture

5. **Department of Fisheries, South Australia,** Adelaide, S.A.
    - M. KING Biology and fishery of *Penaeus latisulcatus*
6. **Department of Fisheries and Fauna,** Western Australia.
   Marine Laboratory, Waterman, W.A.
    - J. PENN Biology and fishery of *Penaeus latisulcatus* in W.A.
7. **CSIRO Division of Food Research,** North Ryde, N.S.W.
    - J. H. RUELLO Processing and quality of 'northern prawns'
8. **Queensland Department of Primary Industries,** Sandy Trout Food Preservation Laboratory, Hamilton, Brisbane Qld.
    - B. I. BROWN Control of melanosis in *Penaeus plebejus*
9. **University of Sydney, Zoology Department**, Sydney, N.S.W.
    - A. A. RACEK Studies on the *Dana* and *Galathea* collections of deep water prawns
10. **University of Queensland, Zoology Department**, St Lucia, Queensland.
    - D. J. MORIARTY Physiology of digestion in prawns
11. **University of Adelaide, Zoology Department**, Adelaide, S.A.
    - P. ZED Biology of *Penaeus latisulcatus*

PART II

AN ANNOTATED BIBLIOGRAPHY OF PRAWNS AND THE PRAWNING INDUSTRY IN AUSTRALIA

INTRODUCTION

Australia has extensive prawn stocks and large commercial fisheries now exist in all mainland States except Victoria. A natural outcome of the growth of the prawning industry is that there are currently about twenty fisheries scientists, several oceanographers and mathematicians, two food scientists and one microbiologist engaged in research on prawns or some aspect of the prawning industry. As the traditional industry and commercial aquaculture expand the demand and need for 'prawn research' will increase. The Department of Primary Industry, Fisheries Division, produced a *Bibliography of Australian Fisheries* (1971) with 85 references listed under the heading 'prawns' and arranged in chronological order. This bibliography is a useful document but it is incomplete and outdated, and there is a need for a new bibliography.

The present bibliography was hastily prepared for the 1973 National Prawn Seminar, and should be regarded as a provisional edition. This edition will be revised by the author and published as a Technical Report by N.S.W. State Fisheries. The author accepts responsibility for errors of omission or commission and would welcome notification of such errors.

METHODS

Subject definition. For the purposes of this paper the word *prawn* refers to the larger members of the Section Penaeidea and Caridea (Sub-Order Natantia) which have real or potential commercial value.

Types of work included. Books, and research papers or articles published in professional, technical or fishing industry journals (or publications) have been listed in alphabetical order. Articles from newspapers or magazines have been omitted. Many regular publications such as annual reports and various Government publications frequently make mention of prawns or the prawning industry but all such notes were omitted (principally because of space limitation). However, a list of these regular publications is presented below. Brief anonymous articles in the monthly *Australian Fisheries* were also omitted. Unpublished manuscripts and theses are included. Most of the papers presented at the 1967 Australian/N.Z. Meeting on Decapod Crustacea were omitted.

Annotations. Almost all of the references presented herein have been sighted by the author and the annotations were then composed after reading each reference. Papers not seen by the author are marked with an asterisk. The annotations are designed to help the reader determine whether or not a particular reference is worth searching for and reading; they should not be used as a guide to the merit of research work. To save time and space, annotations were kept short and concise—usually less than 50 words.

ACKNOWLEDGMENTS

I would like to thank Mrs J. Bryant for her assistance in obtaining 'obscure' references. My gratitude is also extended to the many other people who assisted me in this work.

REGULAR PUBLICATIONS WHICH FREQUENTLY REFER TO PRAWNS AND PRAWNING INDUSTRY

(a) Annual reports of State Fisheries Departments
  Australian Bureau of Statistics (Fisheries)
  CSIRO Division of Fisheries and Oceanography
  CSIRO Division of Food Research
  Sandy Trout Food Preservation Research Laboratory (Qld)

(b) Australian-State Government Fisheries Conference papers

(c) Reports from various Government Committees associated with (b) above

(d) Departmental publications, e.g.
  The Fisherman (N.S.W.)
  F.I.N.S. (W.A.)
  Prawn Newsletter (S.A.)

(e) State and Australian Government Proclamations, Regulations and Acts.

(f) Progress reports, e.g. northern prawn project information bulletins.

(g) Trade publications, e.g.
  Fish Trade Review (N.S.W.)
  Markwell Fisheries News (Qld)

(h) *Australian Fisheries.* This monthly publication, and its predecessors, has extensive records of the development of prawn research and the prawning industry.

BIBLIOGRAPHY

ALLAN, R. (1950). Report on the Evans Head (N.S.W.) prawn industry. Unpublished report, 6 pp. (in CSIRO Food Research, Ryde, library).
Describes the facilities and methods used by the Evans Head Fishermen's Co-operative and presents recommendations for facilitating handling of prawns and reducing the risks of spoilage.

ALLAN, R. (1953). Investigation on the condition of cooked prawns at the Sydney Fish Market from November 1952 to June 1953. Unpublished report, 8 + ix pp. (in CSIRO Food Research, Ryde, library).
It was concluded that there was need for improvement in the condition of prawns reaching the market to ensure both a reduction in the quantities condemned and a general improvement in their bacteriological condition.

ANONYMOUS (1958). 'Foreign shrimp fisheries. Other than central and South America.' U.S. Fish. Wildl. Serv. *Spec. Sci. Rep. Fish.* 254, pp. 1-71. This is a reasonable review of the Australian industry as it was in the early 1950s (pp. 66-71); much of the information was apparently from Racek (1957b).

ANONYMOUS (1962). 'Prawn farming shows promise.' *World Fishing* 11(4), pp. 59-60.
Describes A. A. Racek's experiments in farming the greasyback prawn (*Metapenaeus bennettae*) in ponds at Taren Point, Sydney. This is the first account of prawn farming in Australia.

ANONYMOUS (1968a). 'Unit fisheries of Australia —east coast prawn trawling fishery.' *Aust. Fish. Newsletter,* 27(2), pp. 17, 19. The species, their distribution, fishing season, fishing unit and gear, catch composition and other fishery characteristics are summarised.

ANONYMOUS (1968b). 'Unit fisheries of Australia —west coast prawn fishery.' *Aust. Fish. Newsletter,* 27(2), pp. 19, 21. As for citation above. Both of these articles were expanded and reprinted in *Aust. Fish. Newsletter,* 27(9).

ANONYMOUS (1971a) 'N.S.W. brackish water fish culture station ready to begin operations'. *Aust. Fish.,* 30(9), pp. 4-6.
Includes a general discussion of prawn farming and an account of the proposed culture methods for the station.

ANONYMOUS (1971b). 'Constructing prawn net otter boards'. *Aust. Fish.,* 30(7), pp. 16-17.
A brief discussion of the method of construction of otter boards. Illustrated with six good photographs.

ANONYMOUS (1972a). 'Black spot in prawns'. *Aust. Fish Insert* 1, 4 pp.
A guide on how to recognise black-spot (melanosis), what causes it and how to determine whether prawns are acceptable or not for export. (From *Aust. Fish.* 31 [6].)

Anonymous (1972b). 'Australia. Shrimp industry grows; in many ways parallels U.S. development'. *Fish Boat,* 17(6), pp. 87-88.
This is a good recent account of the Australian industry, particularly the northern prawn fishery.

Anonymous (1972c). '1972 Gulf prawn season short but hectic'. *Aust. Fish.,* 31(8), pp. 8-11.
A short account of the fishing success in the Gulf of Carpentaria in April-May 1972. Copiously illustrated with photographs of the fishing and processing operations of Markwell Fisheries.

Austin, R. H. (1970). 'Northern prawn project.' *Aust. Fish.* 29(3), pp. 7-10. (Reprinted as *Aust. Fish. Leaflet* no. 15).
An outline of the development and early progress of the northern prawn research project.

Austin, R. H. (1972). 'The northern prawn project—progress report.' *Aust. Fish.,* 31(2), pp. 8-12 (reprinted as *Aust. Fish. Leaflet* no. 17).
The progress of research on the prawn stocks (estimation of juvenile abundance) and the oceanography of the prawning areas are described.

Austin, R. H. (undated). *East Coast Prawn Project.* Information Circular no. 1, 8 pp. (probably published 1973).
This informal publication outlines the life history of the eastern king prawn, particularly in relation to Moreton Bay, and the aim of the project ('to assist the fishery'); the various sections of this research project are then discussed in detail.

Barker, D. J. (1963). 'Prawn market prospects overseas.' *Aust. Fish. Newsletter,* 22(6), pp. 17, 18, 26.
It was reported that there were substantial opportunities for exports to the United States and smaller scale opportunities in Japan and Europe.

Bate, C. S. (1888).* 'Report of the Crustacea Macrura collected by H.M.S. *Challenger* during the years 1873-1876.' *Rep. Sci. Res. Challenger,* 24, pp. 1-942.
Bate described the new species *Trachypenaeus anchoralis,* endemic to Australia, from a single female specimen collected by the *Challenger* in the Arafura Sea. He also recorded the presence of several non-endemic species in Australian waters.

Bishop, J. A. (1967). 'The zoogeography of the Australian freshwater decapod crustacea,' *In Australian inland waters and their fauna. Eleven studies.* (Ed. A. H. Weatherley). A. N. U. Press, Canberra, pp. 107-122.
The evolution and general zoogeography of the Palaemonidae are discussed in this paper. *Macrobrachium* came into Australia from the north via Indonesia and New Guinea; whereas *Palaemonetes* came from Africa, perhaps as a euryhaline larva carried by ocean currents.

