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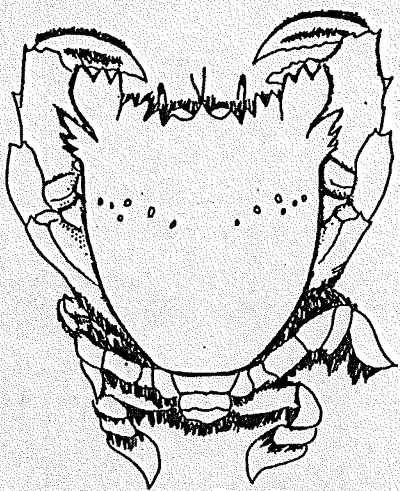
POPULATION BIOLOGY OF THE SPANNER CRAB IN SOUTH-EAST QUEENSLAND



PROJECT 81/71

FINAL REPORT

I.W. BROWN

Queensland Department of Primary Industries

POPULATION BIOLOGY OF THE SPANNER CRAB IN SOUTH-EAST QUEENSLAND

FINAL PROJECT REPORT

to

FISHING INDUSTRY RESEARCH COMMITTEE

by

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SUMMARY

The spanner crab, Queensland's most recently developed fishery resource, is rapidly becoming established on local, interstate and overseas markets as a recognised seafood commodity. An estimated 300 t (worth in the vicinity of $0.5 million) are currently being harvested annually in southern Queensland waters. With the fishery's expansion into northern New South Wales during the past two years, Australia's total production is at least 500 t.

Many spanner crab fishermen are transient operators involved in other (seasonal) fisheries. Spanner crabs are taken during daylight hours by means of baited tangle-nets, typically deployed for about 45 minutes in sets of 20 or so from small (6-7 m) outboard-powered runabouts. The main crabbing grounds are offshore on clean sandy substrates in depths ranging from 20 to 70 m. Apart from a recruitment pulse between mid-autumn and the end of winter, the fishery is essentially non-seasonal, and commercial catch rates currently average 4.3 marketable crabs per net drop.

Male crabs outnumber females by a factor of 3 to 1, and because of divergent growth rates males attain a significantly larger size (15 cm) than females (11.5 cm). As a consequence of this, the present 10 cm minimum legal length regulation protects about 90% of the females from fishing mortality. Crabs appear to prefer substrates characterised by a high proportion of medium to fine sand. They are more vulnerable to capture during the dark phase of the lunar cycle, and in intermediate depths (between 30 and 45 m). There is an observed tendency for catch rates to decline slightly throughout the day, but this trend is of doubtful significance.

Female spanner crabs attain sexual maturity at a carapace length of 7 cm, and are probably able to mate at any stage of the moult cycle. Copulation occurs throughout the year, but peaks immediately prior to ovulation in November when (depending on maternal body size) between 60 000 and 160 000 ova are produced. Large females are capable of multiple ovulation during the relatively brief spawning season, but even so, are considerably less fecund than either of Queensland's commercially exploited portunid crabs. Reduced activity levels amongst ovigerous females results in significant seasonal changes in the sex ratio observed in the catch. Embryonic development takes about 5 weeks, during which-time the female remains partly buried in the substrate, emerging only infrequently to feed. Upon hatching, the planktonic zoeal larvae (characterised by exceptionally long dorsal and rostral spines) undergo eight growth stages over a period of 5-6 weeks. The potential for dispersal of these larvae by the East Australian Current may have a substantial bearing upon the results of stock assessment in individual east-coast fisheries, and therefore upon management strategies which may ultimately be developed.

Fisheries data currently being collected are inadequate for application even to the most simplistic population dynamics or production model. Initial estimates of mortality and growth parameters are not considered representative of the true situation, and require further investigation. On

the basis of the best available information it appears that the stock (as a whole) is not, at the present time, being subjected to excessive levels of fishing pressure.

Recommendations arising from the Project work include (inter alia) the retention of existing minimum legal size and amateur bag-limit legislation, the implementation of a system for collecting and analysing appropriate catch and effort data, and the encouragement of research into growth and larval recruitment patterns.

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1. INTRODUCTION

The spanner crab (also known as the "frog" or "kona" crab) is an edible offshore oceanic species growing to a weight of about 1kg. Its common names derive from the spanner-like appearance of its claws, its postural similarity to a frog, and from its presence along the Kona coast of the island of Hawaii. Live spanner crabs are a pale tan to orange colour, but turn a characteristic strawberry red when cooked. The terminal segments (dactyli) of its walking legs are spatulate and pointed, well adapted to digging, and when not engaged in agonistic or feeding behaviour the animal spends much of its time buried in the substratum with only its stalked eyes and antennae protruding above the sand surface. In contrast to most other brachyuran species, the spanner crab normally moves forwards rather than sideways, and in spite of its short legs, is capable of swimming quite rapidly for brief periods.

1.1 Systematics

Raninids are a somewhat aberrant group whose systematic position has long been in dispute. Prior to the early 1920s systematists placed the family Raninidae either in the Anomura, along with stone crabs, hermit crabs and squat lobsters, or in the heterogeneous Oxystomate subsection or tribe of the Brachyura (true crabs). However Bourne (1922) considered the raninids to be sufficiently distinct morphologically, physiologically and ecologically not only from the Oxystomata, but from all other major groups, that he established a new tribe (Gymnopleura) within the Brachyura to accommodate the family. Stevcic (1973) believes that the family arose through a process of regressive evolution (telomorphosis) during which some of its morphological characteristics reverted to a primitive condition through adaptation to a rather specialised environment. The family is small, most of the genera being known only from the fossil record. **Ranina**'s closest relative in Australian waters is the much smaller non-commercial smooth frog or harp crab **Lyreidus tridentatus**, which occurs in deep water around the south of the continent.

1.2 Distribution

Spanner crabs are found throughout the tropical Indo-Pacific region from the east coast of South Africa through the Indonesian archipelago to Japan and Hawaii (Tinker 1965, Onizuka 1972, Healy & Yaldwyn 1970). In Australia the species occurs from the Abrolhos Islands (WA) through northern tropical and Barrier Reef waters and as far south as southern New South Wales (Healy & Yaldwyn 1970).

1.3 Commercial Spanner Crab Fisheries

Spanner crabs have been fished commercially around the Hawaiian Islands since before the second World War (Brown 1985). Catch statistics compiled by the Hawaii Division of Fish and Game indicate an average annual production in the vicinity of 10 t, with a peak of 35 t in 1972. There is also some limited exploitation around the Philippines and off the southern coast of Japan, but production figures for these areas are unavailable. Little is known of the species' distribution and commercial potential in either the tropical west-Pacific or Indian Oceans.

1.4 Development of the Australian Fishery

Since the advent of offshore otter trawling for prawns along the Queensland coast, spanner crabs have appeared sporadically as part of the by-catch, but only in limited quantities. Little interest was shown in establishing a market for trawl-caught spanner crabs, which were generally considered a nuisance because of their tendency to become meshed in the cod-end. It is difficult to clear these crabs from inside a trawl net without damaging them. The lack of consistent large catches of spanner crabs by prawn trawlers is undoubtedly the result of the animals' burrowing behaviour: when alarmed (e.g. by the vibrations of a trawl net and otter boards scraping over the sea floor), they are capable of burying themselves beneath the sand with some alacrity.

The fishery targetted specifically on spanner crabs began to develop as a commercially viable operation around 1978-79 when it was found that crab dillies, previously used by recreational fishermen to catch mud crabs (**Scylla serrata**) and sand crabs (**Portunus pelagicus**) in estuarine habitats, were a very effective means of catching spanner crabs in offshore waters. In the early days of the fishery inverted dillies or "witches' hats" were used exclusively. These were basically a baited, conical mesh net attached to a circular metal frame and supported at the apex by a small net float. The equipment was simple to construct, inexpensive, easy to deploy from a small boat, and therefore very attractive to potential crabbers.

The first significant landings were made early in 1979, but it is difficult to establish precisely how the fishery started and who was involved, as a number of current operators all lay claim to having been the first to fish spanner crabs commercially. A considerable proportion of the initial landings were probably attributable to unlicensed fishermen (particularly in the Mooloolaba and Caloundra areas, where the fishing grounds were relatively close to the coast). As a result, early official catch statistics maintained by the Queensland Fish Board probably underestimate the actual landings. With the influx into the fishery of more professional crabbers who generally market their catch through the Board's regional depots, the "official" figures now account for a higher proportion of the total State catch, although the amateur contribution is still believed to be significant, and some professionals are starting to develop alternative outlets for their catch, including co-operatives and processors/dealers.

Because of the low level of capital investment in the fishery, vessels tend to be small (mostly in the 6-10m range) and are therefore very susceptible to weather conditions. There are thus very few commercial fishermen who work spanner crabs exclusively on a year-round basis; most are involved to a greater or lesser extent in alternative seasonal fisheries including sand crabbing, reef handlining and beach seine operations. This seasonal mobility makes it difficult to determine the number of fishermen involved in the spanner crab fishery, and means that the concept of fleet size is of limited value.

Spanner crabs are known to occur on offshore sand substrates between Fraser Island and the north coast of New South Wales. Commercial crab fishing effort was initially concentrated in the area between Mooloolaba (26°40'S) and Cape Moreton (about 27°00'S), largely because of its proximity to harbour and boat launching facilities. However during the past two years fishermen in northern New South Wales have begun to realise the potential of the resource, and sizeable landings are being recorded from some of the Northern Rivers cooperatives.

1.5 Project Background

During the initial developmental phase of the fishery in southern Queensland fishermen were surprised at the large numbers of spanner crabs which could be caught in a baited mesh net. They saw significant potential in the fishery, but also noted the ease with which amateurs and less scrupulous "unlicensed professionals" could obtain and sell large catches. At the time there were no regulations specifically relating to spanner crabs, and many very small individuals were being sold, to the detriment of the general marketing situation. Several **bona fide** crabbers were concerned for the future of the fishery unless some sort of management constraints were introduced. Moreover the lack of any information on the size of the resource or the biological characteristics of the population made it impossible to predict how the stock would react to continuously increasing levels of harvesting pressure. State Fisheries authorities were requested to carry out research into the status of the resource and to institute management controls to discourage the indiscriminate capture and marketing of excessively small crabs. After an initial pilot study in 1980-81 a more detailed and extensive research program was developed by staff at the Southern Fisheries Research Centre, and funded for three years by the Fishing Industry Research Committee.

1.6 **Project Aims**

The general thrust of this project was to provide a management-oriented overview of the resource and its fishery, and an understanding of the more important biological and ecological functions of the stock. The project's specific objectives were as follows:

(i) to elucidate the reproductive cycle and early life history of spanner crabs;

(ii) to determine the magnitude of seasonal and geographical variation in availability;

(iii) to estimate growth rates in male and female crabs;

(iv) to determine the meat recovery rate from crabs of different sizes;

(v) to test the effects on catch rate and size composition of different net designs, mesh sizes and bait types;

(vi) to monitor certain aspects of the commercial spanner crab fishery.

1.7 **Study Area**

Project field work was carried out primarily in the area from Point Cartwright (26°40'S) to Point Lookout, on the northern end of Stradbroke Island (27°27'S) in depths ranging from less than 10m to the 100m isobath (Figure 1). The study area encompassed more than 2000km^2 of ocean, and for convenience was divided into a number of subregions or localities (Figure 2).

At the northern limit of the study area the bathymetric contours are widely spaced, resulting in a gently sloping (1 in 440) continental shelf. Offshore from Moreton Island, however, the slope is much steeper (1 in 125). Bottom sediments outside Moreton Bay consist primarily of medium and find sand corresponding to particle sizes of +2 and +3 Phi units respectively. While the sediments generally are well-sorted, there are nevertheless some significant departures from the norm, especially in the vicinity of unusual bathymetric features and high velocity tidal current streams.

The whole area is exposed to prevailing northeasterly winds during summer and southwest to southeasterlies in winter, and because of this some localities, particularly those on the ocean side of Moreton Island, received considerably less attention than others.

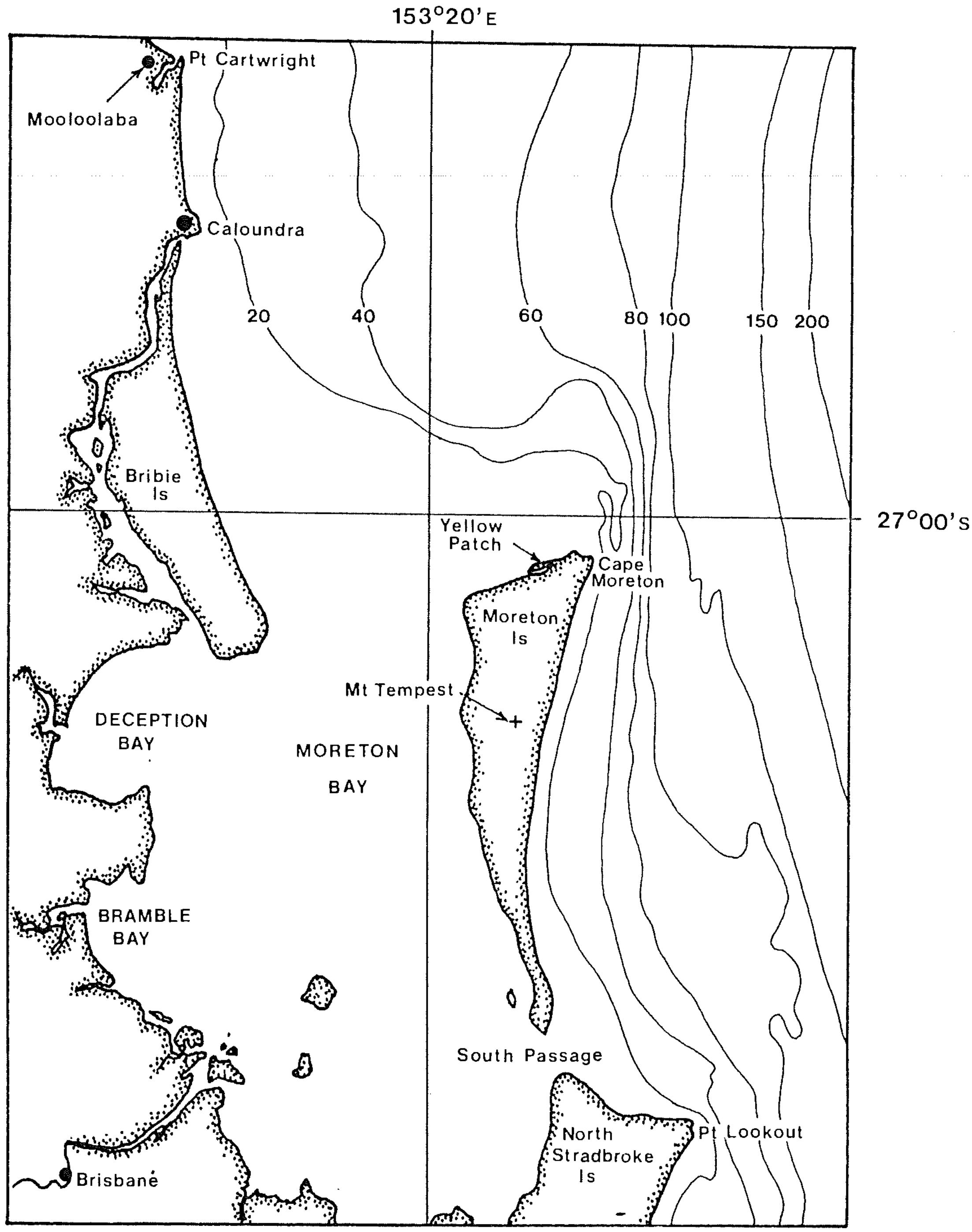

Figure 1. The study area: offshore coastal waters in south-east Queensland between Mooloolaba and Point Lookout.

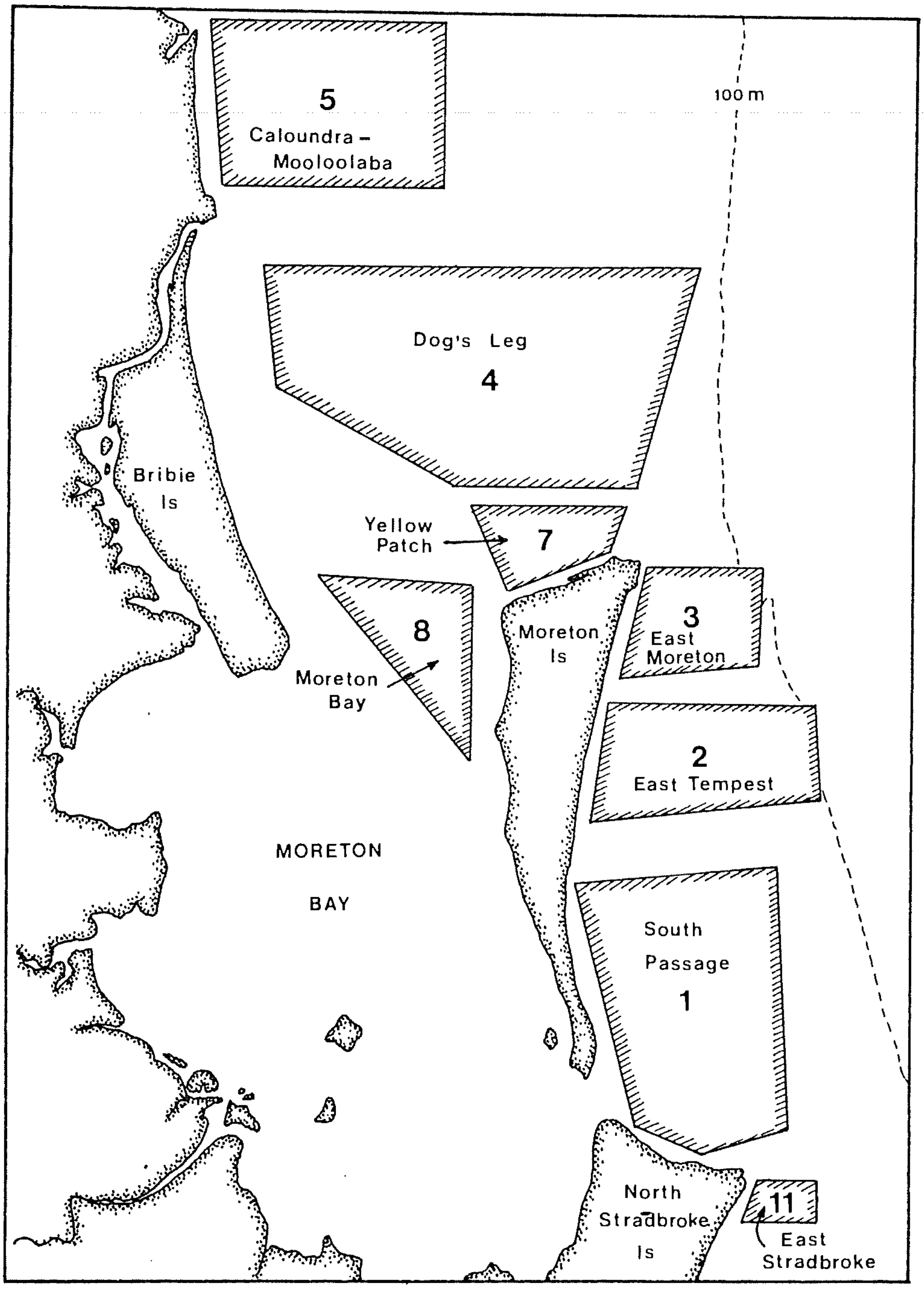

Figure 2. The study area showing regional subdivisions with their locality codes. Regional names refer to prominent local topographic or bathymetric features.

2. MATERIALS AND METHODS

2.1 Project Vessels

The original project vessel (RV "Toorbol") was a 7 metre fibreglass-hulled runabout powered by twin 150HP outboard motors. This boat, about 10 years old at the time, had to be withdrawn from service early in 1983 because of the appearance of major structural defects. Until a suitable replacement could be purchased, a similar vessel (RV "Tanari") was made available from within the Fisheries Research Branch so that field operations could continue uninterrupted. However considerable work was required on "Tanari" before it could put to sea, and this resulted in a loss of fishing time during May and June 1983.

The replacement vessel, a new 8.25 metre Shark Cat express cruiser, was delivered to SFRC in November 1983, and completely fitted out and operational by early December.

Both "Toorbol" and "Tanari" carried regulation safety equipment, including inflatable life raft, SSB radio, compass and Furuno 204-B depth-sounder. The electronics and navigational aids were upgraded on the catamaran RV "Pelates" and included SSB, VHF and 27 MHz radios, Furuno FE-606 chart-recording echo sounder, and a Kyoritsu-AWA 48 n.m. radar unit.

2.2 Gear

The basic sampling unit consisted of a fleet of up to 12 circular tangle nets, each baited with a whole split mullet. Initially the traditional "witch's hat" or inverted dilly was employed, as this was the industry standard at the time. However it was soon found that the Hawaiian style flat net was far easier to clear, less prone to mesh damage, and also less liable to result in damage to the crabs on removal. There was a simultaneous trend towards the flat nets within the commercial sector, but the extent to which this was due to knowledge of the Hawaiian system is not known.

The flat net, with certain slight structural modifications, was used exclusively thereafter. It consisted of a metal hoop (heavy wire or 12 mm reinforcing rod) approximately 1 metre in diameter, with a layer of 50 mm monofilament nylon mesh stretched across and bound around the hoop with netting twine. To provide some support for the centrally-attached bait, two light wires were run across the diameter of the net at right-angles, pulled tight, and secured to the metal ring (Fig. 3). Bait clips were made from 20cm lengths of fencing wire with one end bent into a small loop and the other sharpened to a point. The sharp end was pushed through the bait, passed through the mesh and around the support wire, then bent back in a curve and locked through the loop.

The nets were connected to the buoy-line by shark clips permanently attached to short snoods spliced into the 6 mm polypropylene line.

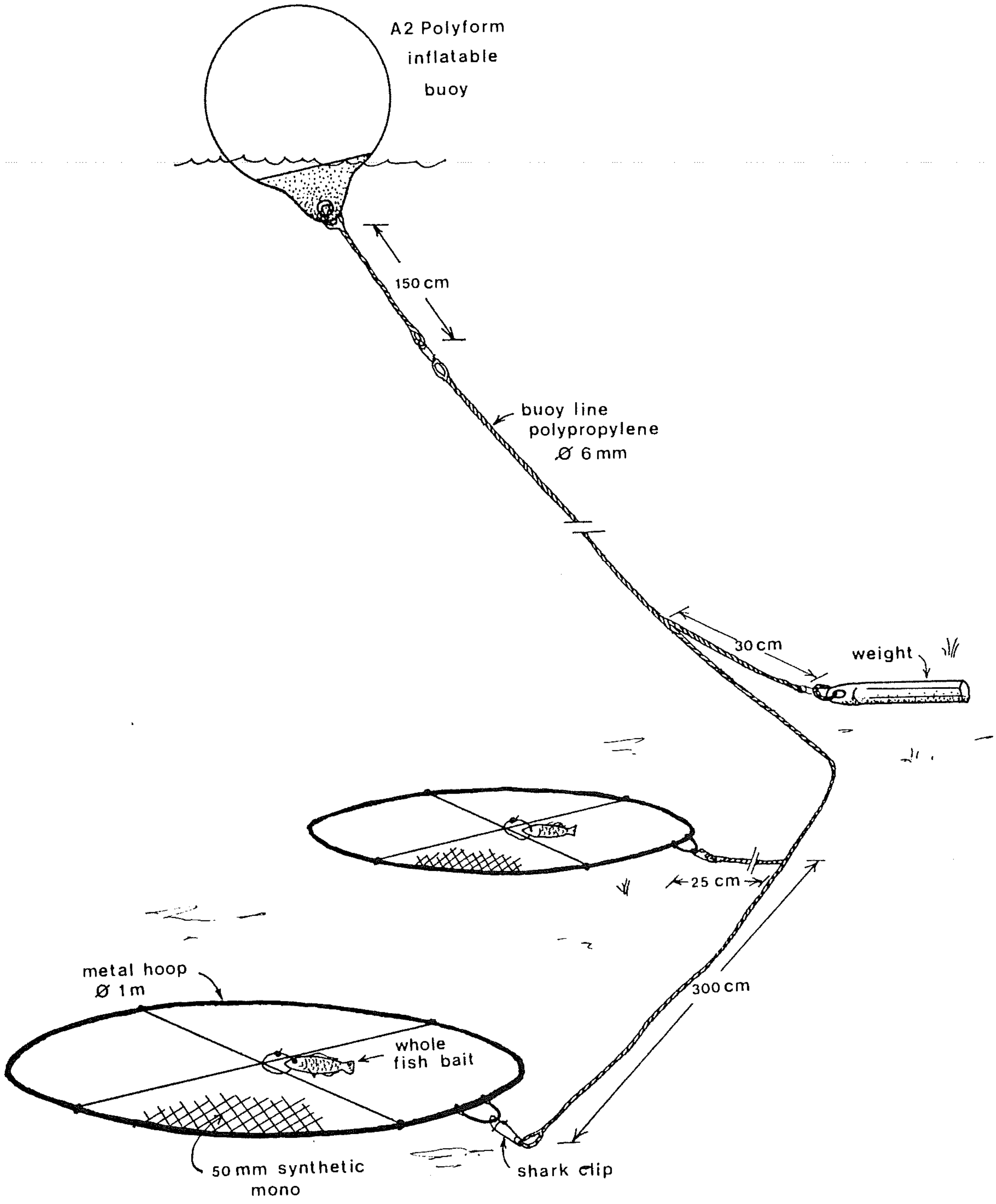

Figure 3. Semi-diagrammatic representation of the sampling gear, comprising two baited tangle nets, a weight, buoyline and surface float.

To avoid damaging or fouling the webbing, the shark clips were attached to small "D"-shaped wire loops firmly clamped onto the net ring (Fig. 3). Several sets of buoy-lines were made up in lengths of 35, 55 and 75 metres to facilitate operation in various depth ranges, and to avoid the problem of having to join short lines or having excessive slack line floating on the surface.

Early in the project buoy-lines were marked with 20 cm white or orange polystyrene floats, but these were later replaced by 43 cm pink "Polyform" inflatable buoys (A-2 size). The latter proved superior because of their visibility and buoyancy (which resulted in less current-induced drag on the lines), although they obviously required more onboard stowage space.

At first the nets were pulled by hand, but an electric hauler was soon installed on the boat. This device, consisting of a gypsy-head driven by an automobile starter motor through a system of V-belts, was effective but somewhat cumbersome and inefficient in terms of energy requirements. It was later replaced by a much more compact and economical device based on a small electric print motor normally used for powering auto-pilot systems. The new line hauler (drawing current from two 12V car batteries connected in series) was constructed such that it would operate virtually untended, coiling the line automatically into a bin or basket. The basic design (see Fig. 4) was taken from similar units used by one or two crab fishermen, and modified to suit our operational requirements.

The 12 nets comprising the fleet were attached in pairs to six separate buoy-lines, each of which was buoyed at the surface and weighted on the sea floor (Figure 3). Although few commercial crabbers use weighted gear, we found it necessary to ensure that the nets remained stationary on the bottom, thus removing one possible source of sampling error. On reaching a sampling area, the echo sounder was used to locate the desired depth. Nets were set at idling speed (approximately 2 knots). A net was clipped onto the end of the line and cast overboard. The second net (of the pair) was likewise attached, and then the concrete or cast iron weight. The line was allowed to stream out until finally the top end, attached with a shark clip to a short buoy painter, was released. The process was repeated until all 12 nets (6 buoy-lines) had been set, generally in a line following the depth contour. The nets were dropped about 50m apart to minimise gear competition effects. Soak time varied according to the size of the catch, since each pair of nets was cleared before the next were hauled, but averaged out at between 40 and 45 minutes. The nets were re-baited when necessary.

2.3 Data Records

As each pair of nets was shot away, the time and sonic depth were recorded. On hauling, the retrieval time was recorded, together with the number of male crabs, the number of females, and the number of ovigerous females in each individual net. The crabs were removed and stored in a plastic mesh tote basket until the entire set had been retrieved. The locality code was recorded, in addition to the date, trip number and vessel name. Bearings on visible landmarks were taken, as accurately as conditions would allow, with an "Enbeeco" monocular hand-bearing compass. These would later

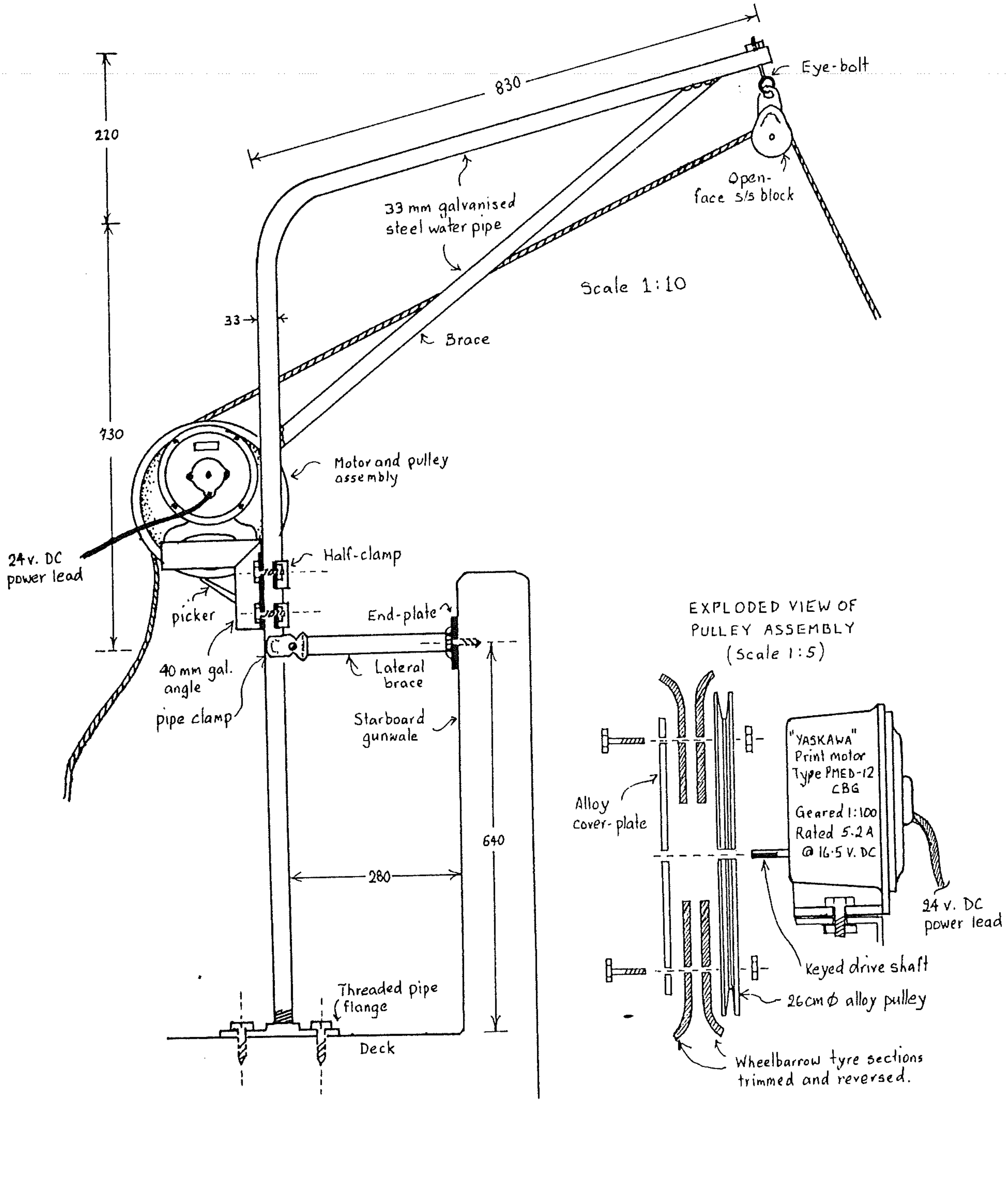

Figure 4. Line-hauling device fabricated by Fisheries Research Branch staff.

be plotted on a Harbours & Marine Department chart to determine the particular 1km grid square from which the sample was taken. Sea surface temperatures were recorded as from December 1983, and during the period May 1982-April 1984 substrate samples were collected from most sites with a van Veen grab.

2.4 **Onboard Catch Processing**

All crabs caught during the field operations were individually measured and sexed. Substantial morphological differences between male and female spanner crabs makes sexing quite straightforward. Apart from a single male which had a somewhat broader than usual tail flap, no instances of hermaphroditism or sex change (which often occurs in sand crabs as a result of **Sacculina** infestation) were observed. Neither was there ever any difficulty in determining the sex of even the smallest crabs captured. Secondary sex characteristics obviously appear at a very early stage in the life cycle.

The standard measure of spanner crab size was the rostral carapace length, i.e. the distance between the rostral tip and the mid-dorsal posterior edge of the carapace (excluding curvature). Lengths were always measured to the nearest millimetre using a set of "Mitutoyo" metric calipers. Subsamples of the catch (particularly females) were put aside for more detailed laboratory examination.

2.5 **Laboratory Procedures**

On the many occasions when time did not permit laboratory processing to be carried out on the day that the samples were collected, they were held overnight on ice in a coldroom. The crabs were then re-measured, sexed and weighed to the nearest gram on an electric top-pan balance, and visual assessment made of their shell "age". Since soft-shelled spanner crabs are rarely (if ever) found, estimates of their moulting status require alternative, and unfortunately less objective, criteria. Shell age was classified as "old", "indeterminate" or "new" on the basis of carapace colour intensity, colour of fringing setae, the presence or otherwise of fouling organisms such as barnacles, and the incidence of exoskeletal damage.

The carapace of each female was then removed with the aid of a small pair of bone cutters. The exposed ovary, having been teased free of the surrounding tissues, was lifted out and placed in an appropriately identified vial. Next, the spermathecum was dissected out and examined to see whether it contained spermatophores. If the spermatophore mass was moderately large, it could be seen readily with the unaided eye; otherwise a low-power binocular microscope was used. The previously removed ovaries were then blotted to remove free surface moisture and weighed on a Mettler top-loading electric balance.

Morphometric data were collected during March 1983 for comparison with the results of Hawaiian research. The following measurements were taken: standard (rostral) carapace length, orbital CL, length of the right chelar propodus, sternite width, and length of the exopod of maxilliped III. The sex and weight of each individual was also recorded.

The egg sponges of several ovigerous females were removed, by cutting the pleopods with scissors, to allow an estimate of the number of eggs per sponge. The sponges were fixed in 8% formalin for several days, then dried to constant weight in an oven. Each mass was teased apart and the pleopods removed. The remaining setae (by which the eggs were attached to the endopodites) were dry and fine, and contributed little to total weight. Total sponge dry weight was measured on a laboratory balance, then a sub-sample of approximately 0.1mg extracted and accurately weighed. The number of eggs in the subsample was counted, allowing an estimate of the total number in the sponge.

Sediment samples were processed by washing a subsample of approximately 25g through a set of brass sieves (4, 2, 1, 0.5, 0.25, 0.125 and 0.063mm mesh), and drying the contents **in situ** at about 60°C until constant weight had been reached. The sieves and contents were weighed, and the weight of the sediment fractions derived by subtraction.

2.6 Data Processing

All field and routinely derived laboratory data were keyed onto floppy disk via the SFRC's SR-72 64K micro-computer. Subsequent analysis was carried out on the same system using mainly Microsoft BASIC programs written by project staff. Reproductive chronology was assessed primarily by analysis of the gonosomatic index (ratio of ovary weight to total weight), which was first tested for independence from carapace length. Supporting data were derived from analysing seasonal changes in the incidence of impregnation and ovigerity.