Boone, L. (1935). 'Scientific results of the world cruise of the yacht *Alva,* 1931. Crustacea Macrura.' *Bull. Vanderbilt Oceanogr. (Mar.) Mus.,* 6, pp. 71-101.
Boone recorded that 12 specimens of *Metapenaeus (Penaeopsis) macleayi* were collected in New Caledonia in 1931 by the *Alva* world expedition. However, the *Alva* specimens are not *M. macleayi* (Racek personal communication).

Breiner, D. J. (1971). 'Northern Australia top prawn producing area.' *Aust. Fish.,* 30(12), pp. 3-5.
The northern Australian production rose from 2.3 million kg in 1968 to 6.8 million kg in 1970 and an estimated 9 million in 1971. The total catch is 'dissected' and discussed in relation to seasonal and areal factors and the size of the vessels.

Breiner, D. J. (1972). 'Australia increasingly important prawn producer and exporter.' *Aust. Fish.,* 31(4), pp. 17-20.
Australian prawn production has increased four-fold in the past decade. The annual rate of increase is five times the world average and Australia is becoming an important exporter. It is suggested that the domestic market could be expanded.

Dakin, W. J. (1931). 'On a new Bopyrid parasite from the coast of New South Wales.' *Proc. Linn. Soc. N.S.W.,* 56(4), pp. 267-272.
The Bopyrid parasite *Crassione aristaei* (n. gen. et sp.) is described and figured. The host is *Aristaeomorpha foliacea,* and the majority of specimens examined were infested.

Dakin, W. J. (1935). *Science and seafisheries with special reference to Australia.* Pap. Proc. R. Soc. Tasmania, 1934, 39 pp. + 2 plates.
This published lecture gives the first account of the life history of *Penaeus plebejus.* (The prawn illustrated in Plate II is not *P. plebejus* despite the caption.)

Dakin, W. J. (1938). 'The habits and life history of a penaeid prawn (*Penaeus plebejus* Hesse).' *Proc. zool. Soc. Lond.,* 108A, pp. 163-183.
The emigration of *P. plebejus* from the estuaries to the ocean, and its life history are discussed. The larval and postlarval stages are then described and figured.

Dakin, W. J. (1940). 'Further notes on the life history of the king prawn, *Penaeus plebejus.*' *Rec. Aust. Mus.,* 20(5), pp. 354-359.
Further notes and figures on the protozoeal and mysis stages of *P. plebejus.*

Dakin, W. J. (1946a). 'Life history of a species of *Metapenaeus* in Australian coastal lakes.' *Nature, Lond.* 158, p. 99.
The unusual—estuarine—breeding habit of *Metapenaeus bennettae* is recorded for the first time.

Dakin, W. J. (1946b). 'Prawns and prawn fisheries.' *Fish. Newsletter,* 5(4), pp. 4, 5, 21.
The Australian prawn fisheries are discussed

and examined in relation to overseas fisheries. The life history and breeding migrations are outlined with special reference to the eastern king prawn (*Penaeus plebejus*).

Dakin, W. J. (1946c). 'A further step in the elucidation of the strange story of the penaeid prawns.' *Aust. J. Sci.*, 8, pp. 160-161.
A note on the oceanic breeding habit of *Penaeus plebejus* and the estuarine spawning habit of *Metapenaeus bennettae*.

Dakin, W. J., and Colefax, A. N. (1940). *The plankton of the Australian coastal waters off New South Wales.* Monogr. Univ. Sydney Dep. Zool., 1, 215 pp.
Includes notes and figures on the larval stages of *Penaeus plebejus*, other penaeids, and carids.

Dall, W. (1956a). 'Australian prawns: Identification and biology.' *Fish. Newsletter*, 15(2), pp. 5, 7, 9, 21.
Excellent notes on taxonomy, colour, distribution, characteristic anatomical features and general biology of the commercial species of prawns.

Dall, W. (1956b). 'Western Australian prawn survey. Peel Inlet and Exmouth Gulf.' *Fish. Newsletter*, 15(6), pp. 11, 13, 15.
The survey results, biological and hydrographical observations, are recorded and discussed: *Penaeus merguiensis* and *P. esculentes* were found in Exmouth Gulf while *Metapenaeus dalli* was common in Peel Inlet.

Dall, W. (1957). 'A revision of the Australian species of Penaeinae (Crustacea : Decapoda : Penaeidae).' *Aust. J. mar. Freshwat. Res.*, 8, pp. 136-231.
Twenty-eight species (six new) are fully described and figured and full keys to genera and species are given. Subsequently revised in part by Racek & Dall (1965).

Dall, W. (1958). Observations on the biology of the greentail prawn, *Metapenaeus mastersii* (Haswell) (Crustacea : Decapoda : Penaeidae).' *Aust. J. mar. Freshwat. Res.*, 9(1), pp. 111-134.
The ecology, growth, and behaviour of *M. mastersii* (now *bennettae*) from the Brisbane River, Qld, are described. A reversed respiratory current and other adaptations to burying in mud, and a possible associated diurnal rhythm are described.

Dall, W. (1964). 'Studies on the physiology of a shrimp, *Metapenaeus mastersii* (Haswell) (Crustacea : Decapoda : Penaeidae). I. Blood constituents.' *Aust. J. mar. Freshwat. Res.*, 15(2), pp. 145-161.
Three cell types were distinguished: a thigmocyte, a lymphocyte-like cell, and a granular amoebocyte. Glucose-6-phosphate, a trace of another ester, glucose, a nucleotide, and glucosamine, probably from mucoproteins, were identified by paper chromatography. Total protein ranged from 1.9 to 4.5%, non-protein N from 13.7 to 25.3 mg %. Starch gel electrophoresis resolved four protein bands.

Dall, W. (1965a). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). II. Endocrines and control of moulting.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 1-12.
Eyestalk ganglionic neurosecretory endocrine glands, the sinus gland, and sensory-pore organ are described and figured. It was concluded that there was little evidence of a specific moult-accelerating hormone in this species, that morphogenetic hormone is ineffective unless extrinsic factors and nutritional state are optimal, and that moult-inhibiting hormone is largely produced within the eyestalk.

Dall, W. (1965b). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). III. Composition and structure of the integument.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 13-23.
Inorganic constituents comprised 38.7% by weight of intermoult cuticle of which 98.5% was calcium carbonate. Chitin was 34.3% of organic constituents. The epicuticle contains vertical submicroscopic structures, while the procuticle consists of fibrils parallel with the surface. During pre-moult the epidermal cells grow progressively taller and the new epicuticle and exocuticle are synthesised.

Dall, W. (1965c). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). IV. Carbohydrate metabolism.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 163-180.
The results of studies on the oxidation of [^{14}C] glucose suggested that glycogen does not play a major role, the animal being dependent on a sustained intake of food for both oxidative metabolism and chitin synthesis. It is suggested that an acid mucopolysaccharide is supplied by the blood to the epidermis as a chitin precursor.

Dall, W. (1965d). 'Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea : Decapoda : Penaeidae). V. Calcium metabolism.' *Aust. J. mar. Freshwat. Res.*, 16(1), pp. 181-203.
The gills account for 90% of total ^{45}Ca uptake and 70% of total output. Exchange also occurs across abdominal cuticle and via the anus. The midgut appeared to be a site of Ca excretion. Calcium in the exocuticle was revealed only by histochemical tests, but visible Ca deposits occurred at the exocuticle-endocuticle interface.

Dall, W. (1967a). 'The functional anatomy of the digestive tract of a shrimp, *Metapenaeus bennettae* Racek and Dall (Crustacea : Decapoda : Penaeidae).' *Aust. J. Zool.*, 15, pp. 699-714.
The anatomy of the proventriculus, digestive gland, midgut and its diverticula, the rectum and the methods of feeding are described.

Copiously illustrated with excellent drawings.

Dall, W. (1967b). 'Hypo-osmoregulation in Crustacea.' *Comp. Biochem. Physiol.*, 21(1), pp. 653-678.

The osmoregulation of *Metapenaeus bennettae*, and three species of crabs was investigated. It was concluded that water uptake and salt excretion in this strong hypo-osmoregulating prawn take place in the gut, and that the major salt excretion does not occur via the gills.

Dall, W. (1968). 'Food and feeding of some Australian penaeid shrimps.' *FAO Fish. Rep.*, no. 57 vol. 2, pp. 251-258.

The food of five species of commercial importance consisted of the remains of small animals and a large amount of unrecognisable material. It is suggested that the latter consists of bacteria, algae and microfauna obtained by browsing on the surface of the substrata and that these micro-organisms form the main component of the diet. Structure and function of the gut are described. Digestion and assimilation is rapid and this is attributed to the fine nature of the food.

Dall, W. (1971). 'The role of homarine in decapod crustacea.' *Comp. Biochem. Physiol.*, 39(1B), pp. 31-44.

The homarine concentration in the blood and muscle of *Metapenaeus* did not vary significantly with salinity, except for an initial increase in blood levels at S $14^{0}/_{00}$. Since no direct role for homarine in osmoregulation could be demonstrated it was suggested that it may have a function associated with osmotically active amino acids.

Dannevig, H. C. (1904). *Preliminary report upon the prawning industry in Port Jackson.* N.S.W. Government Printer 2, 17 pp.

This was the first investigation of an Australian prawn fishery; the effects of prawn hauling nets on young fish were examined following complaints about the destruction of small fish by prawners. Dannevig concluded that the destruction of fishes was not excessive in view of the value of the prawn fishery.