The effects on catch rate of season, area, time of day, depth, moon age and bottom sediment type were investigated using standard ANOVA techniques. It was intended initially that these analyses be based on the time-adjusted catch (i.e. number of crabs per net hour) for each individual net. However inspection of the data revealed a significantly non-Gaussian distribution approximating the negative binomial. It was felt that the situation might be improved (from the parametric statistics point of view) if a larger sampling unit was used. By treating the time-adjusted catch from a complete set as the basic variate, the distribution tended, as is to be expected, to the Poisson. As there was no logical way to increase the unit any further, it became necessary to apply a double square root transformation so that the data would be close enough to normal to allow the use of parametric statistics. The transformation used was:

$$X = \sqrt[4]{\frac{(C + 0.2)}{E}}$$

where x is the transformed variate, C = catch (number of male and female crabs), and E = effort (number of net hours). A small fraction (0.2) was added to C to ensure that the numerator is always greater than zero.

Growth parameters are traditionally estimated using age-structured data. However,for situations where age data are unavailable or very expensive to acquire, a set of algorithms has been developed to operate on length-structured data. The suite of microcomputer-oriented programs known as ELEFAN (Electronic LEngth-Frequency ANalysis) was obtained from the authors (Pauly and David 1981) and modified slightly to run under CP/M BASIC. Raw length and sex data collected in the field were sorted and tabulated in a form suitable for input into the "ELEFAN I" program.

2.7 Larval Development

The larval stages of **Ranina ranina**, like those of other crabs, are planktonic. The species' general geographic distribution is a reflection of the way in which prevailing ocean currents have transported the larvae from the point of hatching. If the processes of recruitment are to be understood, it is important that we know when and where the larvae are released, and how long it takes before settlement occurs.

The definitive work on **R. ranina** zoeal larvae was done in Japan by Sakai (1971), who reared a laboratory culture through eight zoeal stages. However because of high mortality rates throughout the experiment, none survived to the megalopa stage. Although the megalopae of other raninids are known (Chace and Barnish 1976; Knight 1968), that of **R. ranina** is as yet undescribed.

Several attempts were made to rear a series of zoeae in aquarium facilities at the Southern Fisheries Research Centre, with the major aim of providing the first description of the megalopa. Ovigerous female crabs caught during the routine sampling trips were placed in seawater in 750 litre circular plastic tanks containing a clean sand substrate, and fed chopped prawns (**Metapenaeus** sp.) and clams (**Anadara** sp.). Embryonic development was monitored by removing a small number of eggs from the "sponge" and examining them under a dissecting microscope. When the embryos were at a sufficiently advanced stage a recirculating water system was substituted for the flow-through system so that newly-hatched larvae would not be lost. After the bulk of the larvae had been released, small numbers were carefully dipped from the holding tank and transferred to a variety of smaller glass and plastic aquaria.

In the 1981 experiment rectangular 40-litre glass tanks were used, with a closed water system and aquarium heaters to maintain constant temperature. The tanks were cleaned each day, and every 10 days ~80% of the water volume was replaced. A slightly different system was set up for the 1982 season's experiment, with six 3 litre plastic bowls, each with its own air supply, set in a constant temperature water bath. When the final experiment was run in 1983, the aquarium room had been equipped with thermostatically-controlled air conditioning and heaters, and the larval rearing tanks did not need individual temperature control. The 3 litre bowls were again used, in addition to several 40 litre glass aquaria.

Sakai (1971) evidently fed his experimental zoeae with **Artemia** nauplii, but initial trials at SFRC suggested that these are too large for the early larval stages. During the first experiment the zoeae I and II were fed with wild zooplankton (mainly small copepods) captured by net in Moreton

Bay. Zoeae II-V were fed **Artemia** nauplii, which was supplemented with finely minced prawn during Z IV-V.

Rotifers (**Brachyonus plicatilis**) obtained as a starter culture during 1982 from the Tokyo University Laboratory of Fisheries Oceanography, were fed to Z I & II exclusively in 1982 and supplemented with wild plankton in 1983. A substantial culturing system, together with a "green water" (**Dunaliella** sp.) food source facility, was set up in the SFRC grounds to supply adequate quantities of rotifers for the crab rearing experiments.

Subsamples of the zoeal larvae were removed periodically and examined microscopically. Measurements were taken of carapace, rostrum and dorsal spine length, and the distance between rostrum and dorsal spine (in accordance with Sakai's methods) for comparative purposes. Mortality rates were estimated by collecting and counting dead larvae which had settled to the bottom.

2.8 **Tagging**

A tagging program was initiated in 1983 to provide an estimate of growth independent from that of the length frequency analysis, and to determine gross movement patterns. In April and May 1983, 128 crabs were tagged with numbered "Dymo" label strips glued to the carapace with "Super Glue", and released about 7 nautical miles northwest of Cape Moreton in 45-60m. This method, while inexpensive and (judging from tag survival in aquaria) reasonably effective, was time consuming, messy, and obviously inappropriate for growth studies where the tag must survive the moulting process. It was therefore discontinued, and all subsequent tagging involved the use of Floy anchor tags applied through the postero-lateral edge of the carapace. This tagging site was chosen because it is on a moult fracture line, and therefore less likely to result in the tag's being pulled away when the exoskeleton is shed.

During August/September 1983, 704 Floy-tagged crabs were released, mainly in the "Dog's Leg" area northwest of Cape Moreton. Details of the tagging program were circulated among the commercial spanner crab fishermen. Unfortunately, however, only three tagged crabs were returned (in August 1983, November 1983 and March 1984). It was considered unprofitable to spend any more time and effort on tagging, considering the very low return rate, so the program was terminated.

2.9 **Meat Recovery Rate**

Flesh yield and cooking weight losses were determined from samples of spanner crabs caught in June and August 1982. Each crab was labelled with an identification number and measured and weighed before cooking. After cooking and re-weighing, the meat was carefully extracted from the body and claws (but not the walking legs), and weighed. A subsample of meats was also freeze-dried. This allowed calculation of the weight lost due to cooking, the ratio of extracted meat to whole fresh and cooked crab weight, and the moisture content of the flesh.

Small samples of sand crabs (**Portunus pelagicus**) and mud crabs (**Scylla serrata**) obtained from concurrent projects underway at SFRC were likewise cooked and meated to allow comparison between flesh recovery rate in spanner crabs and that in the other main edible crab species of Queensland.

2.10 Bait Testing

During the period 1.2.84 to 6.3.84 several experiments were carried out to test the relative effectiveness of two types of fish bait. The species tested were the sea mullet **Mugil cephalus** (used generally throughout the project), and the long tail tuna **Thunnus tonggol** (line-caught in Moreton Bay during an independent SFRC study). Where possible one of the pair of nets on a given buoy-line was baited with tuna and the other with split mullet. The tuna had previously been cut into pieces approximating the average size of the mullet currently being used. A record of the bait type was appended to the catch data for each individual net, to allow appropriate comparisons to be made. Records of the size frequency of the mullet-caught crabs were not kept distinct from those caught on tuna.

2.11 Net Design and Mesh Selection Tests

Experiments to determine differences in catch rate and size composition between conical inverted dillies and Hawaiian-style flat nets were conducted during the pilot study early in 1981. Approximately equal numbers of the two designs were deployed during the course of 6 sampling cruises. The flat nets were a double ring, double mesh version made with multifilament webbing, and are thus not strictly comparable to those (single ring, monofilament) used during the greater part of the project.

Towards the end of the project in 1984 mesh selection trials were carried out using flat nets with monofilament webbing. A fleet of 12 nets was made up, comprising 4 of each of the following (stretched) mesh dimensions: 30 mm (small), 50 mm (medium), and 75 mm (large). Nets were deployed such that pairs of small, medium and large mesh nets were set sequentially at the one site. Comparisons of the mean catch rates and size distributions between mesh sizes were made using standard statistical tests.

2.12 Logbook Program

Trends in the commercial spanner crab fishery were monitored by analysis of catch and effort data supplied by a small number of fishermen participating in a voluntary logbook scheme. The logsheet format (see Appendix 1) was devised early in 1982 and trialled by one fisherman during the second half of that year. After some minor modification, the sheet was printed and bound into books to be distributed early in 1983. Meanwhile, project staff had established contact with most of the serious spanner crab fishermen, explained the reason behind the logbook program, and urged them to participate. The initial response was good, although enthusiasm tended to flag and the transitory nature of the spanner crab fishing fraternity made it difficult to maintain effective communication. Of the 40 or so fishermen originally contacted, about 10 regularly submitted returns detailing each day's crabbing activities. The data included times of leaving and returning to port, blocks fished, estimated numbers of crabs kept and discarded, most productive depth range, number of sets, and the number of individual nets per set.

It was considered particularly important that fishermen who were prepared to take the trouble to fill out and return the logs should get some regular feedback from the project. The idea of periodic analyses of the logbook data was canvassed amongst the participants, who considered that it would be very interesting and potentially useful. An almost entirely automated computer-based system for routinely analysing the logbook database was devised during 1983. The system merely required the operator to key in the year and range of months required, and a series of unique tables was printed out for each numerically identified program participant. The tables (see Appendix 2) provided fleet totals and averages (catch, effort etc.), and the participant's totals and percentage differences. This enabled him to assess his own fishing performance with respect to that of the fleet as a whole.

In addition to the standard monthly summary, a breakdown of fleet catch, effort and CPUE by month and statistical block was provided in tabular form (see Appendix 3). Occasional "Spanner Crab Project Bulletins" and items of general relevance were also enclosed with the analyses.

3. RESULTS

3.1 Reproduction

Initial examination of the morphology of spanner crab ovaries indicated that analysis of the gonosomatic index (GSI) might be an appropriate method of following the reproductive chronology of this species. The tri-lobed ovary is relatively discrete, compact, easily separable from the surrounding tissue, and shows a significant change in bulk during the course of development and maturation. It also changes colour during development, from pale yellow-white in the resting phase to a deep orange when mature. Colour staging methods sometimes need to be used in species whose reproductive organs are diffuse or difficult to remove, but the gonosomatic index is preferred because of its greater objectivity and reliability.

3.1.1 Relationship between GSI and body size

The advantage of the ratiometric method lies both in its simplicity and the fact that, in theory, it should overcome the difficulty of gonad mass being related to the size of the animal. In other words, if the ratio of gonad weight to total body weight is to be an effective measure of reproductive development in samples containing crabs of various sizes, it must be independent of length. Clearly, any index of changing gonad size must be restricted to individuals in which such changes are physiologically possible. This means that the analysis should ideally exclude all crabs which are below the size at which maturity first occurs.

The correlation between GSI and rostral carapace length was examined in data for all female crabs (regardless of size) in four seasonal groups based on the date of sampling. There was no significant correlation between GSI and CL either in the April-June period ($r=-.0006$; $p>0.05$ with 101 d.f.) or the July-September period ($r=0.008$; $p>0.05$ with 289 d.f.). However r was significant in January-March ($r=0.176$; $p<0.05$ with 275 d.f.) and October-December ($r=0.309$; $p<<0.05$ with 103 d.f.). The data were then displayed as monthly scattergrams of GSI on carapace length (Fig. 5) to allow a visual assessment for the possible reason for length dependence in some of the samples. These graphs reveal that there was no tendency for GSI to correlate with CL at lengths greater than about 70 mm, indicating that the positive relationships above were most likely due to the influence of small immature crabs whose ovaries showed no sign of development.

By successively removing crabs below a certain size for the data set and re-calculating the seasonally grouped correlation coefficients, it was found that r values lost statistical significance when all crabs below 68 mm were removed from the samples. This provides a rough indication that first maturity occurs at a length of around 68 mm, and also that (for animals larger than 68 mm) GSI is independent of CL, and is therefore a useful index of gonad development.

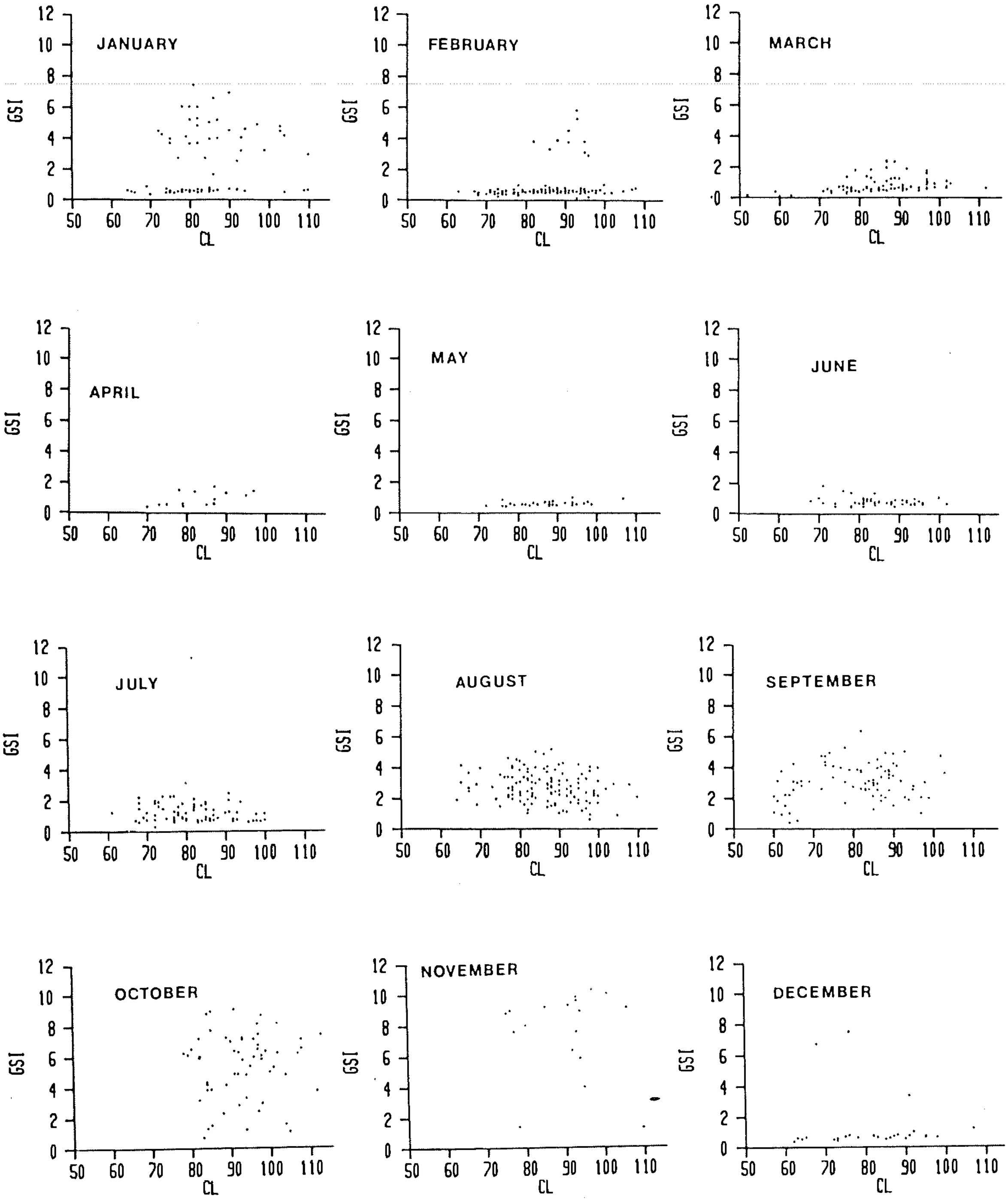

Figure 5. Relationship between GSI (gonosomatic index) and carapace length in female spanner crabs during each month.

3.1.2 **Spawning cycle**

Mean GSI values were calculated for sexually mature crabs and plotted against month (Fig. 6). The resulting trend in ovary development is quite obvious. From February to June the gonads are in a resting state, with GSI values around 1.0 (gonad weight = 1% of body weight). In the latter half of the year this proportion increases steadily until the index peaks at about 7.1 in November, when the ovaries are fully mature. Between November and December there is a dramatic drop in ovarian condition, coinciding with the release of ova.

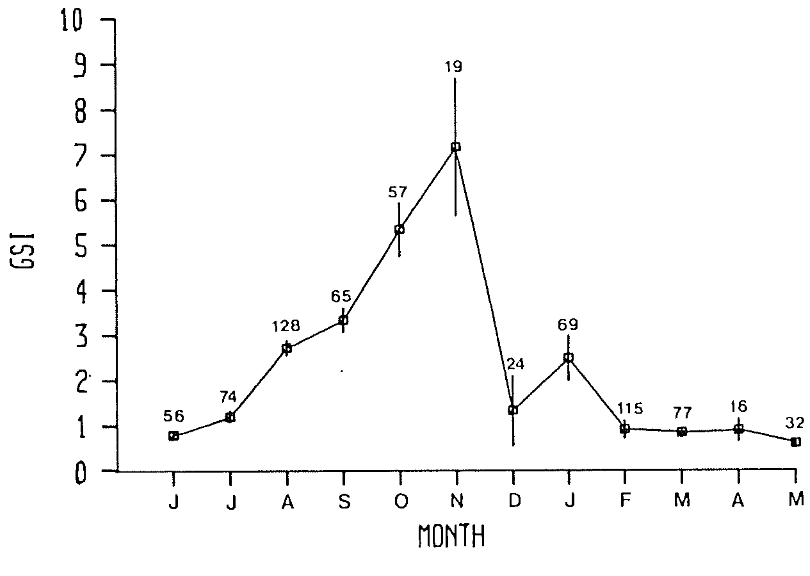

Figure 6. Seasonal changes in gonosomatic index in female spanner crabs greater than 68 mm C.L. Means, sample sizes, and 95% confidence intervals are shown.

Female crabs carry their eggs attached to the setae along the pleopodal endopodites beneath the tail flap. Berried crabs are conspicuous, as the egg mass or "sponge" is relatively large and bright orange in colour. Confirmation of the spawning period as deduced from analysis of seasonal changes in gonosomatic index should be possible by examining the frequency of ovigerous females in the catch at various times of the year. Fig. 7 shows November to be the earliest month in which spawning occurs. More than 60% of the November-caught females were in berry, indicating a high degree of synchrony in ovulation. These figures are derived from the field data which include sexually immature crabs, so the percentage ovigerous would undoubtedly be higher with respect to mature females alone. More than half the females sampled in December were in berry, but by January the proportion had dropped to a little over 10%, and further decreased to 1.4% in February. No ovigerous females appeared in the catch at all from March onward.

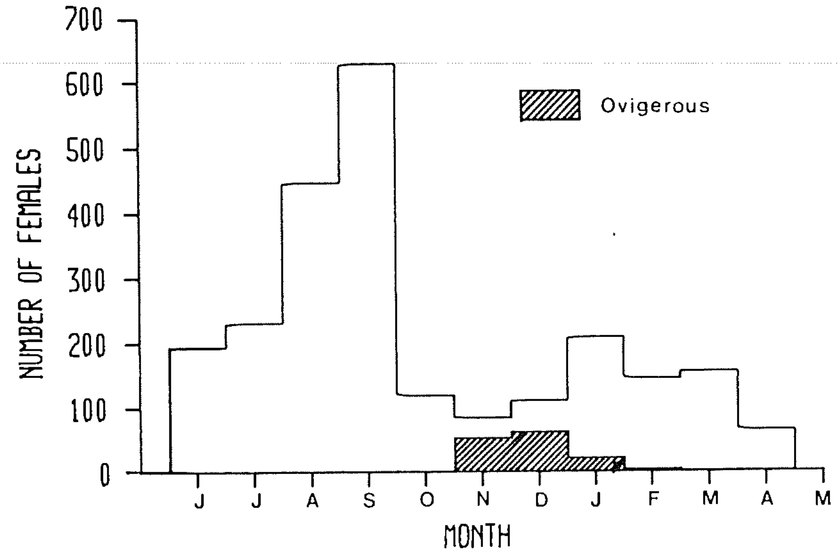

Figure 7. Numbers of ovigerous and total female spanner crabs captured each month.

At the beginning of the 1980-81 spawning period several berried females, carrying fertile but immature eggs, were placed in aquaria at SFRC for general observation. Water temperatures in the aquaria were not controlled and varied between about 20 °and 25 °C. Embryonic development was monitored periodically, and the eggs hatched between three and four weeks after the crabs had been captured. One of the females, isolated in a small aquarium, ovulated again after a period of 4 weeks, and was found to be carrying fertile eggs. This supports Onizuka's (1972) observation, and indicates not only that females are capable of multiple ovulation, but that the stored sperm can remain viable for a considerable period of time. It also probably explains why the spawning period is spread over at least three months. However there may be an alternative reason for this: any tendency for geographical shifts in spawning chronology would extend the period during which ovigerous females occur in the population. To test this, data on GSI and frequency of berried crabs were subdivided into two groups on the basis of whether the material originated north or south of Cape Moreton. Figs 8 and 9 both indicate slight differences in the onset of spawning between the two zones. Maximum monthly GSI values were attained in November in both zones, but the data in Fig. 8 suggest that ovarian development in crabs taken from the northern sites proceeds more rapidly than it does in the southern sub-population, and that the drop in ovary condition occurs earlier and more rapidly. This interpretation is supported by Fig. 9, which shows that the highest frequency of berried crabs occurred during November at the northern sites but in December at southern sites.

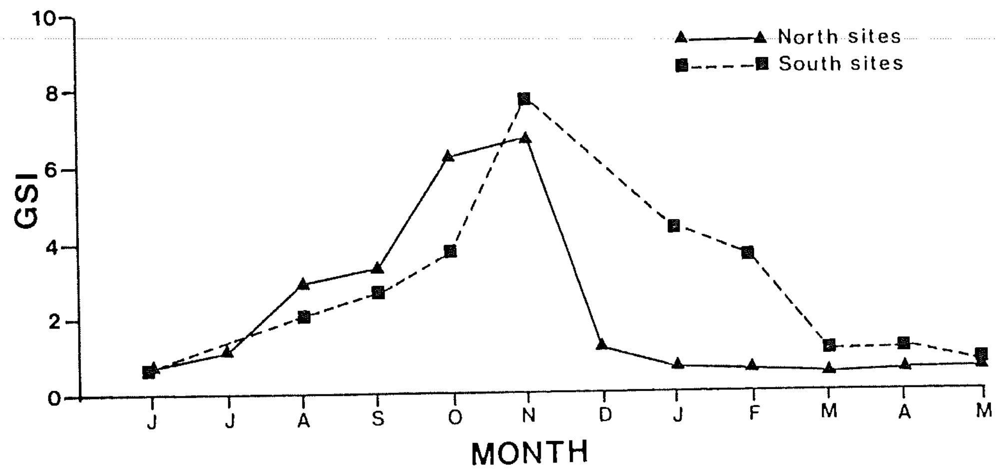

Figure 8. Geographic differences in the chronology of reproductive development as determined by analysis of GSI.

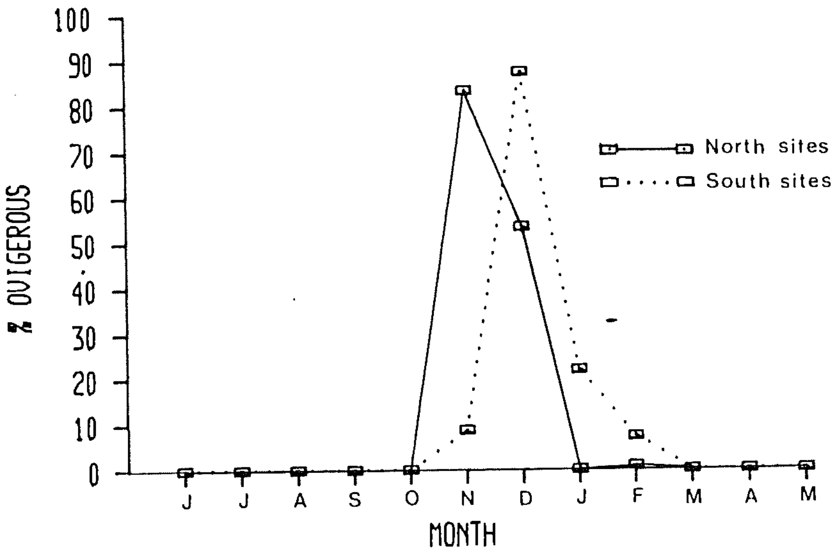

Figure 9. Geographic differences in reproductive chronology as determined by the percentage of females carrying eggs each month.

3.1.3 **Mating**

Male spanner crabs are equipped with a pair of intromittent organs (highly modified pleopodal appendages beneath the tail flap) through which spermatophores (gelatinous "packages" of sperm) are passed into the mid-ventral external spermathecum of the female. In many of the more advanced crab species the spermathecum is internal, an evagination of the distal end of the oviduct near the gonopore, and because of the gonopore's small size, copulation and spermatophore transfer can only be achieved successfully when the female is in an immediate post-moult soft-shelled condition. The spanner crab's spermathecum, however, is not connected to the oviduct but opens exteriorly. It has a relatively broad opening, suggesting that successful copulation may be possible at any stage of the moult cycle.

To determine whether spanner crabs copulate at a particular time of the year, the proportions of females carrying at least one spermatophore were calculated for each month. Apart from May and June (for which no data are available), at least 25% of the females examined each month were carrying spermatophores (Fig. 10). The lowest proportion occured in September, corresponding to one of the highest levels of the incidence of new-shelled females. There appears to be an inverse relationship between the proportion of impregnated and new shelled females. This is not unexpected, as spermatophores are presumably lost along with the integument of the external spermathecum at moulting, and the probability of finding spermatophores therefore bears a direct relationship with the age of the shell. It is interesting to note that copulatory activity appears to decline from the middle of the year to a low in September.

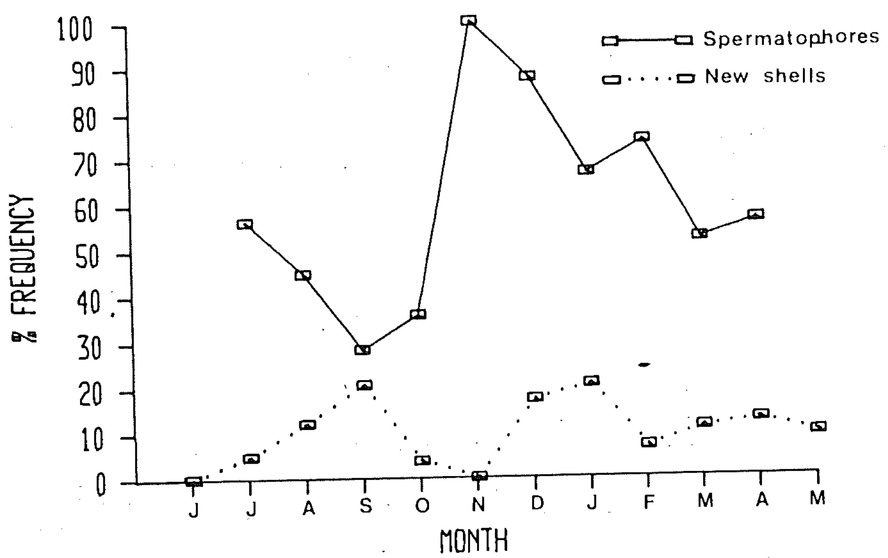

Figure 10. Monthly variation in the proportion of female spanner crabs carrying spermatophores (solid line), and the proportion classed as having "new" shells (dotted line).

It might be expected that, since spawning occurs in November-December, the frequency of impregnated females should be increasing during that period. However this trend may reflect increased moulting activity (and spermatophore loss) in response to rising ambient temperatures rather than a decrease in mating behaviour. In any case, the incidence of spermatophore-carrying crabs rises markedly between October and November, so that nearly all the mature females will have been impregnated prior to ovulation. Crabs apparently continue to mate after spawning, but the percentage of females with spermatophores decreases steadily throughout the summer.

3.1.4 **Fecundity**

The number of eggs per sponge was esimated from 25 ovigerous crabs collected during the 1982 spawning season. The crabs ranged in size from 73 to 103 mm. The linear regression between egg number and maternal carapace length (Fig. 11) was calculated to be

$$Y = 5.524 X - 403.94$$

where Y = thousands of eggs and X = carapace length (mm). The egg mass of the smallest crab (73 mm) contained approximately 7,000 eggs, while the largest crab (103 mm) was carrying in excess of 155,000. The regression for Hawaiian kona crabs calculated by Fielding and Haley (1976) was based on the orbital length measurement, and thus cannot be compared directly with the equation above.

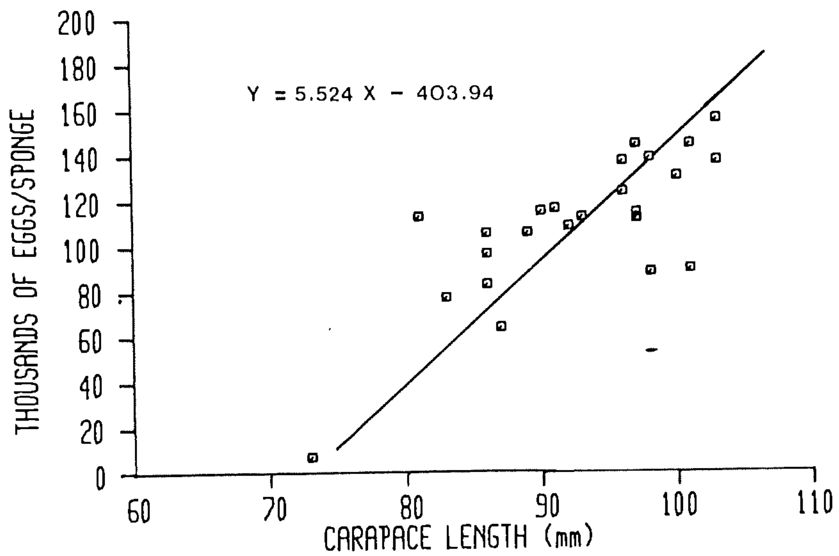

Figure 11. Relationship between number of eggs per sponge (estimated gravimetrically) and maternal body size. Computed regression formula is shown at upper left.

However by converting rostral CL to orbital CL and recalculating the regression parameters (using data from this project) the equation becomes

$$Y = 5.88X - 398.$$

Given the small number and comparative spread of the data points, this regression is probably not substantially different from that of the Hawaiian researchers (Y = 4.25X - 234). Estimates of egg number corresponding to a maternal rostral carapace length of 100 mm are 148,500 for the Queensland data and 161,100 for the Hawaiian data. These figures should not be interpreted as annual fecundity estimates, as the species is known to be capable of multiple ovulation. According to Fielding and Haley (1976) a smaller egg mass results from the second ovulation than from the first , presumably because of the limited time available in which to build up the necessary yolk reserves.

3.1.5 **Length at first maturity**

Forreasons explained in the subsequent section, relatively few ovigerous females were captured during the sampling operations. This makes it difficult to determine accurately the size at which females are capable of reproducing. Nevertheless there are several ways of obtaining an indication of the size at first maturity from the available data.

Analyses of the correlation between carapace length and gonosomatic index (GSI) have indicated that GSIs in female crabs less than 68 mm C.L. are low with respect to those in large crabs (see Section 3.1.1), and this suggests a lack of maturity in individuals less than 68 mm in length. Unfortunately there are few GSI data available for small females in the pre-spawning period of rapid ovary development, so the conclusions must be considered at best somewhat tenuous.

A different approach involves the regression of "fecundity" (or rather the number of eggs per sponge) on carapace length. As the size of the egg sponge is a function of maternal body size (Fig. 11), it might be postulated that the point at which the regression line intersects the X-axis (i.e. the carapace length at which eggs/sponge = 0) should approximate the size at first maturity. The data in Fig. 11 show that such intersection would occur at a carapace length of a little more than 70 mm, but owing to the poor representation of fecundity estimates for females less than about 85 mm C.L., this estimate should also be taken with caution.

Clearly the most direct way of determining the minimum body size for ovulation is to examine the size-frequency of ovigerous animals. Figure 12, which shows the size frequencies of ovigerous and non-ovigerous females captured during the spawning period (November-January), reveals that the smallest berried crab captured during the project period had a carapace length of 64 mm. The data used in this figure included the total field catch, and thus represents far more individuals than were used in the laboratory analyses of gonosomatic index and fecundity.

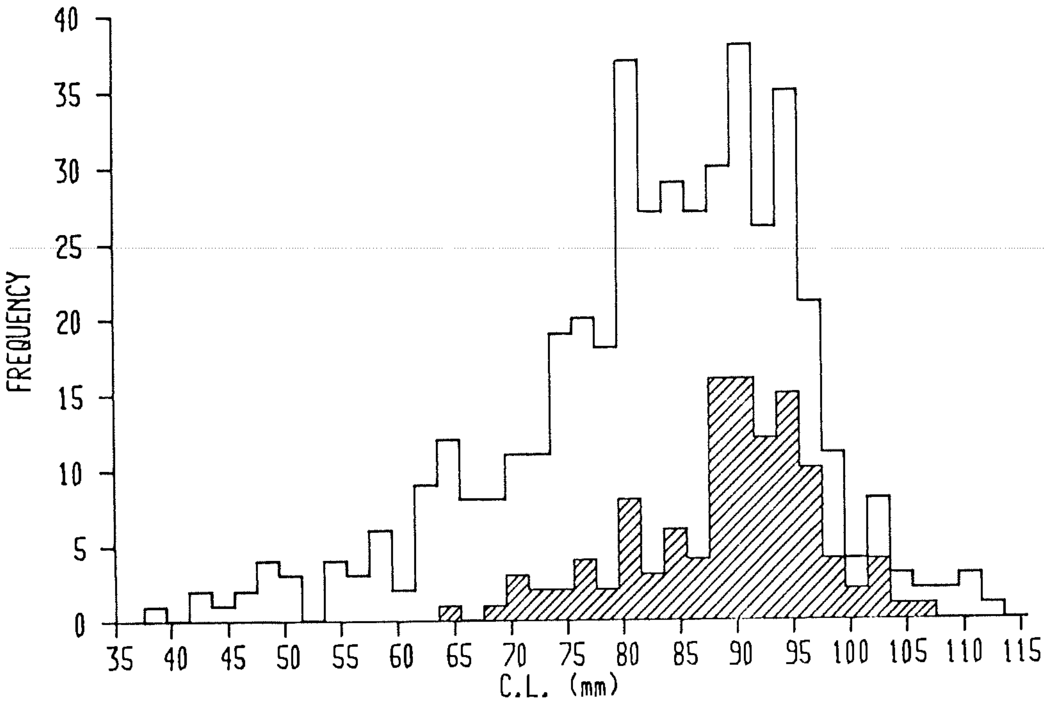

Figure 12. Length-frequency histogram for total females and ovigerous females (shaded) caught during the period November-January.

3.1.6 **Spawning areas**

Ovigerous females appear to be less active, at least in terms of foraging behaviour, than non-ovigerous individuals. Females in aquaria appeared to exhibit decreased levels of foraging activity after ovulation, although no quantitative data were collected to substantiate this. However the transformed catch/effort data for females alone do provide strong evidence that vulnerability is high prior to spawning (September/October) but very depressed during months in which ovulation occurs.

Reduced vulnerability to the sampling gear means that relatively few data are available to permit an assessment of preferred spawning areas. Nevertheless, berried females have been collected from widely separated localities within the region sampled. During an investigation of offshore crab resources in southern Queensland waters, Jones and Brown (1982) located a reproductively active population of spanner crabs in the northern part of Hervey Bay (to the north-west of Sandy Cape, Fraser Island). A small number of ovigerous crabs was taken south-east of Point Lookout on the ocean side of North Stradbroke Island, and a rather larger quantity from the "Dog's Leg" area north-west of Cape Moreton.