Denne, L. B. (1968). 'Some aspects of osmotic and ionic regulation in the prawns *Macrobrachium australiense* (Holthuis) and *M. equidens* (Dana).' *Comp. Biochem. Physiol.*, 26(1), pp. 17-30.

The brackish water prawn *M. equidens* is a hyper-hypo-osmotic regulator while the fresh water species *M. australiense* is a hyper-osmotic regulator. Both are capable of producing a blood hypo-osmotic urine and both are able to regulate their Na and Cl blood concentrations by means of urine, under certain conditions.

Department of Fisheries and Fauna, W.A. (1966). *The Shark Bay prawning industry.* An 'irregular' Bulletin produced for fishermen. 13 pp.

This is a high quality production outlining the early development of the Shark Bay fishery, the existing fishery, fleet composition and research program on the biology of the commercial species. Considerable attention is given to the collection and processing of fishermen's log-book data.

Department of Fisheries and Fauna, W.A. (1967). *Licence limitation in the prawn fisheries.* Australian Fisheries Development Conference, 1967. Paper BP/32, 11 pp.

This is a detailed discussion of the management policy, in particular licence limitation, for the Shark Bay and Exmouth Gulf fisheries, and outlines the policy proposed for prospective fisheries north of Exmouth.

Department of Fisheries, S.A. (1972). *The South Australian prawn fishery.* Informal publication. 6 pp. The history, development and current status of the South Australian prawn fisheries are outlined.

Department of Labour and National Service (1967). *The manpower situation in the fishing industry.* Australian Fisheries Development Conference, 1967. Paper BP/59, 6 pp. + Appendix.

The level and distribution of employment in the fishing industry, the labour supply and demand and working conditions are examined. The appendix discusses the labour aspects of selected fisheries for each State.

Department of Primary Industry (1959). *Exploratory prawn trawling in eastern Australian waters.* 114 pp. + 19 maps.

Details are given of the results of exploratory trawling off the east coast of Australia, by the L.F.B. *Challenge*, during the period July 1957 to August 1958. Descriptions and plans of the trawls used during the survey are included. (Reprinted as *Aust. Fish. Paper* no. 17, 1961).

Department of Primary Industry (1966). *The United States market for prawns.* Aust. Fish. Paper no. 1, 31 pp. The U.S. market is discussed in great detail, utilising many tables and graphs. It was concluded that the prospects for Australian exports were favourable.

Department of Primary Industry (1967a). *Air transport of prawns from remote areas.* Australian Fisheries Development Conference, 1967. Paper BP/34, 2 pp.

The availability of air transport for prawns is discussed briefly and the costs of such transport between several Queensland towns and cities are catalogued.

Department of Primary Industry (1967b). *The Australian prawning industry—resources, fisheries, production, handling and prospects.* Australian Fisheries Development Conference, 1967. Paper BP/49, 29 + 25 pp.

The title fully describes this fact-filled paper which is amply illustrated with graphs and other figures. A most useful document.

Department of Primary Industry (1969). *The Japanese market for prawns.* Aust. Fish.

Paper no. 5, 13 pp.
The Japanese consumption of prawns has risen steadily in recent years. Between 1963 and 1966 wholesale prices of Japanese prawns remained fairly stable while prices of imported prawns rose slightly. The widening gap between consumption and domestic production should enhance Australia's opportunities for exports to Japan. Has considerable amount of data in tables and appendixes.

DEPARTMENT OF PRIMARY INDUSTRY (1970). *An economic survey of the Shark Bay and Exmouth Gulf prawn fisheries 1966–67 and 1967–68.* Fisheries Rept. no. 6, 46 pp.
When gross receipts and costs from prawning only are considered (some vessels also participate in the rock lobster fishery), Shark Bay boats under 18 m earned an average return to capital of 11.7%; for larger boats earnings averaged 12.5%. In Exmouth Gulf earnings were 19% and this higher earning is attributed to the smaller size and operating costs of vessels in the Gulf fishery. Includes much valuable data.

DEPARTMENT OF PRIMARY INDUSTRY (1971). *Bibliography of Australian fisheries.* Aust. Fish. Paper no. 12, 58 pp. This paper has a subject and author list for references. It has 85 references under the heading 'Prawns', dating back to Ogilby 1893, arranged in chronological (not alphabetical) order.

DEPARTMENT OF PRIMARY INDUSTRY (1973). *An economic investigation of the northern prawn fishery. Costs and earnings of trawlers.* Fisheries Rept. no. 8, 62 pp.
Average return on capital invested was less than 3% in 1968–69 and 1969–70 but averaged 28% in 1970–71. In all, 35% of vessels surveyed recorded a net loss on a three-year average basis while 30% of vessels recorded an average rate of return greater than 20%. Contains much useful data.

ELLEM, A. W. (1967). The development of the fishing industry on the north coast of N.S.W. (A paper prepared for the Clarence Regional Development Committee. 32 pp.)
This paper was prepared for an analysis and determination of the future development of the fishing industry by the Committee. Prawn fishing is the principal section of the industry in the region and the production, fishing gear, research, industry problems and development are discussed. No evidence is provided to support many of the author's opinions.

EMPEY, W. A. (1954). 'Report on handling of prawns.' *Fish. Newsletter*, 13(11), pp. 5, 7, 23.
The handling and marketing of prawns in N.S.W. are discussed and recommendations presented for improving the quality of prawns being sold.

FARNELL, F. (1898). *Report upon the trawling operations off the coast of New South Wales between the Manning River and Jervis Bay, carried on by H.M.C.S.* Thetis. N.S.W. Sea Fisheries Rep., N.S.W. Govt. Printer, Sydney, 61 pp.
The *Thetis* found king and school prawns off the N.S.W. coast and provided the first records of littoral penaeids of commercial value in Australian seas.

FIELDER, D. R. (1970). 'The larval development of *Macrobrachium australiense* Holthuis, 1950 (Decapoda, Palaemonidae) reared in the laboratory.' *Crustaceana*, 18, pp. 60-74.
An excellent description of the various larval stages of this species; includes many figures.

FISH ENQUIRY COMMISSION (1880). *Report of the Royal Commission appointed to enquire into and report upon the actual state and prospects of the fisheries industry in this colony.* N.S.W. Legislative Council Doc. C 100, 128 pp.
This report has many valuable (historic and practical) items of information on the prawn fisheries in N.S.W. prior to 1880.

GATES, D. J. (1956). 'Sulphite ice stops prawn black spot.' *Fish. Newsletter*, 15(9), p. 7.
Notes that American workers found that prawns packed in ice containing 0.25% sodium bisulphite or sulphite were protected almost perfectly from black spot formation for 14 days.

GORMAN, T. B. (1966a). 'Unusual Australian method, double-rig trawling for prawns.' *World Fishing*, 15(6), pp. 36-37.
The unusual but effective method of double-rig trawling and the trawl nets used by the 16 m fishing boat *Alveda* are described.

GORMAN, T. B. (1966b). 'Prawning in New South Wales.' *World Fishing*, 15(10), pp. 58-60 and 15(12), pp. 44-46.
The first part of this article discusses the trawl doors and nets used by the 9 m fishing boat *Rossetta* and by other vessels in N.S.W. Part II has a description and designs of six Australian prawn trawls.

GORMAN, T. B. (1972). 'Investigated: Two prawn trawls and a fish trawl.' *Fisherman*, 4(5), pp. 9-22.
The design and construction of two small prawn trawl nets and underwater observations on these nets are discussed and illustrated with diagrams and photographs.

GORMAN, T. B., GRAHAM, K., AND JACKSON, C. J. (1972). F.R.V. *Kapala* cruise report no. 11.
The results of cruises on exploratory prawn trawling for deep water prawns are presented. Observations on the warp load and power requirements of selected trawls and otter boards are recorded.

GORMAN, T. B. AND JACKSON, C. J. (1972). F.R.V. *Kapala* cruise report nos 8, 9, 10.
Further results of exploratory trawling, prawn preservation studies and observations on warp

loads and power requirements of fishing gear. *Hymenopenaeus sibogae* was found between 230 and 825 m.

GORMAN, T. B., AND JOHNSON, H. T. (1971). F.R.V. *Kapala* cruise report nos. 1, 2, 3, 4.
The fishing gear, methods, and the results of exploratory trawling on the N.S.W. continental slope are discussed. The best catch of *Hymenopenaeus sibogae* between Port Stephens and Eden was 90 kg per hour. Report no. 4 has an appendix on the palatability studies on *H. sibogae*, prepared by A. J. Collins.

GRANT, E. M. (1972). *Guide to fishes.* Department of Primary Industries, Brisbane, 472 pp.
Both editions of this book (1972 and 1965) have descriptive notes and black and white, and colour, plates on the more important commercial species of prawns.

GRIFFIN, D. J. G. (1970). 'A re-examination of the type material of *Penaeus granulosus* Haswell, 1879 (Decapoda, Penaeidae).' *Crustaceana*, 19, pp. 99-102.
The history of nine specimens used by Haswell in his description of *P. granulosus* is outlined, and the selection of the lectotype, by the author, is discussed.

GRIFFIN, D. J. G., AND STANBURY, P. J. (1970). 'Type specimens in the Macleay Museum, University of Sydney. V. Decapod crustaceans.' *Proc. Linn. Soc. N.S.W.*, 95(1), pp. 122-131.
The type specimens of five penaeid species are re-examined and listed.

GRIFFIN, D. J. G., AND YALDWYN, J. C. (1968). The constitution, distribution and relationships of the Australian decapod crustacea. *Proc. Linn. Soc. N.S.W.*, 93(1), pp. 164-183.
Includes an interesting and valuable discussion of the prawn fauna.