3.2 **Distribution and Abundance**

Spanner crab distribution patterns were investigated using time-adjusted catch per net as the basic variate. Attempts were made to determine whether catch rates had varied significantly throughout the project period (1980-84, including the DPI-funded initial pilot study), whether catch rate is subject to cyclic seasonal influences , and the extent to which it is affected by non-cyclic environmental conditions such as depth and bottom sediment type. The results presented here are based on parametric statistical tests which, as outlined previously, required that the catch rate or CPUE data be transformed in order to achieve approximate normality. It should be remembered that the geometric mean of a set of data will always be somewhat lower than the corresponding arithmetic mean, and the back-transformed values have not been adjusted to account for this difference. It should also be noted that although the results are presented as "mean numbers of crabs of both sexes per net-hour", the sampling unit was actually the "set" or pattern of up to 12 nets.

3.2.1 **Differences between years**

Initial analysis of CPUE by year included data from all sampling sites in all areas. The mean annual catch rate varied from 1.3 in 1980 (n=30) to 3.0 in 1984 (n=40). However the within-year variance was such that the differences between years were not statistically significant (F=2.32 with 4 and 311 d.f.). It could perhaps be argued that possible real annual changes in apparent abundance could have been masked by changes in sampling strategy from year to year, as it was impossible to sample all areas equally intensively in all years because of weather and other contingencies. To test this hypothesis, the ANOVA was again carried out, but only on data from the primary sampling area between Cape Moreton and Caloundra. Average catch rates in this area ranged from 1.9 in 1981 (n=16) to 3.7 in 1984 (n=25), but were again not significantly different at the 95% confidence level (F=1.32 with 4 and 141 d.f.). Given that the annual means were statistically similar, it was considered reasonable that subsequent analyses of the CPUE data base should involve pooling the data over years.

3.2.2 **Effect of depth on CPUE**

The field data were first divided into four depth ranges (0-15, 16-30, 31-45, and >46 metres) but pooled over seasons and areas. The mean transformed catch rates varied from 1.3 in the shallowest depth range to 3.1 in depths between 31 and 45 metres. An analysis of variance showed that these differences were statistically significant (F=4.42; $p<0.05$ with 3 and 312 d.f.). To obtain a better idea of the crabs' depth distribution (assuming that catch rate is a reasonably reliable indicator of abundance), the depth ranges were narrowed down to 10-metre intervals and the analysis was repeated, again with pooled data. This time the differences, which are portrayed by the dotted line in Fig. 13, were only marginally significant at the 95% confidence level (F=2.12 with 6 and 309 d.f.). However a trend towards higher catch rates in the intermediate depth ranges was obvious.

The next step was to assess whether this depth-related trend could have been an artifact of the sampling procedure- i.e. whether isolated samples from certain localities outside the main sampling area had confounded the

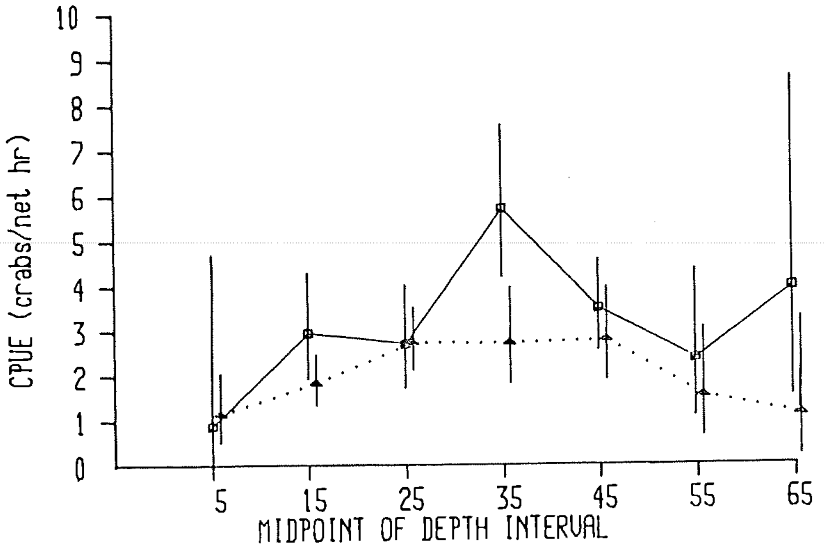

Figure 13. Relationship between catch rate and depth at Area 4 (solid line) and all areas pooled (dotted line). Mean catch rate and 95% confidence intervals are shown.

picture. Using only catch data from area 4 ("Dog's Leg"), the average catch rates at each of seven depth ranges were compared. There were again significant differences between the means (Fig. 13, solid line), the lowest of which was in the shallowest depth-range (0-10 m; n=4), and the highest in a broad range of intermediate depths from 20 to 50 m. In this analysis $F=2.74$ and $p<0.05$ with 6 and 139 d.f.

To determine whether the above situation applies throughout the year, or whether it may be the result of seasonal differences in behaviour patterns, the data from Area 4 were divided into three seasonal groups on the basis of reproductive development chronology. The groupings were September-December (ovulation and hatching), January-March (post-spawning), and April-August (resting and gonad development). Analysis of variance between mean catch rate at 4 levels of depth (0-15, 16-30, 31-45, and >45 m) showed significant differences only during the "ovulation/hatching" period, when the catch rate at depth level 3 (31-45 m) was very much greater than at any of the other depths (Fig. 14). Comparative values of F and associated statistics for each of the three seasonal groups are shown in Table 1.

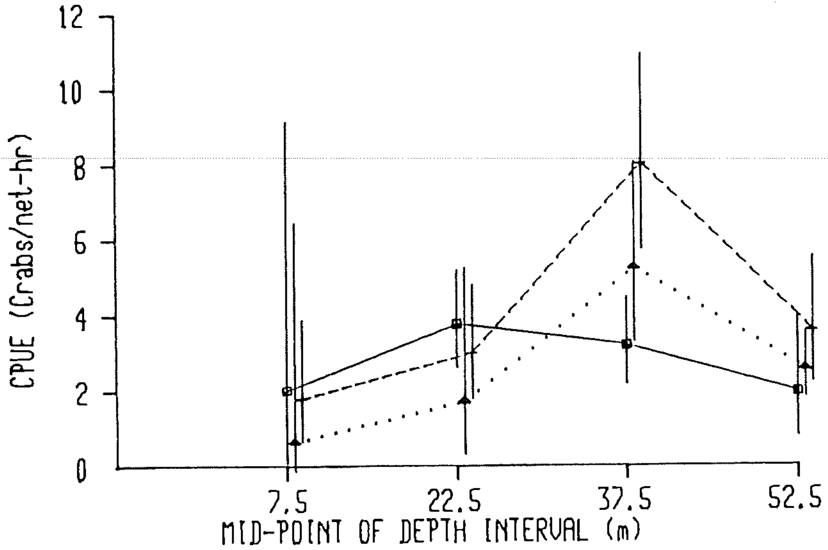

Figure 14. Relationship between catch rate and depth during each of three seasonal periods of reproductive significance (Jan-Mar, solid line; Apr-Aug, dotted line; Sept-Dec, dashed line).

Table 1. Variance ratios and associated probabilities from the seasonal ANOVA of the influence of depth on CPUE.

Seasonal Group	F	d.f.	p
September-December	6.25	3,57	<0.01
January-March	1.49	3,51	>0.05
April-August	2.27	3,26	>0.05

3.2.3 **Effect of season on CPUE**

It has been shown above (Section 2.2) that catch rate at certain depths can vary at different times of the year. This may be due to an actual shift in population density from shallow to deep water (and vice versa) resulting from cyclic local "migration" patterns, or alternatively to cyclic changes in feeding behaviour, and hence vulnerability to the fishing gear, which for some reason is non-uniform with respect to depth.

Using pooled data from all sampling localities, the "two-monthly mean" catch rates were statistically homogeneous both at shallow (<30 m) and deep (>30 m) stations. These data, shown in Fig. 15, suggest that catch rates in shallow waters are less seasonally variable than they are in deeper areas, and also that there is no tendency for the patterns to be inversely correlated. Again, the within-group sample variance is almost certainly inflated as a result of the inclusion of data from less well-sampled areas, and in an attempt to reduce the confounding effects of geographic (and associated abiotic) influences, the ANOVA was re-run using only data from Area 4. As was found in the previous analysis, catch rates at the shallow sites showed less tendency towards seasonal variation than did those at the deep sites (Fig. 16). It is interesting to note that although there was no statistical difference between means at the shallow sites ($F=0.42$; $p>0.05$ with 5 and 65 d.f.), the pattern was similar to that in Fig. 15 for the pooled data, with the highest catch rates occurring during the warmer months (November to March). In contrast, catch rates at "deep" sites (>30 m) were generally low during the first half of the year and steadily increased to a peak in September-December. These seasonal differences were marginally significant at the 95% level ($F=2.33$ with 5 and 69 d.f.). Figure 16 indicates that from about May onwards, catch rates were considerably higher at deep water sites than they were in shallow areas.

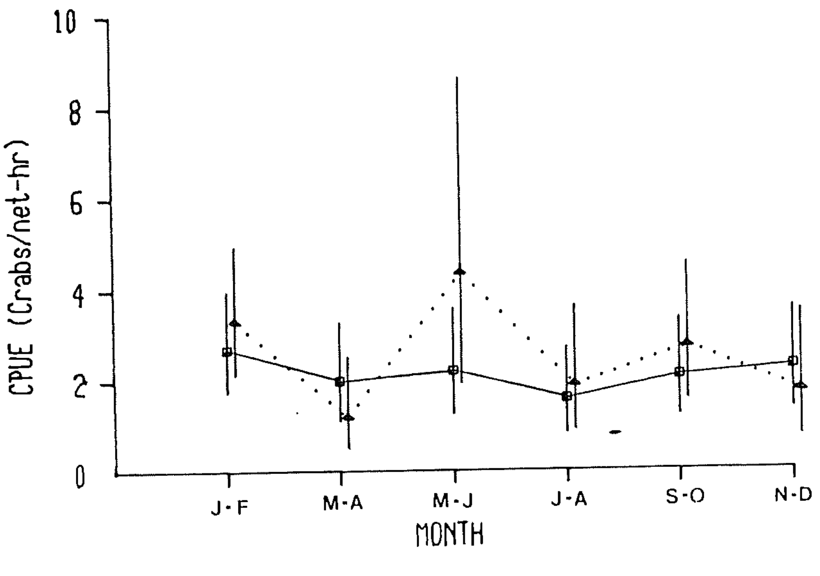

Figure 15. Seasonal changes in catch rate at shallow sites (solid line) and deep sites (dotted line). Data have been pooled over all areas.

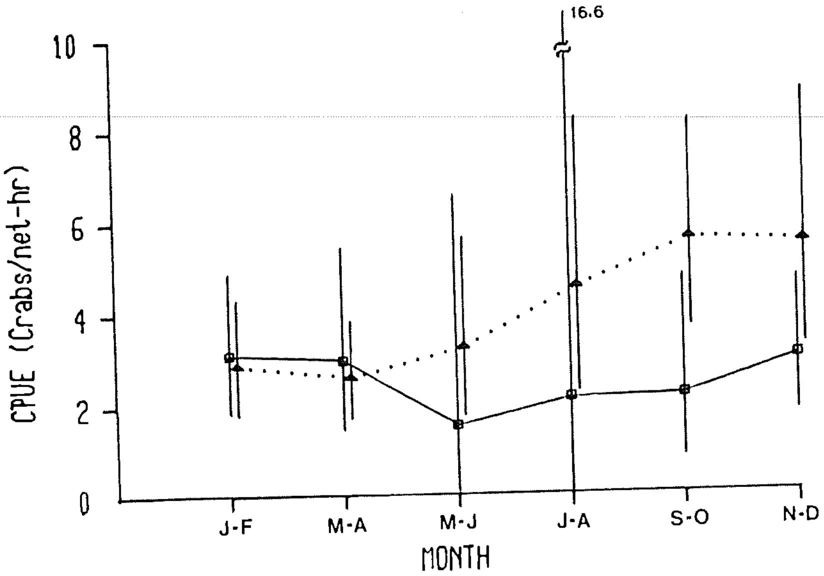

Figure 16. Seasonal changes in catch rate at shallow sites (solid line) and deep sites (dotted line) in the "Dog's Leg" area (Area 4).

3.2.4 Effect of time of day on CPUE

No attempt was made during the project period specifically to sample a particular area over the complete 24-hr cycle, although a few isolated night "shots" involving 2 or 3 nets set for varying periods provided some tentative confirmation of the generally-held view that spanner crabs are difficult to capture at night. However the project data are sufficient to test another common hypotheis - that catch rates drop off markedly in the middle of the day.

The pooled data (all areas, seasons and depths combined) were divided into five groups depending on the time at which the first net of the set was dropped (before 0800, 0801-1000, 1001-1200, 1201-1400, and after 1400 hr). Although there was a tendency for the CPUE means to decline gradually from a "high" in the early morning (Fig. 17), the differences were not significant at the 95% level of confidence (F=1.21 with 4 and 311 d.f.). Repeating the ANOVA with data only from Area 4 yielded, not surprisingly, a similar result, with even less significance attached to the variance ratio (F=0.87 with 4 and 141 d.f.).

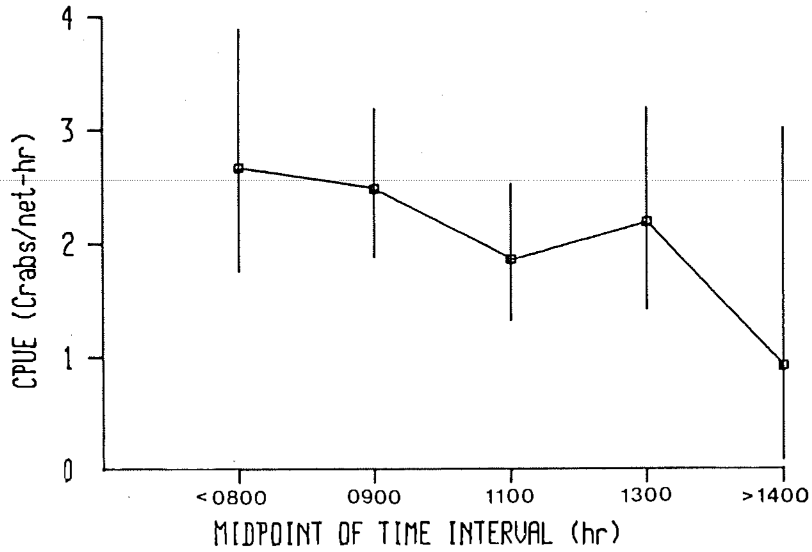

Figure 17. Variation in catch rate (all areas, depths and seasons pooled) at different times of the day.

3.2.5 Effect of substrate type on CPUE

During the course of the project it became apparent that spanner crabs were not distributed at equal density throughout the total study area. Even in offshore habitats of similar depth and distance from the coast, consistent differences in catch-rate were observed. It seemed that the two most probable abiotic factors involved in determining the species' apparent geographic distribution were current velocity and (or) substrate type. Some circumstantial evidence suggested that in areas of moderate current strength catches were depressed, but (despite the original intention of examining this potentially important relationship) the hypothesis could not be tested, because Departmental financial constraints precluded the purchase of suitable current-metering instrumentation.

The data used in the analysis of variation in catch rate due to sediment differences were restricted to sets at localities from which simultaneous bottom samples were obtained. While statistics such as graphic mean particle-size, graphic skewness, and kurtosis were calculated for each sediment sample, the final ANOVA was simply based on a division of the data according to the percentage of +2 and +3 phi-unit sediment classes (medium to fine sand). The pooled ANOVA revealed highly significant differences between the CPUE means (F=8.10 with 4 and 135 d.f.), which increased steadily from a minimum of 0.2 in areas at which the substrate contained very little fine sediment, to a maximum of about 3.5 where the "fine" fraction comprised more than 60% of the total substrate (Fig. 18; solid line). When the analysis was repeated using a data set restricted to the primary sampling area, an almost identical trend was observed (Fig. 18; dotted line), but the differences were only barely significant (F=2.52 with 4 and 67 d.f.). The latter is probably due to large within-group variances particularly in sediment classes at the lower end of the range. The Dog's Leg area (Area 4) is relatively homogeneous with respect to substrate, and few sediment samples comprised less than about 40% of "fines". This is therefore one instance where it is more appropriate to examine data from all areas sampled than to restrict the analysis to one rather uniform area.

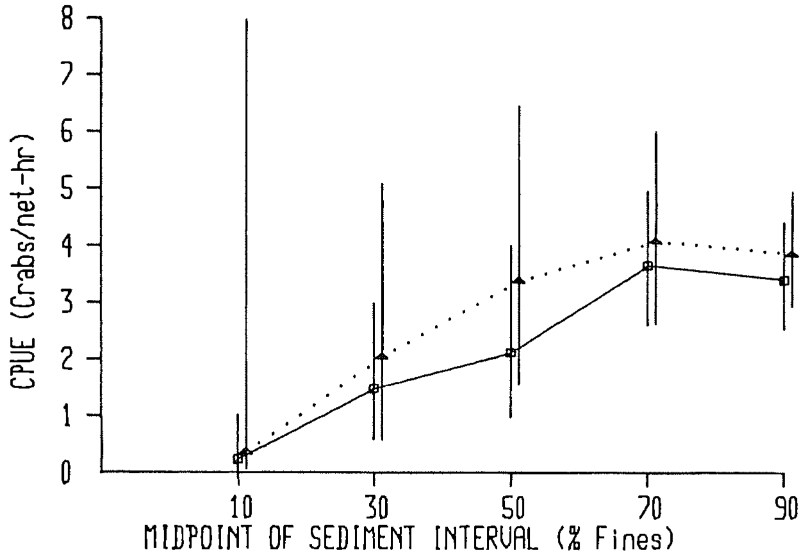

Figure 18. Effect of substrate type on catch rate at Area 4 (dotted line) and all areas pooled (solid line). "Sediment interval" on the X-axis refers to the percentage of sediments of 2 and 3 phi in the substrate sample.

3.2.6 Effect of moon-phase on CPUE

Many marine organisms are affected one way or another by lunar cycles, either directly or (more usually) via the moon's influence on tidal patterns. As the spanner crab is a relatively deep-water non-estuarine inhabitant, there was no a priori reason to believe that lunar cycles would feature significantly in the species' behavioural or distributional patterns. Nonetheless some commercial crabbers were of the opinion that catches tended to be better on certain phases of the moon than others, and as moon-age data could be obtained readily from the meteorological tables, the hypothesis could be tested retrospectively.

Moon age (i.e. number of days since the previous full moon) was computed for each sampling date, and the catch data from Area 4 allocated to one of four moon-age intervals, each of which spanned a period of approximately eight days. Catch rates showed significant differences among moon-age classes ($F=3.35$; $p<0.025$ with 3 and 142 d.f.), with the larger catches being taken on the "dark" of the moon - i.e. 3rd quarter to 1st quarter including new moon - than during the period including full moon (Fig. 19).

To determine whether this lunar periodicity could have been due to short-term inshore/offshore movement, the data were further subdivided into two depth classes (<30 and >30 m). This obviously reduced the size of the samples in the analysis, with the result that differences between the group means lost their statistical significance. Fig. 19 shows the spread of the confidence intervals attached to the depth-subdivided means, but also indicates that the trend in CPUE throughout the lunar cycle was similar at both shallow and deep-water sites. The latter provides evidence that lunar periodicity in catch rate is not due to small-scale cyclic migratory patterns.

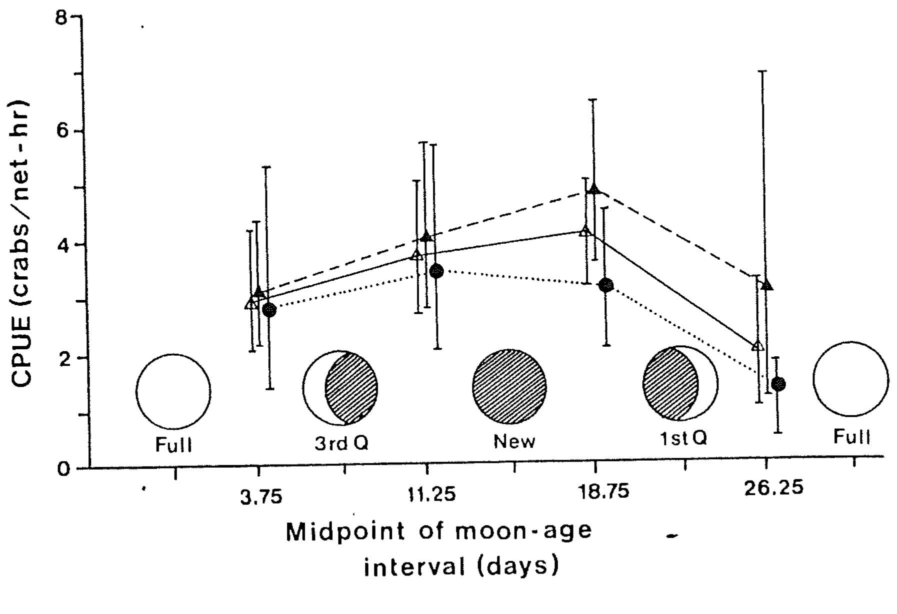

Figure 19. Changes in catch rate in response to lunar periodicity at shallow sites (dotted line), deep sites (dashed line) and all sites pooled (solid line). Moon age is the number of days since the previous full moon.

3.2.7 Geographic differences in CPUE

Although the greatest sampling effort during the project period was applied in the "Dog's Leg" area (Area 4), there were sufficient data from most of the other areas sampled opportunistically to allow a gross comparison of catch rates. Six areas were compared by ANOVA:- South Passage, East Tempest, East Moreton, Dog's Leg, Caloundra/Mooloolaba, and Yellow Patch/Moreton Bay. The analysis revealed a very highly significant difference between mean CPUEs from the various areas ($F=6.05$; $p<0.01$ with 5 and 299 d.f.). Catch rates ranged from a minimum of 0.66 in Yellow Patch/Moreton Bay to a maximum of 3.29 in the Dog's Leg (Figure 20). South Passage (actually the region offshore from the southern end of Moreton Island) yielded an overall catch rate only slightly less than that at the Dog's Leg. Offshore from the central (Tempest) and northern parts of Moreton Island yielded almost identical CPUEs (2.0 and 1.9 respectively), while Caloundra/Mooloolaba, somewhat surprisingly, was only marginally more productive than Yellow Patch/Moreton Bay. The latter is almost certainly due to bias in the particularly small number of samples obtained north of Caloundra (22 sets), as a significant proportion of the total commercial fishing effort is concentrated in that region, and an average catch rate of 1.1 crabs per net hour would not sustain commercial interest for very long.

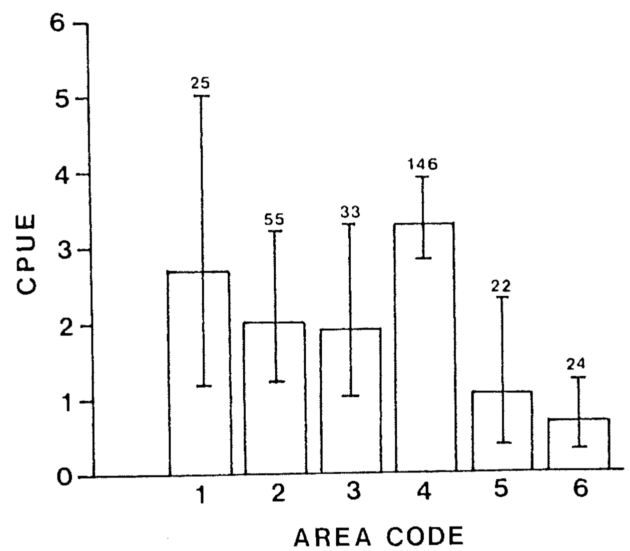

Figure 20. Differences in geometric mean catch rates between sampling areas. Area codes are 1: South Passage, 2: East Tempest, 3: East Moreton, 4: Dog's Leg, 5: Caloundra/Mooloolaba, 6: Yellow Patch/Moreton Bay. Sample sizes and 95% confidence intervals are shown.

It is unfortunate that a more definite statement as to geographical variation in catch rate cannot be made on the basis of the sampling data. However, such information was expected to emerge from analyses of commercial logbook returns (see subsequent section).

3.3 Population Structure

3.3.1 General size distribution and sex ratio

At this relatively early stage in the development of the spanner crab fishery it is appropriate to examine the size-structure of the stock. While this may appear to be of little more than academic interest at the present time, it will be of crucial importance in later years when (hopefully) the status of the fishery and stock will be assessed periodically. Changes in size structure will greatly assist in interpreting the effect of continuous fishing pressure on the resource.

Length data from whatever source (including opportunistic trawl shots and commercial operations as well as regular sampling trips) were pooled and assembled into length-frequency distributions. Figure 21 shows the length-frequency distributions for males and females separately. Two characteristics are immediately apparent - the very much larger number of males in the catch, and a significant difference in modal size. The overall sex ratio was 3.02 which means that, on average, there are about three times as many males in the catch as females.

Not only are males more abundant, they are (on average) rather larger than females by about 20 mm C.L., and grow to a significantly greater size (150 mm vs. 115 mm). Assuming that the stock is in dynamic equilibrium, the left hand limbs of the distribution curves provide an indication of the size at which spanner crabs are recruited into the commercial fishery. Curiously, maximum recruitment of males appears to occur at a greater size (90-100 mm) than it does in females (80-90 mm C.L.). Very few crabs of either sex below a carapace length of 70 mm were taken in the baited tangle nets, perhaps because of mesh selectivity, a significant change in post-adolescent feeding behaviour, or possibly a spatial separation between mature and immature components of the population. Most of the small immature crabs represented in Fig. 21 were captured by trawling, either in a commercial-sized prawn net or in an experimental try-net.

The sex ratio amongst immature crabs appears to favour females (Fig. 22) but owing to the small numbers involved this may not be significantly different from 1:1. The difference between sexes in size at recruitment could explain the predominance of females in the 60-85 mm size-range, but above 85 mm the sex ratio in the catch is believed to reflect that in the population. Fig. 22 clearly demonstrates the increasing predominance of males at larger size intervals, until at lengths exceeding 114 mm there are no females at all.

3.3.2 Variation in size structure

Analytical results relating to factors affecting patterns of spanner crab distribution and abundance (Section 3.2) are based on total catch data, i.e. including both sexes and all sizes. It is quite possible that the size distribution of the catch will vary in response to certain factors as well, and an understanding of such variability would presumably be of some

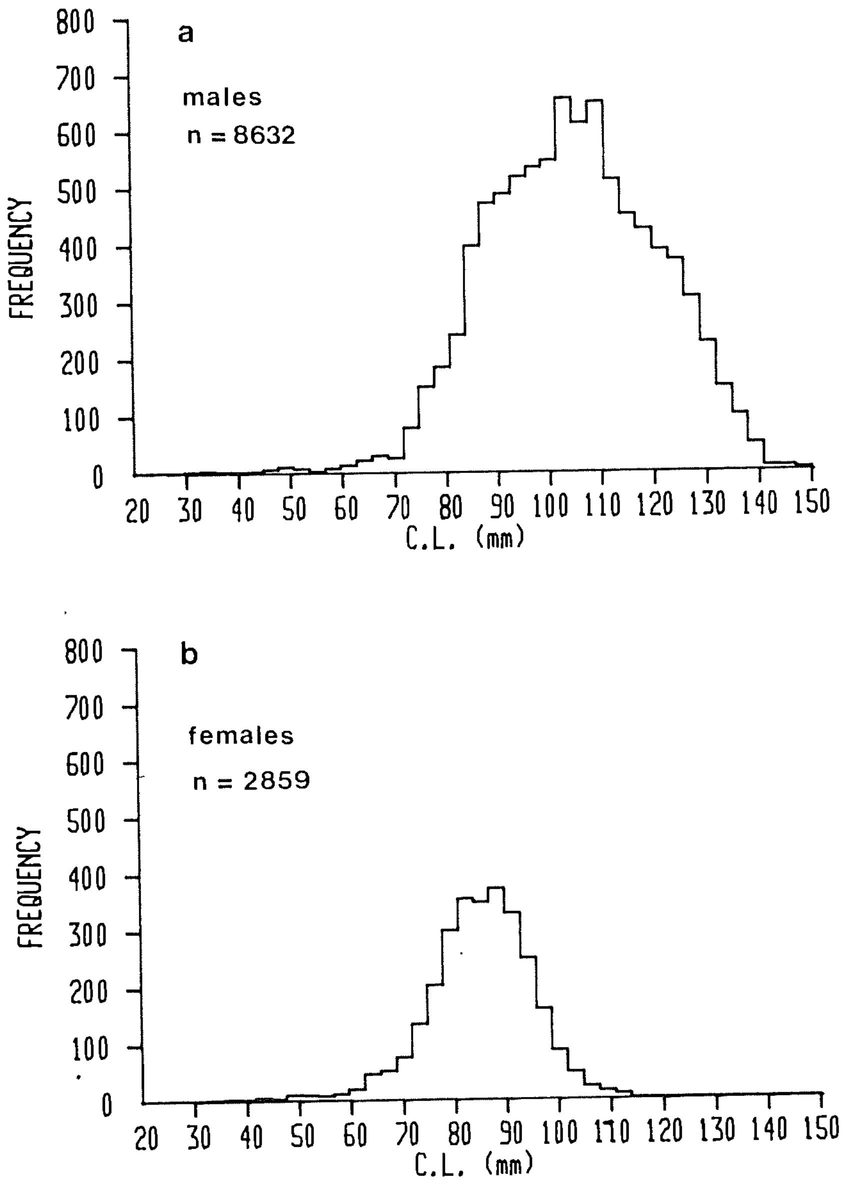

Figure 21. Length-frequency histograms for male (a) and female (b) spanner crabs captured at all sites during the sampling period. Data have been grouped into 3 mm size classes.

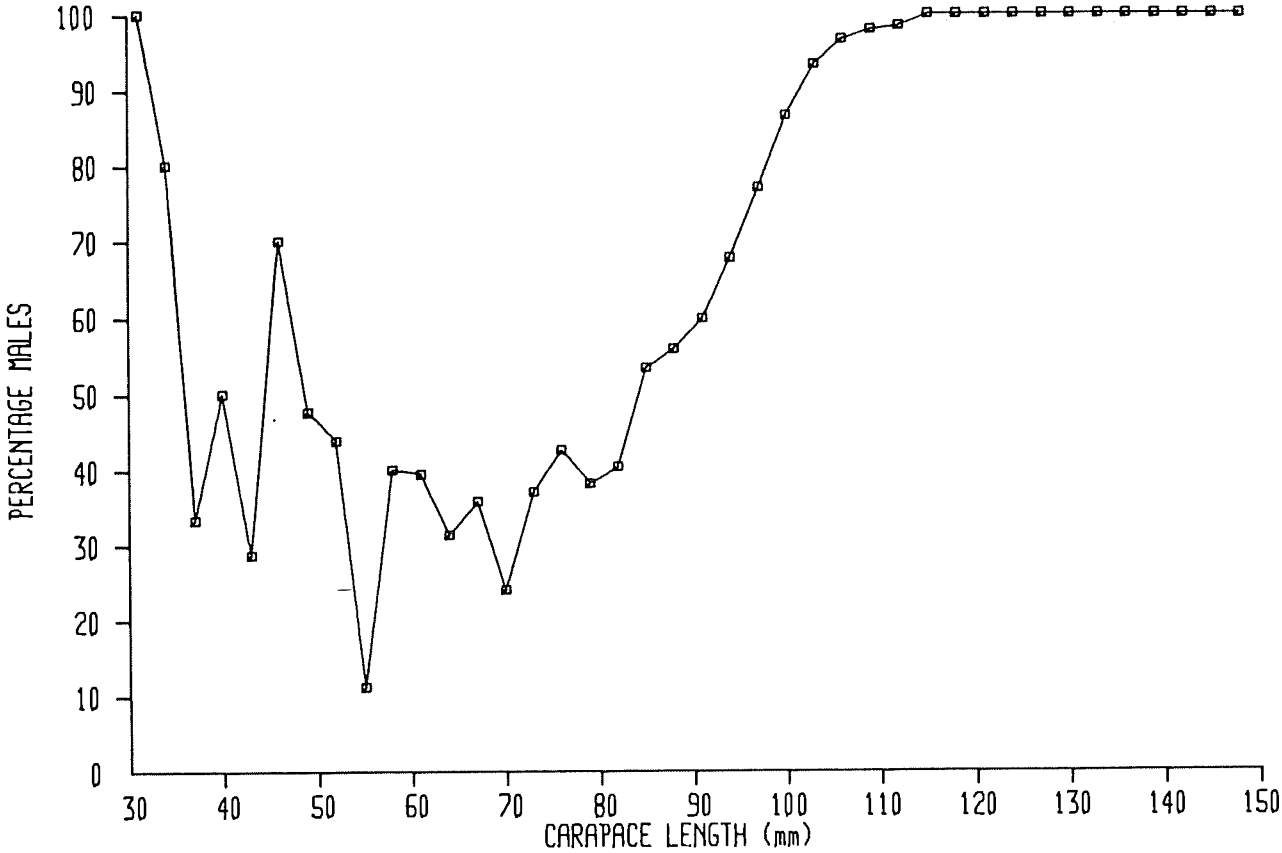

Figure 22. Changes in sex ratio (M:F) with respect to size (carapace length). Data have been grouped into 3 mm size classes.

considerable interest to the commercial crab fisherman. The crabber would prefer a moderate CPUE where the ratio of keepers to discards was high than a large CPUE consisting mainly of sub-legals.

The effects of depth and season on the size structure of the catch were examined by analysing i) the proportion of large to small males, and ii) the catch rate of large males. Since the recommended minimum legal length had been introduced prior to this analysis, it was considered appropriate to use the legislated size (100 mm C.L.) as the point of separation between small and large male crabs. Females were excluded from the analysis because they constitute such a minor proportion of the "legal" catch.

Unlike previous analyses relating to CPUE, the following results are based on the untransformed catch rate, derived by dividing the total number of large crabs captured in a particular combination of season and depth by the total effort (net hours) expended in effecting that catch. It is therefore impossible to calculate within-cell variances or (by extension) confidence ranges around the means.

Because of variation in the number of samples obtained for particular combinations of month and depth interval, some pooling of the data was required. Data were combined into six 2-month "seasonal" groups (January - February, March - April, ... November - December) and five depth classes (0-19, 20-29, 30-39, 40-49, and >49 metres). This resulted in a minimum number of cells lacking data while at the same time maintaining a reasonable degree of resolution.

The ratio of large males to small males in the catch at each depth-season combination are shown in Table 2. It can be seen from the "totals" row that the proportion of legal to sublegal male crabs increases consistently with increasing depth from 0.85 at the shallowest sites to 1.42 in depths exceeding 49 m.

Table 2. Effect of season and depth on the ratio of large to small male spanner crabs.

SEASONAL	DEPTH INTERVAL (m)					
GROUP	0-19	20-29	30-39	40-49	>49	Total
J/F	0.60	0.95	1.43	2.00	12.55	1.33
M/A	1.23	0.64	1.64	1.92	2.35	1.50
M/J	0.94	0.65	1.33	1.36	---	1.04
J/A	---	0.98	1.03	0.81	3.28	0.99
S/O	0.58	1.30	---	0.81	1.43	1.08
N/D	0.90	1.20	1.29	5.87	0.58	1.16
Total	0.85	0.99	1.31	1.37	1.42	1.19

The overall differences due to season (Table 2, "totals" column) were slight, but there appears to be a pattern with minimum values occurring mid-year (July/August) and a progressive increase until March/April. By and large, the best ratios of legal to sublegal male crabs were encountered during summer and autumn, and at depths greater than 40 m. However it would be unwise to use these statistics in isolation as a guide to optimal fishing strategy, since they contain no information about the actual magnitude of the catch. The data in Table 2 should therefore be examined with reference to catch-effort statistics for large male crabs (Table 3).