HALE, H. M. (1927). *The Crustaceans of South Australia.* Govt Printer, Adelaide, 201 pp.
Has brief notes on *Penaeus latisulcatus* and *Penaeopsis novaeguineae.*

HANCOCK, D. A. (1972). 'Shark Bay prawn fishery—Consideration of a closed season proposal.' *F.I.N.S.*, 5(2), pp. 33-35, 43.
Fishermen's suggestion for a closed season (summer) on prawn trawling in Shark Bay is discussed. It is concluded that on biological grounds there is no valid reason for the suggested closure.

HANCOCK, D. A. (1973). 'Why log books?' *F.I.N.S.*, 6, pp. 1-7. A useful article explaining the importance of fishermen's log books to fishery management.

HARRIS, N. V. (1955) 'Offshore prawning grounds off Sydney.' *Fish. Newsletter*, 14(10), p. 15.
Detailed results are given of experimental deep water trawling for king prawns off the N.S.W. coast, between Botany Bay and Palm Beach (by A. A. Racek in June 1955). The tests were conducted from a 20 m trawler from Sydney.

HARRISON, G. G. T. (1965). 'Gulf of Carpentaria Prawn Survey Committee, progress report to 30 June 1964.' *Fish. Notes Qld*, 2(1), pp. 1-22.
An account is given of the circumstances and decisions leading up to the initiation of the survey, and of the general outline of the first year's operation. A summary of the results is given and the conduct of operations is reviewed. Some tentative conclusions are drawn from the observations made in the first year's operations.

HASWELL, W. A. (1879). 'On the Australian species of *Penaeus.*' *Proc. Linn. Soc. N.S.W.*, 4(1), pp. 38-44.
This has the original description of the school prawn *Metapenaeus (Penaeus) macleayi* and several other new species.

HASWELL, W. A. (1882). *Catalogue of the Australian Stalk and Sessile-eyed Crustacea.* Australian Museum, Sydney, 324 pp.
More new species and records of prawns are presented. Also has an illustrated discussion of the anatomy of *Penaeus (canaliculatus) plebejus.*

HAYSOM, N. M. (1953). 'Prawning in Queensland.' *Fish. Newsletter*, 12(2), pp. 11, 23.
An interesting article on the development of prawn trawling in Moreton Bay and Queensland oceanic waters in the early 1950s.

HAYSOM, N. M. (1967). *Prawn fishery development in remote areas.* Australian Fisheries Development Conference, 1967. Paper MP/4, 5 pp.
The author suggests that fishery development in remote areas is hampered by: (a) distance from established alternative fishing grounds; (b) distance from major centres of population; (c) lack of knowledge or experience; (d) unusual fishing conditions, and (e) lack of knowledge of economic factors. Suggestions are given for reducing the effects of such adverse factors.

HESS, W. (1865).* 'Beitraege zur Kenntnis der Decapoden–Krebse Ost–Australiens.' *Arch. Naturgesch.*, 31, p. 168.
This includes the description of the new species *Penaeus plebejus,* the eastern king prawn, which was one of the first species fished in this country and currently the most important commercial species in eastern Australia.

HINDLEY, P. R. (1972). Investigations into the feeding biology of the banana prawn, *Penaeus merguiensis de Man.* (Ph.D. thesis, James Cook University of North Queensland.) *P. merguiensis* detects and locates its food by chemosensory mechanisms. Vision was not found to play any part in the process. Feeding behaviour and circadian rhythm are discussed in relation to light and water flow conditions.

HOOD, W. J. (1966). Design study on lines necessary for a 15 m prawn trawler suited to bar work. (Technical meeting on fishing boats, Paper no. 4, 15 pp. + 12 pp. discussion.)
The hazards of bar work and their relationship

to the vessel's hull are described. The design of two vessels specially designed for bar work are presented and discussed. A summary of this paper appeared in *Aust. Fish. Newsletter*, 25(4), pp. 15, 17.

Hughes, W. D. (1972). 'Northern prawn fishery —gear, boats and methods.' *Aust. Fish.*, 31(2), pp. 13-21.

Vessel layout, winches, trawls, otter boards and the handling of the catch are examined in this comprehensive article.

Ivanov, B. G. (1964). *A world survey of the shrimping trade.* Israel Program for Scientific Translations, 106 pp. This paper has a poor and outdated account of the Australian industry (pp. 101-105).

Jones, A. R. (1969). Studies on trawled invertebrates from Moreton Bay. (M.Sc thesis, University of Queensland, 196 pp.)

This includes a discussion of the seasonal and circadian fluctuations in the catches of a number of penaeid prawns.

Kailis, T. G. (1967). *Restricting factors in the development of prawn fisheries in northern western Australia.* Australian Fisheries Development Conference, 1967. Paper BP/43, 8 pp. This paper is chiefly concerned with the Exmouth Gulf fishery. The factors discussed are: 1. Research and technical information. 2. Labour. 3. Recreation. 4. Fuel and water. 5. Accommodation. 6. Communications. 7. Unloading facilities. 8. Engineering and slipping. 9. Transport.

Kearns, F. J. (1956). 'Australian prawns: the broad view on exports.' *Fish. Newsletter*, 15(2), pp. 17, 23.

A brief discussion of the overseas market and the prospects for Australian exports.

Kirkegaard, I. (1969). 'Further records of a rare Sergestid larva (Crustacea : Decapoda).' *J. Nat. Hist.*, 3, pp. 591-595.

The protozoea III of an unidentified Sergestid from the Gulf of Carpentaria is figured and described, and the probable identity (*Sicyonella*) is discussed.

Kirkegaard, I. (1970). 'The larvae of *Trachypenaeus fulvus* Dall (Crustacea : Decapoda : Penaeinae).' *Fish. Notes Qld*, 3(1), pp. 15-26.

Larval stages were described from material obtained from laboratory hatched eggs and from the plankton in Moreton Bay. Similarities to, and differences from, other *Trachypenaeus* larvae are discussed.

Kirkegaard, I. (1972). 'The fauna of the Gulf of Carpentaria. III. Larval stages of Penaeidae (Crustacea : Decapoda).' *Fish. Notes Qld*, (N.S.) 2, pp. 58-70.

A taxonomic account of larval stages obtained in the southern Gulf and Norman River plankton. Seven genera are covered in this report, which is amply illustrated with line drawings.

Kirkegaard, I., and Griffin, R. (1971). 'Smaller prawns do sell.' *Turnoff*, 3(2), pp. 33-36.

The distribution and biology of the rainbow prawn *Parapenaeopsis sculptilis* are outlined, and the authors suggest that this species has potential economic importance in the Northern Territory.

Kirkegaard, I., Tuma, D. J., and Walker, R. H. (1970). 'Synopsis of biological data on the banana prawn, *Penaeus merguiensis* de Man, 1888.' *CSIRO Fish. Synopsis*, 8.

The species synopses are a compendium of data on the distribution, biology, fishery and culture of the species.

Kirkegaard, I., and Walker, R. H. (1969). 'Synopsis of biological data on the tiger prawn, *Penaeus esculentes* Haswell, 1879.' *CSIRO Fish. Synopsis*, 3.

Kirkegaard, I., and Walker, R. H. (1970a). 'Synopsis of biological data on the rainbow prawn (*Parapenaeopsis Sculptilis*) (Heller, 1862).' *CSIRO Fish. Synopsis*, 4.

Kirkegaard, I., and Walker, R. H. (1970b). 'Synopsis of biological data on the school prawn, *Metapenaeus macleayi* (Haswell, 1879).' *CSIRO Fish. Synopsis*, 5.

In need of revision in view of recent publications on this species.

Kirkegaard, I., and Walker, R. H. (1970c). 'Synopsis of biological data on the greentail prawn, *Metapenaeus bennettae,* Racek and Dall, 1965.' *CSIRO Fish. Synopsis*, 6.

Kirkegaard, I., and Walker, R. H. (1970d). 'Synopsis of biological data on the eastern king prawn, *Penaeus plebejus* Hess 1865.' *CSIRO Fish. Synopsis*, 7.

Kirkegaard, I., and White, G. F. (1970). 'Brown tiger prawn. Introducing the prawns behind their industry.' *Turnoff*, 2(4), pp. 38-41.

An article on the distribution, habits and fishery of *Penaeus esculentes.*

Leyendekkers, J. V. (1965). 'Gulf prawn survey.' *Aust. Fish. Newsletter*, 24(3), pp. 15, 17.

This article traces the (early) progress of the survey of the prawn resources of the Gulf of Carpentaria. Twenty-two species of prawns had been found in the 1600 experimental trawls. The 'balling up' behaviour pattern of *Penaeus merguiensis* is briefly noted.

Lorimer, P. D. (1967). *The suitability of existing prawn trawlers and their gear.* Australian Fisheries Development Conference, 1967. Paper BP/37, 5 pp.

A brief discussion of the fishing craft, gear and nets used in Australian fisheries.

Lorimer, P. D., and Innes, W. J. (1969). *Australian prawn trawling gear.* Aust. Fish. Paper no. 6, 15 pp.

An excellent guide to net making and rigging, board setting, warp lengths and winch capacities. The history and evolution of the gear are also discussed.

Lucas, C. (MS.).* Preliminary estimates of stocks of the king prawn *Penaeus plebejus,* in south-east Queensland. (For submission to *Aust. J. mar. Freshwat. Res.*)

Lucas, C., Young, P. C., and Brundritt, J. K. (1972). 'Preliminary mortality rates of marked king prawns *Penaeus plebejus*, in laboratory tanks.' *Aust. J. mar. Freshwat. Res.*, 23, pp. 143-149.
Petersen-tags produced a mortality of the order of $M = 0.11$ per week in juveniles but no significant mortality in adults. Floy tags had an initial mortality of 50% and an instantaneous mortality of $M = 0.15$ per week in juveniles; in adults there was an initial mortality of 25% but no further mortality.

McDonnell, J. C. D. (1969). 'Prawning—the new industry.' *Turnoff*, 1, pp. 59-64.
Outlines the origins of the prawn fishery in northern Australia with emphasis on the Northern Territory and the prospective development of the fishery and research in the Territory.

Maclean, J. L. (1971). *The potential of aquaculture in Australia.* Aust. Fisheries Paper no. 21 (provisional edition), 161 pp.
The biological, legal and marketing aspects of the culture of freshwater and marine prawns (and other organisms) are examined in this review.

Maclean, J. L. (1973). 'An analysis of the catch by trawlers in Moreton Bay (Qld) during the 1966-67 prawning season.' *Proc. Linn. Soc. N.S.W.*, 98, pp. 35-42.
This study showed that the catch rate of prawns by trawl has not changed significantly since the early years (1950 +) of the fishery, and that there was no evidence of a decline in the winter whiting (*Sillago maculata*) fishery in the Bay.

McNeill, F. A. (1944). 'Prawns and prawning.' *Aust. Mus. Mag.*, 8(8), pp. 262-266.
Principally about prawns and prawn fishing in Tuggerah Lakes in N.S.W. Notes that the Australian (estuarine) fishery is second only to the American fishery. Also notes that there was a serious diminution in the number of prawns in the previous ten years (in N.S.W.).

McNeill, F. A. (1950). 'The new ocean prawn fishery.' *Aust. Mus. Mag.*, 10(2), pp. 37-40.
This article records that the first concentration of ocean prawns was discovered off Palm Beach (Broken Bay). Good photographs of converted seine trawlers prawning off Evans Head.

McNeill, F. A. (1958). 'The Australian prawn industry.' *Aust. Mus. Mag.*, 12(10), pp. 321-326.
An illustrated article on the N.S.W. prawn fishery; suggests that the Sydney fishery was started in Botany Bay by Welsh, English and Scottish migrants in the early days of settlement.

McNeill, F. A. (1968). *Great Barrier Reef Expedition 1928–29. Crustacea, Decapoda and Stomatopoda.* Scient. Rep. G. Barrier Reef Exped., VII (1).) 98 pp. + 2 plates.
Nine species of penaeid prawns and 30 carid species taken from the central Barrier Reef area by the British Expedition and others are recorded in this large report.

Meany, T. F. (1967). *Australian prawn marketing.* Australian Fisheries Development Conference, 1967. Paper 15, 3 pp. + 6 tables.
The Australian production of prawns and the import and export trades are discussed. It is concluded that the prospects on the local and export trade are excellent.

Montgomery, W. A., and Prater, A. R. (1963). 'Fisheries products 7. Krupek (Kroepoek) or prawn crisps.' *Aust. Fish. Newsletter*, 22(9), p. 21.
A detailed account of the manufacturing procedure for the commercial production of prawn crisps from peeled prawn and tapioca flour.

Montgomery, W. A., and Sidhu, G. S. (1968a). 'Prawn preservation and processing.' *Aust. Fish. Newsletter*, 27(1), pp. 7, 9, 11.
An interesting review of the methods used to preserve and process (cook) prawns in Australia. Includes a discussion of the development of black spot (melanosis) and of bacterial spoilage in prawns.

Montgomery, W. A., and Sidhu, G. S. (1968b). 'Current trends in prawn processing.' *Aust. Fish. Newsletter*, 27(2), pp. 13, 15.
New techniques for processing prawns, principally breaded prawns and accelerated freeze drying are examined.

Montgomery, W. A., and Sidhu, G. S. (1972). 'Crustacean processing and quality.' *CSIRO Fd. Res. Q.*, 32(1), pp. 10-14.
The preservation of prawns in refrigerated sea-water systems, and by (dry) freezing, on Australian vessels is outlined in this address to the Australian Institute of Refrigeration, Air Conditioning and Heating (Inc.).

Montgomery, W. A., Sidhu, G. S., and Vale, G. L. (1970). 'The Australian prawn industry. I. Natural resources and quality aspects of whole cooked fresh prawns and frozen prawn meat.' *CSIRO Fd. Preserv. Q.*, 30(2), pp. 21-27.
The quality aspects of fresh prawns and prawn products and the operation of the quality inspection system for local and imported prawns are well discussed.

Montgomery, W. A., Sidhu, G. S., and Christie, E. M. (1970). 'The Australian prawn industry. II. Quality aspects for export prawns.' *CSIRO Fd. Preserv. Q.*, 30(3), pp. 44-50.
The refrigeration and salt uptake of prawns are discussed. The paper then presents the results of taste-panel and chemical tests of quality in export packs and the results of a survey of the salt content of local and export prawns.

Moore, R. B. (1963). Shark Bay prawn fishery.

Report of proceedings Fisheries Management Seminar, 1963, pp. 117-122. The circumstances leading to the entry of the Nor-West Whaling Company Ltd into the prawn fishing and processing business at Shark Bay are outlined and the results of the first year of operation are discussed.

Morris, Muriel C., and Bennett, Isobel (1951). 'The life-history of a penaeid prawn (*Metapenaeus*) breeding in a coastal lake (Tuggerah, New South Wales). *Proc. Linn. Soc. N.S.W.*, 76, pp. 164-82.
Metapenaeus bennettae is an unusual penaeid in that it may breed in estuarine waters and does not normally migrate to sea for reproduction. The egg, nauplius, protozoea, mysis, post-mysis and postlarval stages (from the plankton) are described and figured and compared with other penaeidae.

Munro, I. S. R. (1966). 'The Gulf of Carpentaria prawn survey as an example of fisheries resource prospecting *Northern Territory Scientific Liaison Conference 1966*, vol. 2, 8 pp.
The background and preliminary results of the Gulf survey are discussed. The operating difficulties and survey problems, the habitat, and the distribution and abundance of prawns are described. This survey differed from many earlier resource surveys (and some later ones) in that it was organised to study the organisms in relation to their environment concurrently with prospecting operations.

Munro, I. S. R. (1968a). 'Prawns of tropical Australia.' *Aust. Fish. Newsletter*, 27(1), pp. 12-14.
An illustrated account of the principal species in northern Australia. Distributions, maximum sizes and distinguishing features are presented.

Munro, I. S. R. (1968b). 'The prawn, its habitat and life.' *Aust. Fish. Newsletter*, 27(1), pp. 25-27.
Outlines the general features of penaeid biology and associated environment with particular reference to tropical Australian waters. The life cycle, including larval development, of *Penaeus merguiensis* is used as an example.

Munro, I. S. R. (1968c). Predicting when to catch banana prawns. The schooling behaviour of *Penaeus merguiensis* is discussed in relation to tidal phenomena in the southern part of the Gulf of Carpentaria. The appearance of prawns in 'balled-up' schools as seen on echo-sounders is illustrated. The detection of schools by 'mudboils' and sounder traces is described.

Munro, I. S. R. (1973). 'The fauna of the Gulf of Carpentaria: No. 1. Introduction and station lists.' *Fish. Notes Qd* (N.S.), 2, pp. 1-38.
Dates, positions and depths of trawl stations occupied by *Rama*, *Laakanuki* and *Kestrel* (in the Gulf survey) are listed. A summary description of the geography, climate and oceanography of the survey area is given. The sampling pattern used in prospecting for commercial quantities of penaeid prawns is described.

N.T.A. Fisheries Division. Undated informal publication. *The Northern Territory prawn fishery*. 6 pp. roneoed.
This publication (produced about 1972) outlines the development and operation of the N.T. fishery, and has a discussion of the life history and biology of prawns. One of the few publications on the N.T. fishery.

Ogilby, D. J. (1893). *Edible fishes and crustaceans of New South Wales*. N.S.W. Govt Printer, Sydney, 212 pp. + 51 figs. Some interesting historical notes on Sydney's prawns. The *Penaeus* sp. cited is almost certainly *Metapenaeus bennettae* Racek and Dall.

O'Grady, A. (1955). Prawn trawling gear in Australian ocean waters. Paper prepared for the 1955 meeting of the Indo Pacific Fisheries Council, 26 pp. Published as 'Australian prawns: the gear that takes them' in *Aust. Fish. Newsletter*, 15(2), pp. 11, 13, 15, 23 (1956). (Also *World Fishing*, 5(5), pp. 54-56.)
The fishing gear, particularly trawls and otter boards, is described and illustrated.

Phillips, W. J. (1925). 'Notes on an Australian shrimp of the genus *Penaeus*.' *Aust. Zool.*, 4(1), p. 3.
A brief record of the export of school (*Metapenaeus macleayi*) and tiger prawns (*Penaeus*) from Sydney to Wellington, New Zealand. One company alone was importing half a tonne per month.

Pluckrose, D. H. (1956). 'Fish Board prawn export review.' *Fish. Newslett.*, 15(7), pp. 9, 27.
An account is given of early attempts, by the Queensland Fish Board, to market prawns and to establish facilities for the export trade. The first, experimental, shipments of prawns to the United States are described.

Pownall, P. C. (1972). 'Fishing banana and tiger prawns in north Australia.' *Fishing News International*, 11(9), pp. 48-50, 53.
This article describes the northern fishery, its catches and the fishing gear and techniques.