The best catches of legal-size males were generally taken at intermediate depths (30-39 m) throughout the entire year. From January to October the overall catch rate varied only slightly around an average of approx. 1.6 large individuals per net-hour. However in November and December the catch rate increased appreciably at sites in the intermediate and shallow depth zones, but not in the deeper areas.

Table 3. Effect of season and depth on the untransformed CPUE of large male spanner crabs.

SEASONAL	DEPTH INTERVAL (m)					
GROUP	0-19	20-29	30-39	40-49	>49	Total
J/F	0.78	1.65	1.94	2.36	1.38	1.75
M/A	1.73	0.81	2.66	1.88	1.67	1.72
M/J	1.53	0.91	1.88	1.95	---	1.36
J/A	---	1.55	2.14	1.70	1.31	1.73
S/O	0.57	1.52	---	2.05	1.86	1.65
N/D	1.90	1.90	3.83	1.82	1.15	2.42
Total	1.37	1.46	2.74	1.95	1.59	1.85

It would appear, from simultaneous examination of the data in Tables 2 and 3 that the optimum commercial catches (i.e. the highest ratio of keepers to discards and the greatest catch rate of keepers) should be taken in the 3rd and 4th depth intervals (approx. 35-45 metres). While seasonal effects are less marked than those due to depth, there is a tendency for both indices to be lower in the middle of the year than during the period November-March.

3.3.3 **Variation in sex ratio**

The sex ratio amongst all catches from Area 4 was 3.42, slightly higher than that calculated from all areas pooled (see Section 3.3.1). To determine the extent to which this ratio changes in response to season and depth, the data were sorted into depth and month subgroups as in Section 3.3.2. It is clear from Table 4 that the proportion of males to females in the catch does indeed change quite substantially as a result of these factors.

Table 4. Effect of season and depth on sex-ratio (M:F).

SEASONAL GROUP	DEPTH INTERVAL (m) 0-19	20-29	30-39	40-49	>49	Total
J/F	2.75	6.12	5.10	2.90	3.11	3.87
M/A	3.55	2.42	5.38	6.30	10.88	4.72
M/J	3.88	3.47	4.67	5.50	---	4.20
J/A	---	2.19	1.27	1.50	3.78	1.58
S/O	49.00	2.51	---	1.05	3.84	1.93
N/D	15.35	26.14	6.78	4.00	11.90	8.85
Total	6.24	4.03	4.06	1.94	5.08	3.42

Changes in sex ratio with respect to depth do not conform to a regular trend. The lowest proportion of males to females (or conversely the highest proportion of females to males) occurred in the 40-49m depth range, where males outnumbered females by a factor of only 2:1. At the other extreme, there were more than 6 times as many males as females in the catches obtained from the shallowest (0-19m) depth interval. It could be argued that the value of 49.00 during September/October is unrealistic becauseof the small size of the sample (n = 50), but during the following two month period, when the sex ratio was again very much higher than average, the sample (n = 327) was quite large enough to provide a reliable estimate.

At all other depths the sex ratio ranged between about 4 and 5. One possible explanation for the irregular bathymetric distribution of this index is that it reflects (inversely) the distribution of commercial fishing effort. Probably the greatest fishing pressure has been applied in depths between 35 and 50m, which has resulted in the "culling" of a significant proportion of the male crabs. It should be remembered that because of the difference in average size between male and female spanner crabs, fishing mortality is not distributed evenly over both sexes. Few females grow to the minimum legal length, so mortality amongst females due to fishing is predominantly the result of critical damage to a relatively small number of animals while being removed from the net prior to being returned to the water.

Sex ratio also changes dramatically throughout the year. It is difficult toimagine that this could truly reflect the situation in the population, since it would imply some extraordinary changes in the differential instantaneous rate of natural mortality. Cyclic variation in vulnerability due to behavioural periodicity seems a much more likely explanation. The ratio of M:F in the catch is exceptionally high in November/December (the species' spawning period) but declines steadily throughout summer to a low in winter and early spring (July-October) when ovarian development is accelerating. Perhaps the low sex ratio in winter-spring is the result of peak feeding activity amongst females at the time when their energy requirements are greatest (production of nutrients for egg development and maturation). At the onset of spawning (November) the females may bury to incubate and protect the egg sponges, and thus become much less vulnerable to the fishing gear. This would result in a dramatic increase in the ratio of males to females between October and November. Apart from the anomalous value in September/October (Table 4), the timing of this increase is identical throughout the entire spectrum of depth ranges.

After their eggs hatch, the females presumably emerge and recommence feeding, resulting in increased vulnerability and a concomitant drop in the sex ratio. Between March and June food intake may be required only for maintenance and growth, as ovaries at that time are in the resting phase.

Although no data were collected on cyclic changes in testis development, the fact that a proportion of the females carry spermatophores throughout the year (see Section 3.1.3) suggests that males are capable of mating at any time of the year. This implies that the sexual "cycle" of the male (if it exists at all) is much less pronounced than that of the female, which, in turn, suggests that behaviourally-mediated changes in vulnerability amongst males would assume proportionally less significance.

3.4 Length-weight Relationship

As is to be expected, the weight of spanner crabs varies approximately with the cube of the length. Plotting the raw weight scores against carapace length (Figure 23) results in the usual exponential curve suggesting that the curve could be satisfactorily rectified by a logarithmic transformation.

Conversion of the lengths and weights to their natural logarithms produces an excellent straight-line fit ($r = 0.993$ and $r = 0.986$ for males and females respectively, each with degrees of freedom in excess of 1000). The associated regression parameters are shown in Table 5.

Table 5. Regression parameters b (slope) and a (intercept) for the regression of ln W on ln L in male and female spanner crabs, where W = weight (g) and L = carapace length (mm). Mean ln W and ln L are also shown.

Sex	N	b	a	$\ln \bar{L}$	$\ln \bar{W}$
Males	1410	3.234	-9.1254	4.6232	5.8248
Females	1032	3.075	-8.4078	4.4266	5.2031

Analysis of covariance shows that the between-slopes difference is very highly significant ($F = 71.46$ with 1 and 2438 d.f.; $p<0.001$). There is thus nothing to be achieved by comparing elevations. The slope for females is significantly different from 3.0000 ($t = 4.6941$ with 1030 d.f.; $p<0.001$); that for males is obviously so, indicating that in neither sex are weight and length isometrically related. The greater degree of allometry in males is probably due to a factor implicated in sexual dimorphism within the species:- viz. the development in maturing males of enlarged antero-lateral processes ("horns") from the carapace. These structures clearly increase the weight of the live animal, while not affecting the standard rostral length measure of linear size.

The rate of increase in weight with respect to carapace length can be seen from the calculated values in Table 6, which also indicates the slight difference between sexes.

Table 6. Computed weights at a series of carapace lenths in male and female spanner crabs, using regression parameters in Table 5.

Carapace length (mm)	Computed weight (g)	
	Males	Females
20	1.8	2.2
40	16.5	18.8
60	61.3	65.5
80	155.5	158.7
100	319.9	315.1
120	576.9	552.1
140	949.7	-

3.5 **Morphometrics**

An analysis of relationships between various somatic measurements can sometimes provide an indication of inflections or discontinuities which may be related to events (such as the onset of sexual maturity) in the animal's life cycle or development. From the practical viewpoint such analyses can also demonstrate which alternative measurements could be applied in instances where the standard measure of minimum legal size is, for one reason or another, in doubt.

Measurements of orbital carapace length, the length of the right chelar propodus, sternite width, and the length of the exopod of the third maxilliped were taken from a sample of 128 male and 29 female crabs collected during March 1983. The relationships between these measurements and standard rostral C.L. were examined by regression and correlation techniques, and the data were plotted on scatter graphs to see whether there were any obvious discontinuities or inflections. In all cases the correlation coefficients were highly significant at the 99.9% level (Table 7), indicating that the relationships were linear with no substantial inflections (see also Figures 24 and 25). The patterns of relative growth in orbital C.L., sternite width and MxIII exopod length, as indicated by the regression slope estimates in Table 7, were similar for males and females.

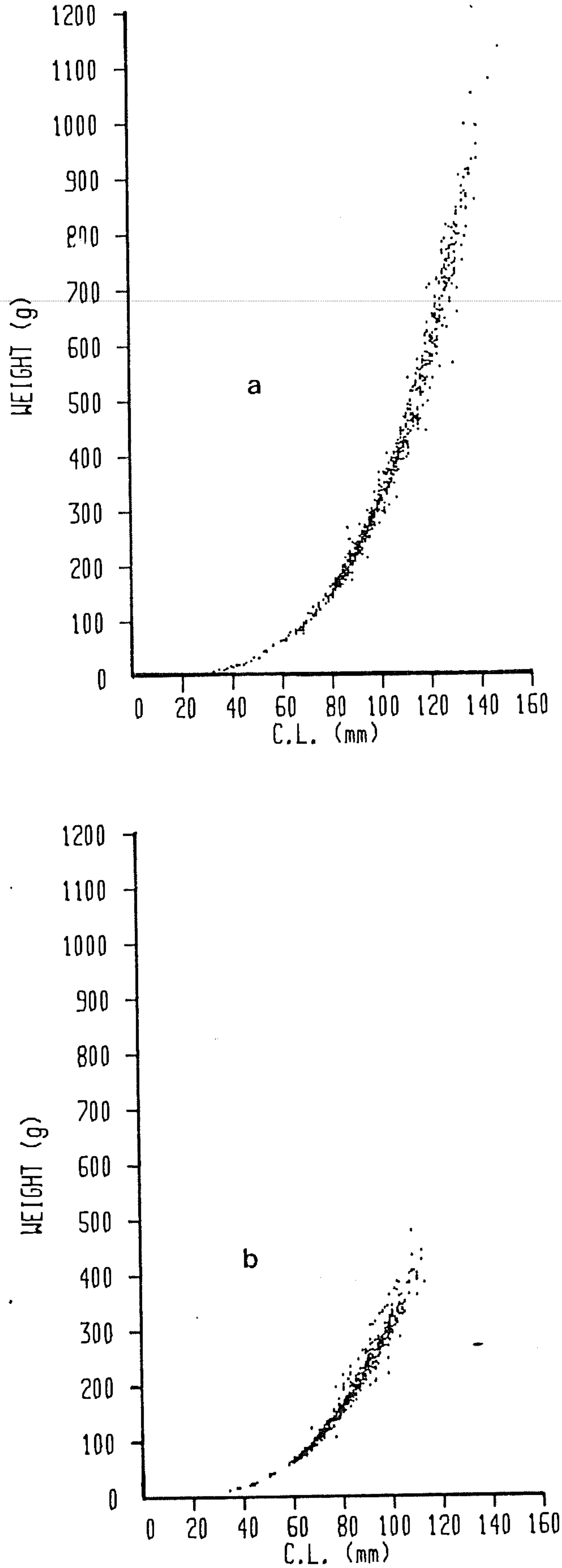

Figure 23. Relationship between total body weight (g) and carapace length (mm) in a) male and b) female spanner crabs.

Table 7. Regression parameter estimates, correlation coefficients and associated probability values for the relationship between four somatic linear dimensions (all in mm) and standard rostral C.L. (mm). D.f. were 126 for males and 27 for females.

DIMENSION	Sex	a	b	r	p
Orbital C.L.	M	-1.4987	0.9460	0.999	<0.001
	F	-0.9058	0.9392	0.998	<0.001
Propodus length	M	-54.3307	1.0810	0.959	<0.001
	F	-6.9115	0.5349	0.986	<0.001
Sternite width	M	-2.6469	0.2833	0.975	<0.001
	F	1.8053	0.2289	0.956	<0.001
MxIII exopod length	M	-1.4504	0.2758	0.979	<0.001
	F	-1.2556	0.2736	0.987	<0.001

The only dimension which showed a significant difference in relative growth pattern between sexes was the length of the chelar propodus (i.e. the main claw segment). The claw of the male spanner crab increases in length at about twice the rate (with respect to standard carapace length) as that of the female. This can clearly be seen by comparing the slopes in Figures 24c and d.

An interesting feature of Figure 24c is the discontinuity in the elevation of the regression line at carapace lengths of between 110 and 125mm. There are clearly two overlapping parallel regression lines, which suggests that when the male crab reaches a length of 110mm or so a physiological change takes place resulting in the development of a claw which is disproportionately larger (by nearly 10mm) than would be expected on the basis of its previous growth pattern. Apparently this feature occurs only once in male crabs greater than 80mm C.L., and not at all in females (see Figure 24d).

Some research work on spanner crabs in Hawaii (e.g. Fielding and Haley, 1976) has employed orbital carapace length as the standard linear measure of size. It is thus useful, for comparative purposes, to know the relationship between orbital and rostral C.L., and also to have some idea of how closely the two measures correlate. Table 7 indicates that of the four dimensions examined, orbital C.L. was the least variable with respect to rostral C.L. ($r = 0.999$ and 0.998 for males and females respectively). The tight clustering of data points around the regression lines in Figures 24a and b provides visual confirmation of this. Orbital C.L. can be predicted quite accurately from a given rostral C.L. value by the following formulae:

a) Males: O.C.L. = 0.946 R.C.L. - 1.499
b) Females: O.C.L. = 0.939 R.C.L. - 0.906

Thus the minimum legal size (100mm C.L. [rostral]) equates to 93.1mm (males) and 93.0mm (females) on the orbital C.L. scale, i.e. the distance between the base of the right eye socket to the central posterior margin of the carapace, as per Fielding and Haley (1976).

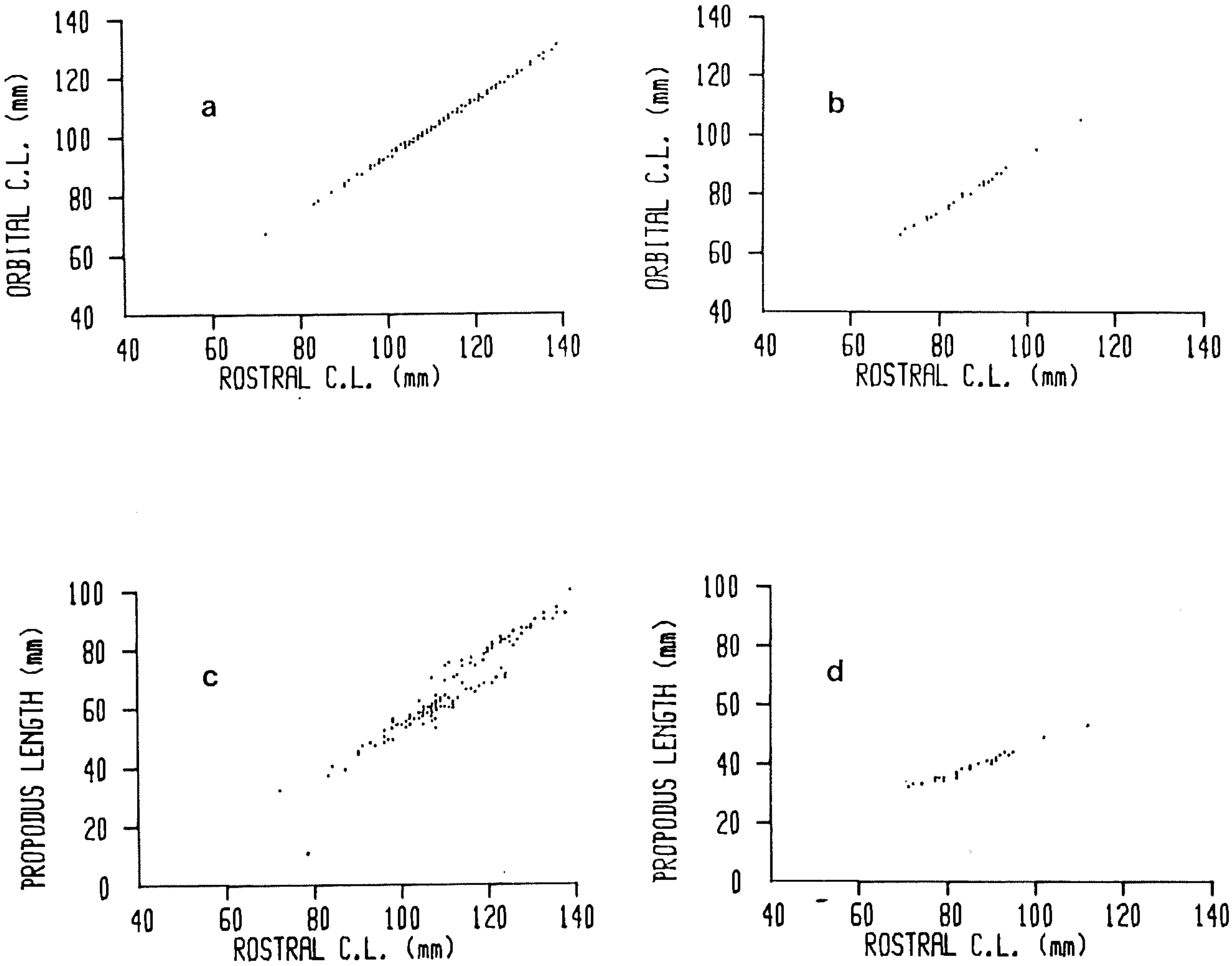

Figure 24. Relationship between orbital and rostral carapace lengths in males (a) and females (b), and between right chelar propodus and rostral carapace lengths in males (c) and females (d).