Prater, A. R., and Montgomery, W. A. (1963). 'Fisheries Products 6. Frozen raw breaded prawns.' *Fish. Newslett.* 22(8), pp. 26-27.
A brief and comprehensive discussion of the methods of preparation, packaging and freezing of breaded prawns (cutlets). Also includes the U.S.A. 'definition and standards of identity for frozen raw breaded shrimp'.

Proudford, R. W. (1972). *Microbial findings in food.* Irregular publication N.S.W. Govt Analyst Laboratories, 46 pp.
This paper was a contribution to the ANZAAS 1972 symposium on 'Changing Food Habits'. It summarises the results of surveys of the

microbiological status of local and imported prawns and other foods.

Racek, A. A. (1955). 'Littoral Penaeinae from New South Wales and adjacent Queensland waters.' *Aust. J. mar. Freshwat. Res*,, 6(2), pp. 209-241. (Res. Bull. St. Fish. N.S.W. no. 2.)
A revision of the Penaeinae, including full descriptions of 16 'Australian' species. A key to groups, genera and species is given for Penaeinae in Australian waters and the adjacent Indo-Pacific region.

Racek, A. A. (1957a). 'The systematic position of the school prawn from Western Australia.' *Fish. Bull. State Fish. W.A.*, 6, pp. 1-13.
Metapenaeus dalli, a commercially important species from W.A., is described and figured. This species was previously believed to be identical with *M. mastersii* from eastern Australia.

Racek, A. A. (1957b). 'Penaeid prawn fisheries of Australia with special reference to New South Wales.' *Res. Bull. St. Fish. N.S.W.*, 3, 19 pp. (Proc. Indo-Pacif. Fish. Coun. 6(III), pp. 347-358).
The biological, technological and marketing aspects of the Australian prawn fisheries of the 1950s are discussed in this Symposium paper. The early results of Racek's prawn investigations are also presented.

Racek, A. A. (1959). 'Prawn investigations in eastern Australia.' *Res. Bull. St. Fish. N.S.W.* 6, pp. 1-57.
This paper gives the results of detailed investigations on the biology, ecology and embryology of commercially important penaeid prawns in N.S.W. and adjacent waters. It is probably the best known Australian publication on prawns.

Racek, A. A. (1968). 'A new species of *Metapenaeopsis* (Crustacea : Decapoda) from northern Australian waters.' *Proc. Linn. Soc. N.S.W.*, 92(3), pp. 251-253 + 2 plates.
Metapenaeopsis wellsi is described from specimens from Exmouth Gulf (W.A.) and the Gulf of Carpentaria (Qld.).

Racek, A. A. (1970). Indo-west Pacific Penaeid prawn species of commercial importance. Indo-Pacif. Fish. Coun. 14th Session Symp. Paper 3, 31 pp.
This paper discusses the zoogeographical distribution, length-weight relationships and suitability for artificial cultivation of 40 species. Different farming methods, and early attempts at artificial cultivation of *Metapenaeus bennettae* are described.

Racek, A. A., and Dall, W. (1965). 'Littoral Penaeinae (Crustacea : Decapoda) from northern Australia, New Guinea and adjacent waters.' *Verh. Akad. Wet. Amst.* (b) 56(3), pp. 1-119.
A comprehensive taxonomic study and revision of the littoral Penaeinae; 13 new species are described and revised. Keys are given for the Indo-West-Pacific species of *Metapenaeopsis* and *Metapenaeus*.

Racek, A. A., and Yaldwyn, J. C. (1971). 'Notes on littoral Penaeinae (Crustacea : Decapoda) from the New Guinea area.' *Proc. Linn. Soc. N.S.W.*, 95(3), pp. 209-214.
The distribution and relationships of 12 species from the New Guinea-West Irian area are discussed.

Riek, E. F. (1951). 'The Australian freshwater prawns of the family Palaemonidae.' *Rec. Aust. Mus.*, 22, pp. 358-67.
Macrobrachium and *Palaemonetes* species are described. A key to the Australian *Macrobrachium* is presented and distributional notes are recorded.

Riek, E. F. (1953). 'A corallanid isopod parasitic on freshwater prawns in Queensland.' *Proc. Linn. Soc. N.S.W.*, 77, pp. 259-261.
A new genus and species of corallanid isopod, *Austroargathona caridophaga*, parasitic on freshwater prawns of the families Palaemonidae and Atyidae in Queensland, is described.

Riek, E. F. (1959). 'The Australian freshwater Crustacea,' in *Biogeography and ecology in Australia*. Monographiae biol., 8, pp. 246-258.
Includes a discussion of the origin and present distribution of the Palaemonidae.

Riek, E. F. (1967). 'A new corallanid isopod parasitic on Australian freshwater prawns.' *Proc. Linn. Soc. N.S.W.*, 91(3), pp. 176-178.
Austroargathona picta is described from inland N.S.W. and Queensland. The species is parasitic on freshwater prawns of the genera *Macrobrachium* and *Paratya*. The type species and only other described species are parasitic on the related prawns of the easterly flowing streams of coastal Queensland and N.S.W.

Roughley, T. C. (1966). *Fish and fisheries of Australia*. Angus and Robertson, Sydney, 328 pp.
The later editions of this book have notes and plates on several of the important commercial species of prawns.

Ruello, J. H., and McBride, R. L. (1973). *Consumer acceptability of the royal red prawn* Hymenopenaeus sibogae. CSIRO Fd. Res. Rep. no. 76, 9 pp. (Reprinted in *Fisherman* 5(2), in press.)
The consumer acceptability of *H. sibogae* is examined and compared to that of the king prawn *Penaeus plebejus*. As a boiled prawn, the latter species was more preferred whereas the former species was preferred by most tasters when the prawns were presented as fried cutlets.

Ruello, N. V. (1967a). 'Unit fisheries of Australia. N.S.W. East Coast estuary prawning.' *Aust. Fish. Newsletter*, 26(9), p. 26.
A brief outline of the species, fishing grounds, fishing craft, gear and season for the otter trawl, running net and hauling (seine) net

fishery in N.S.W. Fishing regulations, catch composition, annual production and disposal of catch are also summarised.

Ruello, N. V. (1967b). 'Unit fisheries of Australia. N.S.W. Set pocket net prawn fishery.' *Aust. Fish. Newsletter*, 26(9), pp. 26-27.
The pocket net fishery is briefly discussed under the headings given for the preceding paper.

Ruello, N. V. (1967c). 'New South Wales prawning industry.' *Fisherman*, 2(8), pp. 18-22. (Reprinted in *Aust. Fish. Newsletter*, 26(9), pp. 23-25, 27 and as *Aust. Fish. Reprint*, no. 2.)
An account of the history and development of prawn fishing and of past, current and proposed prawn research in N.S.W.

Ruello, N. V. (1969a). 'Prawn behaviour in the Hunter region.' *Fisherman*, 3(4), pp. 1-6. (Reprinted in *Comm. Fish. Marketing*, 4(6), pp. 12-16.)
The behaviour of the king and school prawn (*Penaeus plebejus* and *Metapenaeus macleayi*) in the Hunter River are discussed; the early results of research on the school prawn stock and fishery are then outlined and discussed in relation to the existing management procedures.

Ruello, N. V. (1969b). 'Hunter region prawn fishery.' *Fisherman*, 3(5), pp. 20-24.
An account of the history, development and current practices in the Hunter region estuarine and oceanic prawn fisheries. The school prawn *Metapenaeus macleayi* is the dominant species in the Hunter River but king prawns *Penaeus plebejus* are also caught in the river and at sea. *Parapenaeus australiensis* and *Plesionika ortmanni* are also taken offshore but only in small numbers.

Ruello, N. V. (1970). 'Prawn tagging experiments in New South Wales.' *Proc. Linn. Soc. N.S.W.*, 94(3), pp. 277-287.
An account is given of five field experiments in which an Atkins-type tag was attached to 3 358 prawns which were released in various areas of N.S.W. The methods used, the percentage of prawns recaptured and the initial mortality due to tagging are described and discussed. The first record of extensive migration of king prawns was obtained in one of the experiments.

Ruello, N. V. (1971). Some aspects of the ecology of the school prawn *Metapenaeus macleayi* in the Hunter River region of New South Wales. (M.Sc. thesis, University of Sydney, 145 pp.)
A study of the distribution, population composition, abundance, growth, movements and migrations, reproduction, feeding and burrowing habits of the species. Much of this work has been published as Ruello 1973a, b, c. A paper on growth and movements is in preparation.

Ruello, N. V. (1971–72). 'The influence of rainfall and man on the prawn populations of the Hunter River region.' *AMSA Bull.*, 36, pp. 11-12, 1971. (Reprinted in *Fisherman*, 4(3), pp. 8-12, 1972, and in *Hunter Natural History*, 4(3), pp. 189-193).
This brief paper was read at the 1971 AMSA meeting in Brisbane. The adverse effects of reclamation and pollution were described and illustrated and other human activities noted. The influence of rainfall on the distribution and abundance of *Penaeus plebejus* and *Metapenaeus macleayi* was discussed.

Ruello, N. V. (1973a). 'Burrowing, feeding, and spatial distribution of the school prawn *Metapenaeus macleayi* (Haswell) in the Hunter region (Australia).' *J. exp. mar. Biol. Ecol.*, 13, pp. 189-206.
The feeding and burrowing habits of the school prawn were studied as part of an investigation designed to determine the influence of the food content and particle size of the sediment on prawn distribution and abundance. Field and laboratory studies indicated that the particle size was more important than the food content for juvenile prawns.

Ruello, N. V. (1973b). Biological research and the management of prawn fisheries in New South Wales. (28 pp. MS)
Reviews the history and value of traditional fisheries regulations. This paper then describes how the results of recent biological studies on *Metapenaeus macleayi* and *Penaeus plebejus* are being used to formulate better management policies for N.S.W. fisheries.

Ruello, N. V. (1973c). 'The influence of rainfall on the distribution and abundance of the school prawn *Metapenaeus macleayi* in the Hunter River region (Australia).' *Mar. Biol.*, 23, pp. 221-228.
The initial and ultimate effects of heavy rainfall on the school prawn are described. The positive correlation observed between annual rainfall and the prawn catch of the following year is attributed to the influence of rainfall on the density of adults, on reproductive potential, recruitment and survival of young prawns in the region.

Ruello, N. V. (MS.). Geographical distribution, growth and spawning migration of the eastern king prawn *Penaeus plebejus* Hess in eastern Australia. MS submitted for publication in *Aust. J. mar. and Freshwat. Res.*
P. plebejus is commonly caught between Bundaberg (Qld) and Lakes Entrance (Vic.); a few specimens have been taken at Lord Howe I. and in Tasmania. The distribution is discussed in relation to the influence of the East Australia Current (EAC) system; it is postulated that the Tasmanian and Lord Howe prawns are transported from Australia as larvae, by the EAC system. A record migration of 930 km was noted.

RUELLO, N. V. (in press). A small beam trawl for sampling surface or demersal and benthic animals. MS. submitted for publication in *Aust. Soc. Limnology Bull.* (read at ASL Meeting 1973).

This paper describes and discusses the methods of construction and operation of a small trawl for sampling small prawns and other animals. Tables showing the animals collected with this trawl are presented.

RUELLO, N. V., MOFFITT, P. F., AND PHILLIPS, S. G. (1973). 'Reproductive behaviour in captive freshwater shrimp *Macrobrachium australiense* Holthuis.' *Aust. J. mar. Freshwat. Res.*, 24(2), pp. 197-202.

The nest building and beckoning behaviour, the female premating moult, the mating process, and parental care demonstrated by a pair of captive shrimps are described and compared with the reproductive activity previously recorded for several other palaemonid shrimps.

SCHMITT, W. L. (1926). 'Report on the Crustacea Macrura (Fam. Peneidae, Campylonotidae and Pandalidae) obtained by the F.I.S. *Endeavour* in Australian seas.' *Biol. Res. Fish. Exp. Endeavour*, 5(6), pp. 311-381.

A discussion of the 13 penaeid and three caridean species taken by the *Endeavour*, including descriptions of the new species *Penaeus maccullochi* and *Metapenaeopsis* (later *Metapenaeus*) *endeavouri*.

SCOTT, W. J. (1948). Food poisoning due to prawns. Unpublished report, 18 pp. (CSIRO Food Research, Ryde, library.)

A report on the investigation of alleged food poisoning in the Newcastle (N.S.W.) area following consumption of prawns from the Tuggerah Lakes and the Myall Lake region.

SLACK-SMITH, R. J. (1963). Licence limitation in the Shark Bay prawn fishery. (Report of Proceedings, Fisheries Management Seminar, 1963, pp. 36-38.)

The number of licences issued for the Shark Bay fishery in 1963 (25) was determined after a comparative study of the area of Shark Bay and Tortugas ground off Florida (U.S.A.) and of the optimal catch per unit effort of the latter fishery.

SLACK-SMITH, R. J. (1969a). 'A descriptive and analytical model of the Shark Bay prawn fishery.' *FAO Fish. Rep.*, no. 57, vol. 3, pp. 657-666.

A model based on the use of detailed data on catch, effort and size composition of catches is presented. The model distinguishes between the effects of growth, migration and variation in density with time. It provides a means of examining time, place and strength of recruit groups entering the fishery.

SLACK-SMITH, R. J. (1969b). 'The prawn fishery of Shark Bay, Western Australia.' *FAO Fish. Rep.*, no. 57, vol. 3, pp. 717-734.

The history, present status and management of the industry and the methods of fishery data collection are described. The importance of distinguishing the contributions of growth and migration to fluctuations of the fishery is illustrated by data on catch, effort and size-composition.

SLACK-SMITH, R. J., AND STARK, A. E. (1968). 'Automatic processing of Western Australian prawn fishermen's log-books.' *FAO Fish. Rep.*, no. 57, vol. 2, pp. 309-319.

The system of intensive log-book data collection from Western Australian fishermen and the computer processing systems for these data are described in full. The system is flexible and could be readily adapted to other research programs where large quantities of data are stored and manipulated.

SMITH, I. (1966). 'A hungry world looks to the prawn for an "Aquicultural Revolution."' *Fisherman*, 2(7), pp. 18-20.

A general account of overseas prawn farming methods and a brief discussion of the suitability of the greasyback prawn (*Metapenaeus bennettae*) for farming.

SMITH, I. (1971). 'Research into commercial fish farming gets underway at new research station.' *Fisherman*, 3(12), pp. 1-7.

Discusses the facilities of the Brackish Water Fish Culture Research Station at Port Stephens (N.S.W.), the potential of aquaculture of various species of fish and invertebrates and the methods proposed for culturing the greasyback prawn (*Metapenaeus bennettae*).

STARK, A. E., AND SLACK-SMITH, R. J. (1968). 'General remarks on the design, analysis and evaluation of fishery resource surveys.' *FAO Fish. Rep.*, no. 57, vol. 2, pp. 549-558.

The results of the prawn research program in Shark Bay (W.A.) are used to illustrate the way in which several types of biological and behavioural factors affect the distribution of abundance.

STEAD, D. G. (1898)*. 'Notes on the habits of some of the Australian malacostracous Crustacea.' *Zoologist*, 4(2), p. 209. Cited in Dakins (1938) paper and in Racek's (1955) discussion of *Penaeus plebejus*.

STEAD, D. G. (1905). *Crustaceans : Ancient*, modern and mythical. W. Brooks, Sydney, 62 pp.

Some interesting notes on *Penaeus monodon*, and on the king (*P. plebejus*) and the school (*Metapenaeus macleayi*) prawn.

These two common names are recorded apparently for the first time.

STEAD, D. G. (1908). *Edible fishes of New South Wales.* N.S.W. Govt Printer, Sydney, 123 pp.

More historical notes by Stead.

STEAD, D. G. (1910). *A brief review of the fisheries of New South Wales. Present and Potential.* N.S.W. Govt Printer, Sydney. 31 pp. + 17 plates.

Further notes; records large numbers of *Penaeus monodon* off Vaucluse (Port Jackson) in 1908.

Thompson, L. G. (1893). *History of the fisheries of New South Wales, with a sketch of the laws by which they have been regulated.* N.S.W. Govt Printer, Sydney (for the Chicago Exposition 1893), 126 pp.
Has some brief notes on prawns, particularly school prawns in the Hunter River, many inaccurate.

Thomson, J. M. (1956). 'Fluctuations in Australian prawn catch.' *Indo-Pacif. Fish. Coun.* 6(III), pp. 444-447.
The east coast fisheries are discussed with emphasis on the fluctuations in catch and their correlation with rainfall.

Traung, J. (1967). *Problems with Australian fishing boats.* Australian Fisheries Development Conference, 1967. Paper BP/27, 9 pp. (Also published as *Fisheries Report* no. 1; in *Aust. Fish. Newsletter*, 26(2), pp. 23-26 and as *Indo-Pacif. Fish. Coun. Paper* C.P. 20, 1968 meeting.)
The standard of Australian boats was generally good. Winches in prawn trawlers are practical and inexpensive but could be simplified; nets could be hauled on large net drums to reduce labour. The prawn trawlers in Sydney and Newcastle were considered sub-standard.

Tuma, D. J. (1967). 'A description of the development of primary and secondary sexual characters in the banana prawn, *Penaeus merguiensis* de Man (Crustacea : Decapoda : Penaeinae).' *Aust. J. mar. Freshwat. Res.*, 18(1), pp. 73-88.
The metamorphosis and functional aspects of male and female genitalia and the primary sexual development of both sexes are described. The effect of parasitism, by the bopyrid *Epipenaeon* sp., on the sexual development of the host is outlined.

Tuma, D. J. (MS). Guide to the genitalia of Australian commercial penaeids.
This is part of an incomplete CSIRO Tech. Paper, designed as an aid to the identification of commercial species; *Penaeus merguiensis, P. esculentes, P. latisculcatus* and *Metapenaeus endeavouri* were dealt with.

Walker, R. H. (MS). The otter trawl fisheries for banana prawns in Queensland and Western Australia prior to 1969. (22 pp. + 19 tables.)
A comprehensive account of the history and development of the banana prawn fisheries. There is much valuable data presented in the tables. A most useful historical document.

Welsby, T. (1967). *The collected works of Thomas Welsby.* (Ed. A. K. Thomson.) Vol. 1, Jacaranda Press, Brisbane, 397 pp.
Chapter 11. 'Principally Prawning' is a delightful essay on prawning in the Brisbane area at the close of the last century. Chapter 16. 'Marwedel's shoals and trawling' has a few historical records of trawling experiments in Moreton Bay.

Wharton, J. C. F. (1967). *Prawns in Victoria.* Informal publication, Vict. Fisheries & Wildlife Dept. (Prepared for Australian/N.Z. Meeting on Decapod Crustacea 1967), 11 pp.
This paper summarises the information available on prawns and prawn fishing in Victoria; the only publication on prawns in Victoria.

White, T. (1973).* Population dynamics of the tiger prawn—*Penaeus esculentes*—in Exmouth Gulf and implications for the management of the fishery. (Ph.D. thesis, University of Western Australia.)

Whitelegge, J. (1889). 'List of the marine and freshwater invertebrate fauna of Port Jackson and the neighbourhood.' *Proc. R. Soc. N.S.W.* 28, pp. 163-323.
Has records of several prawn species. Records that *Penaeus* sp., the greasyback prawn, was the most common prawn in Sydney and that the school prawn, *Metapenaeus macleayi*, was least common.

Whitelegge, J. (1900). 'The Crustacea, Part I, Decapoda and Stomatopoda,' in *Scientific results of the trawling expedition of H.M.C.S.* Thetis *off the coast of New South Wales, in February and March 1898.* Mem. Aust. Mus. 4, pp. 135-199.
The first records of king prawns in ocean waters, off Newcastle and Shoalhaven Bight, and school prawns in Shoalhaven Bight.

Williamson, D. I. (1972). 'Larval development in a marine and a freshwater species of *Macrobrachium* (Decapoda, Palaemonidae).' *Crustaceana*, 23(3) pp. 282-298.
The larval development of *M. intermedium* is described and illustrated from laboratory reared larvae. The parent was an ovigerous female collected at Cronulla, N.S.W. The freshwater species, *M. niloticus*, is from Lake Chad, Africa.

Wright, R. T. (1966). A study of winches, deck-gear and layout for fishing vessels and in particular prawn trawlers. Technical Meeting on Fishing Boats, Paper No. 9, 21 pp. + 7 pp. discussion.
The winches, gallows arrangement and construction, the combination sorting tray-ice box and deck layout of the 'East Coast' prawn trawler are discussed and illustrated with photographs and figures. A summary of this paper appeared in *Aust. Fish. Newsletter*, 25(7), pp. 13, 15, 17, 19.

APPENDIX III

PARTICIPANTS

Dr K. R. Allen
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Mr R. Ambrose
National Bank of A/Asia Ltd
43 Creek Street
BRISBANE, Qld 4000

Mr R. Austin
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Dr W. E. Barber
CSIRO, Division of Fisheries
and Oceanography
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Mr E. O. Burns
Queensland Fish Board
P.O. Box 54
MORNINGSIDE, Qld 4170

Mr D. Callaghan
Keppels Pty
P.O. Box 839
BUNDABERG, Qld 4670

M/s S. Carpenter
Division of Mathematics and Statistics
CSIRO
P.O. Box 1700
CANBERRA CITY, A.C.T. 2601

Mr A. W. Charles
CSIRO
P.O. Box 225
DICKSON, A.C.T. 2602

Dr W. Dall
CSIRO, Division of Fisheries
and Oceanography
W.A. Marine Research Laboratories
P.O. Box 20
NORTH BEACH, W.A. 6020

Mr P. A. Darling
Albright & Wilson (Aust.) Ltd
605 Toohey Road
SALISBURY, Qld 4170

Mr M. Dredge
Fisheries Branch
Department of Primary Industries
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Mr G. Evans
Fisheries Division
Department of Agriculture
CANBERRA, A.C.T. 2600

Mr L. W. Filewood
Department of Agriculture,
Stock and Fisheries
P.O. Box 2417
KONEDOBU, PAPUA/NEW GUINEA

Mr R. N. Garrett
Fisheries Branch
Department of Primary Industries
Fisheries Research Laboratory
M.S. 1800
MOURILYAN HARBOUR, Qld 4858

Dr K. T. Glasziou
David North Plant Research Centre
C.S.R. Research Limited
P.O. Box 68
TOOWONG, Qld 4006

Mr T. B. Gorman
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr K. J. Graham
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr D. L. Grey
Forestry, Fisheries, Wildlife, National
Parks and Environment Branch
P.O. Box 2783
DARWIN, N.T. 5794

Dr D. A. Hancock
Department of Fisheries and Fauna
W.A. Marine Research Laboratories
P.O. Box 20
NORTH BEACH, W.A. 6020

Mr M. Harris
Aquaculture
C/- Amatil
Box 145, G.P.O.
SYDNEY, N.S.W. 2001

Mr G. G. T. Harrison
Fisheries Branch
Department of Primary Industries
William Street
BRISBANE, Qld 4000

Mr N. M. Haysom
Fisheries Branch
Department of Primary Industries
William Street
BRISBANE, Qld 4000

Mr C. S. Hillery
J.W. Greer Aust. Pty Ltd
58 Wecker Road
MT GRAVATT, Qld 4122

Dr J. P. R. Hindley
CSIRO, Division of Fisheries
and Oceanography
W.A. Marine Research Laboratories
P.O. Box 20
NORTH BEACH, W.A. 6020

Mr J. S. Hynd
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Mr D. G. James
CSIRO, Tasmanian Regional Laboratory
Stowell Avenue
HOBART, Tas. 7000

Mr M. King
Department of Fisheries
Box 1191, G.P.O.
ADELAIDE, S.A. 5001

Mr I. R. Kirkegaard
Forestry, Fisheries, Wildlife, National
Parks and Environment Branch
Department of the Northern Territory
P.O. Box 2783
DARWIN, N.T. 5794

Mr H. Kirkman
CSIRO, Division of Fisheries
and Oceanography
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Mr J. S. Lake
Forestry, Fisheries, Wildlife, National
Parks and Environment Branch
Department of the Northern Territory
P.O. Box 2783
DARWIN, N.T. 5794

M/s M. Leedow
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr C. P. Lee
Fisheries Branch
Department of Primary Industries
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Dr C. Lucas
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Mr G. B. Maguire
Fisheries Branch
Chief Secretary's Department
Brackish Water Fish Culture Station,
C/- Post Office
SALAMANDER BAY, N.S.W. 2301

Dr W. B. Malcolm
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr C. McIntosh
Department of Agriculture,
Stock and Fisheries
P.O. Box 2417
KONEDOBU, PAPUA/NEW GUINEA

Mr B. McMahon
Biology and Environmental Study
Block W
Queensland Institute of Technology
BRISBANE, Qld 4000

Mr M. V. Melvin
Alkali Chemical Group
I.C.I. Australia
1 Nicholson Street
MELBOURNE, Vic. 3000

Dr D. J. W. Moriarty
Department of Zoology
University of Queensland
ST LUCIA, Qld 4067

Mr I. S. R. Munro
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Mr W. Murray
Queensland Fish Board
P.O. Box 54
MORNINGSIDE, Qld 4170

Dr R. A. Neal
Aquaculture Research and Technology
U.S. Department of Commerce
Gulf Coastal Fisheries Centre
Galveston Laboratory
4700 Avenue U
GALVESTON, TEXAS 77550, U.S.A.

Mr A. M. Olsen
Department of Fisheries
Box 1191, G.P.O.
ADELAIDE, S.A. 5001

Dr A. Osbourne
David North Plant Research Centre
CSR Research Limited
P.O. Box 68
TOOWONG, Qld 4006

Mr L. G. Pane
Keppels Pty
P.O. Box 839
BUNDABERG, Qld 4670

Mr M. A. Partis
Queensland Fish Board
P.O. Box 54
MORNINGSIDE Qld 4170

Mr J. W. Penn
Department of Fisheries and Fauna
W.A. Marine Research Laboratories
P.O. Box 20
NORTH BEACH, W.A. 6020

Mr M. A. Potter
Fisheries Branch
Department of Primary Industries
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Mr P. Pownall
Fisheries Division
Department of Agriculture
CANBERRA, A.C.T. 2600

Mr R. Pyne
Fisheries Branch
Department of Primary Industries
William Street
BRISBANE, Qld 4000

Mr J. C. Ryall
Aquaculture
Box 17, G.P.O.
BRISBANE, Qld 4001

Mr P. Ryan
Fisheries Division
Department of Agriculture
CANBERRA, A.C.T. 2600

M/s J. H. Ruello
CSIRO, Division of Food Research
Box 52, P.O.
NORTH RYDE, N.S.W. 2113

Mr N. V. Ruello
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr M. Sanders
Department of Fisheries and Wildlife
632 Bourke Street
MELBOURNE, Vic. 3000

Dr D. F. Smith
CSIRO, Division of Fisheries
and Oceanography
P.O. Box 21
CRONULLA, N.S.W. 2230

Mr I. R. Smith
Fisheries Branch
Chief Secretary's Department
211 Kent Street
SYDNEY, N.S.W. 2000

Mr L. G. Smith
Department of Primary Industries
Food Preservation Research Lab.
Harbour Road
HAMILTON, Qld 4007

Mr I. Somers
CSIRO, Division of Fisheries
and Oceanography
Fisheries Research Station
13 Beach Road
DECEPTION BAY, Qld 4508

Mr G. Temperley
C.S.R.
1-7 O'Connell Street
SYDNEY, N.S.W. 2000

Professor J. M. Thomson
Department of Zoology
University of Queensland
ST LUCIA, Qld 4067

Mr J. Waldron
David North Plant Research Centre
C.S.R. Research Limited
P.O. Box 68
TOOWONG, Qld 4006

Mr R. H. Walker
Fisheries Division
Department of Agriculture
CANBERRA, A.C.T. 2600

Mr T. White
M.G. Kailis Gulf Fisheries
P.O. Box 745
FREMANTLE, W.A. 6160

Dr B. Wisely
Fisheries Branch
Chief Secretary's Department
Brackish Water Fish Culture Station
C/- Post Office
SALAMANDER BAY, N.S.W. 2301

Mr A. Vala
Department of Agriculture,
  Stock and Fisheries
P.O. Box 2417
KONEDOBU, PAPUA/NEW GUINEA

Mr P. A. Zed
Department of Zoology
University of Adelaide
North Terrace
ADELAIDE, S.A. 5000

(R73/3054)