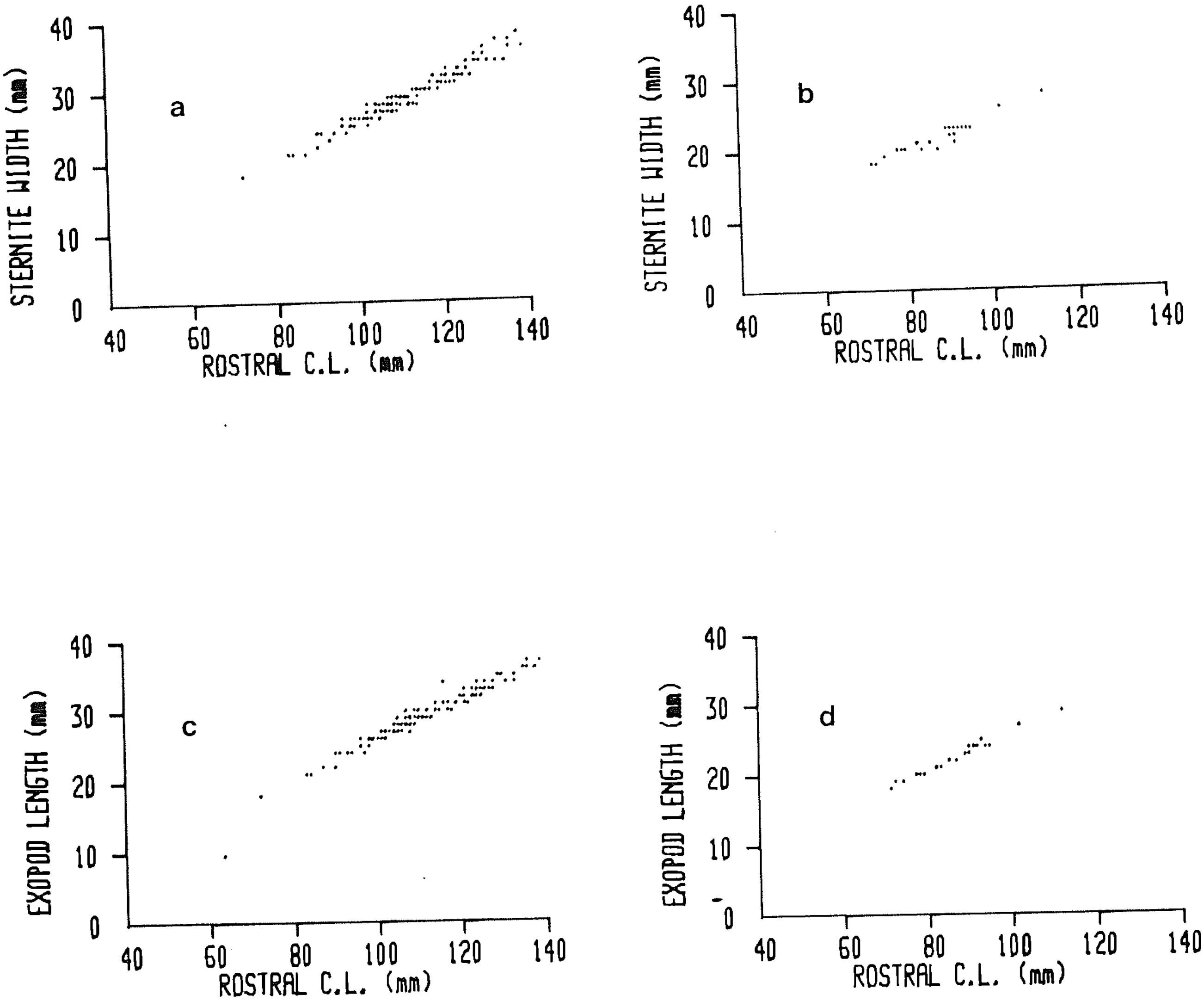

Figure 25. Relationship between sternite width and carapace length in males (a) and females (b), and between maxilliped III propodus and rostral carapace lengths in males (c) and females (d).

3.6 **Meat Recovery Rate**

There is often discussion amongst fishermen and consumers about the quantity of meat that can be extracted from a spanner crab, and how it compares with meat recovery from sand and mud crabs. During the early stages of the project it became apparent that some consumers were disillusioned about the amount of extractable meat. Investigation showed that the dissatisfied customers were using only the animal's legs and claws, not realising that the bulk of spanner crab meat is within the body. In an attempt to enlighten such people, project staff co-operated with two Mooloolaba crab fishermen (Messrs D. Jones and A. McMullen) in producing a leaflet explaining where the meat is located and detailing a relatively simple and effective method for extracting it. The handout, which also incorporated several recipes for spanner crab meat dishes, was printed in the "Cooking with DPI" information leaflet series (Appendix 4) and distributed to seafood dealers, fishermen and private individuals.

To determine the relative meat weights from the three species on a simple weight-for-weight basis, samples of the crabs were obtained from various sources, cooked according to accepted standard procedures, and meated. Meat picking was done meticulously and probably resulted in slightly higher extraction rates than would be expected in a more rapid commercial operation. Since spanner crab legs contain little flesh, only the body and claw meats were picked from this species. However body, leg and claw meats were removed (and separately weighed) from the sand crab and mud crab samples.

The total cooked meat weights were plotted against green (uncooked) body weights (Figure 26), and the associated regression parameters estimated for each species. The relationship between meat weight and total body weight was linear in all three species, although the amount of scatter varied somewhat, largely as a result of variability in the condition or "fullness" of mud crabs. The correlation coefficients were, however, highly significant in each case. Figure 26 indicates that for a given body weight, sand crabs will yield a considerably greater quantity of meat than either spanner or mud crabs, the difference between the latter species being only slight. This somewhat surprising observation is due partly to differences in claw size and partly to exoskeleton mass. Sand crab carapaces are relatively thin with respect to the other species, hence the elevated meat:body weight ratio. Moreover sand crab claw and leg meat weights are substantially greater than those in spanner crabs. On the other hand mud crabs have very massive exoskeletons (which obviously contributes significantly to total body weight). A 600g mud crab might therefore be rather smaller (both in linear dimensions and volume) than a spanner or sand crab of equivalent weight, and would thus contain proportionately less musculature.

On the basis of the data presented in Figure 26, meat yields (Y) for a given body weight (X) can be estimated from the following formulae:

a) Spanner crabs: $Y = 11.1 + 0.22X$
b) Sand crabs: $Y = 2.28 + 0.34X$
c) Mud crabs: $Y = 4.19 + 0.25X$

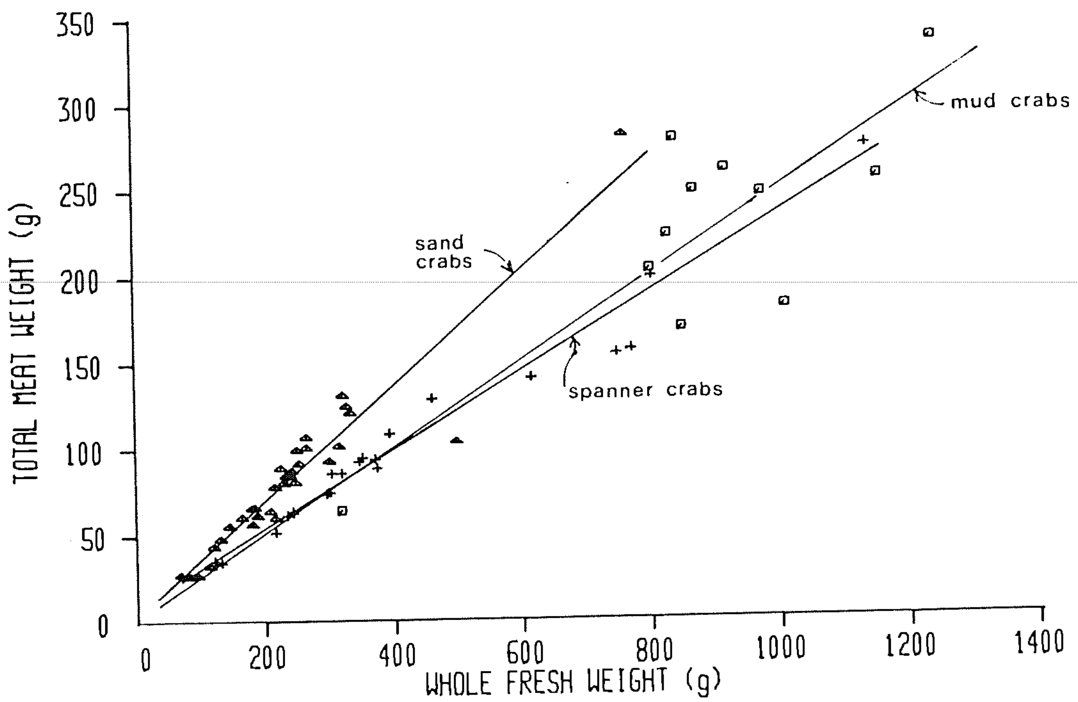

Figure 26. Relationship between cooked meat yield and uncooked body weight in three edible crab species from south-east Queensland (sand crabs ▵ , spanner crabs + , and mud crabs ⊡).

A simplified analysis of the relationship between total weights and meat weights in each of the three species is presented in Table 8. This analysis is based on the total sample statistics, i.e. without reference to the effects of variation in the size of individuals within samples.

Table 8. Pooled statistics and relationship between total weights and meat weights in three edible crab species.

STATISTIC	R. ranina	P. pelagicus	S. serrata
Total green (uncooked) weight (g)	9409	7518	9751
Total cooked weight (g)	8524	6583	8421
Body meat weight (g)	2329	1477	1106
Claw meat weight (g)	incl. in above	838	924
Leg meat weight (g)	not measured	288	429
Total meat weight (g)	2329	2603	2459
Cooking weight loss (%)	9.4	12.4	13.6
Claw meat as % of total meat	—	32.2	37.6
Leg meat as % of total meat	—	11.1	17.4
Total meat as % of green weight	24.8	34.6	25.2

The total extractable meat averages about one quarter of the green weight of spanner and mud crabs, and a little more than one third of the green weight of sand crabs. Cooking results in a weight loss of around 9% in spanner crabs and about 13% in both sand and mud crabs. Claw meat represents a very significant fraction (more than one third) of the meat which can be extracted from sand and mud crabs. Spanner crab claw meats were not weighed separately from the body meats, but their contribution to total meat weight is certainly much less than it is in either of the other two species. The legs of spanner crabs are relatively short and contain little meat, so no attempt was made to analyse the meat recovery rate from this source. On the other hand, sand crab and mud crab legs are considerably larger and contain enough musculature (about 11% and 17% respectively) to warrant picking.

A subsample of meats from seven spanner crabs was weighed, then freeze-dried to constant weight to determine moisture content. The cooked meat weighed (in total) 632 g immediately after extraction, and 123 g after freeze-drying. The difference of 509 g indicates that spanner crab flesh comprises, on average, slightly more than 80% water.

3.7 Mesh Selection Trials

During the period July-December 1984 (Trips 97 - 101 inclusive) several experiments were carried out to determine the effect of varying mesh dimensions on the size and size composition of the catch. In these tests the standard mesh (50 mm) was used as a reference, together with a smaller (30 mm) and a larger (75 mm) mesh. In the following discussion the three sizes will be referred to as small (S), medium (M), and large (L).

3.7.1 Effect of mesh size on frequency distribution

Length data pertaining to the total catch from each of the three mesh sizes were pooled over trips and sets, and sorted into 3-mm class intervals. The resultant length-frequency distributions were compared using the Kolmogorov Smirnov non-parametric two sample test (Siegel 1956, Conover 1980). The cumulative frequency distributions of carapace length in catches from the three mesh sizes are shown in Figure 27.

Computed values of the sample statistic "D" (for a two-tailed test) and chi-square (for a 1-tailed test) reveal that the cumulative frequency distributions differed significantly in both L x S and L x M comparisons, but not in the S x M comparison (Table 9). In other words, the small and medium mesh nets sampled essentially the same statistical population with respect to crab size (carapace length). From the point of view of size composition alone, there would be no advantage to the commercial operator in choosing either one over the other. However, the large-meshed nets appeared to sample a structurally different statistical population. The hypothesis that crabs caught in the large mesh nets are, on the whole, larger than those caught in either the small or medium meshes, is supported by the significance of the chi-square values in a one-tailed test. In both instances the sign of D(max) was indicative of a trend in the expected direction.

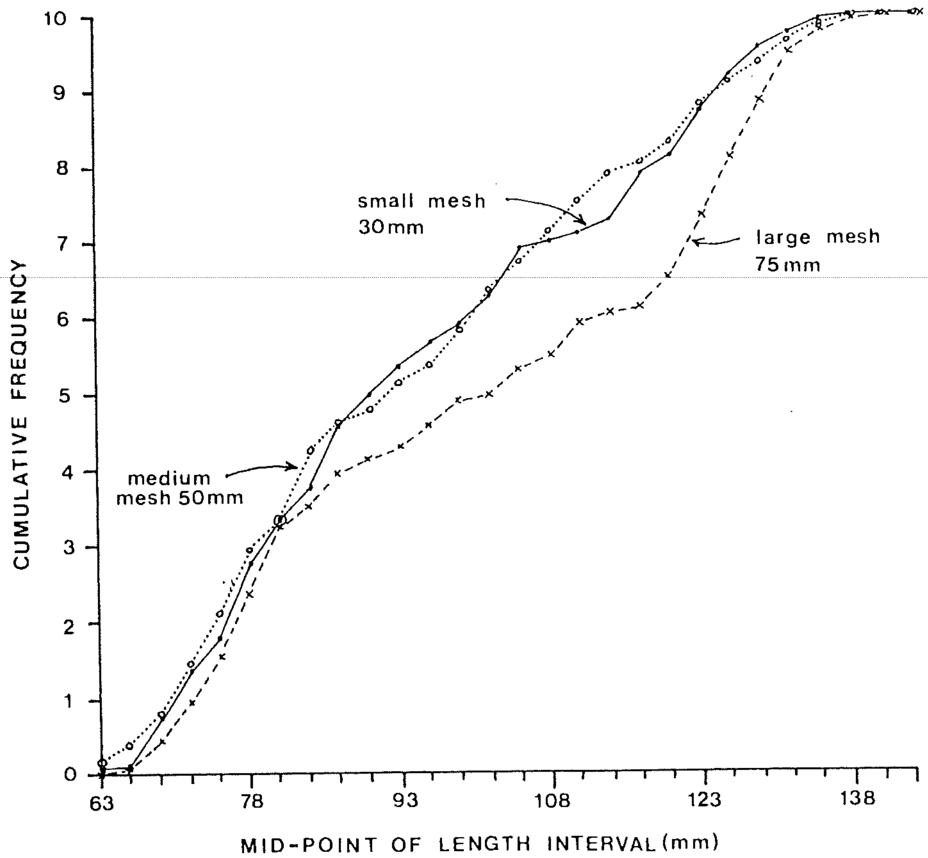

Figure 27. Cumulative relative frequency distributions of carapace length in spanner crabs caught by small (30 mm), medium (50 mm) and large (75 mm) meshed nets.

Table 9. Values of D and X^2 with associated probabilities resulting from the Kolmogorov-Smirnov test of size-frequency distributions between small, medium and large-mesh nets. Sample sizes are given as N_1 and N_2.

COMPARISON	N_1	N_2	D	P	X^2	P
S x M	207	155	0.058	>0.05	0.313	>0.05
M x L	155	96	0.185	<0.05*	8.152	<0.025*
S x L	207	96	0.178	<0.05*	- 8.283	<0.025*

A 2 x 3 contingency table was used to test whether the proportions of large (>=100 mm C.L.) and small (<100 mm C.L.) crabs caught by each of the three mesh sizes were the same. The computed value of chi-square (2.88; 2 d.f.) was not significant at the 0.05 level, indicating that the observed differences between the proportions of small and large crabs could have been due to chance.

3.7.2 **Effect of mesh size on catch rate**

Choice of the optimum mesh size for commercial use needs to take into account not only size composition, but the actual catch rate as well. To determine whether catches from the three mesh sizes were substantially different, a non-parametric test was used to avoid having to find a normalising transformation. The Wilcoxon two-sample test (Sokal and Rohlf 1969) provides the Mann-Whitney statistic U which can be compared either with tabulated critical values (when N_1 and N_2 are both less than 20) or with a computed test statistic when the samples are larger. The reduced data (total and average numbers of crabs per net, for each sampling trip) are set out in Table 10. The pooled means (Table 10, bottom line) exhibit a strong inverse relationship with mesh size, ranging from about 2.5 in the large-mesh nets to 5.7 in nets with the smallest mesh size.

Table 10. Reduced data for the total catches (numbers of crabs per net) by trip number and mesh size.

TRIP No.	No. SETS	LARGE MESH			MEDIUM MESH			SMALL MESH		
		n	ΣX	$\bar{X}$	n	ΣX	$\bar{X}$	n	ΣX	$\bar{X}$
97	2	8	7	0.88	8	14	1.75	8	26	3.25
98	4	16	84	5.25	16	135	8.44	16	174	10.88
99	1	4	3	0.75	4	6	1.50	4	12	3.00
100	4	14	20	1.43	16	27	1.69	16	58	3.63
101	2	6	4	0.67	10	13	1.30	8	27	3.38
TOT	13	48	118	2.46	54	195	3.61	52	297	5.71

Results of the Wilcoxon tests (Table 11) are somewhat confusing. Given the spanner crab's patchy distribution, it is not really surprising that none of the U_s values from Trips 97 and 99 were statistically significant. With such small samples (8 and 4 pairs respectively), any substantial overlap in the data would very likely lead to a non-significant result in a rank test of this type. However the relatively large sample of comparisons from Trip 100 also lacked significance.

Real differences in catch rate between large and small-mesh nets (Trips 98 and 101) and also between large and medium-mesh nets (Trip 98) are apparent from Table 11. In none of the tests on data from individual trips was there a significant difference in the S x M comparison. On the other hand, when the whole of the data are pooled, the test (which then produces the statistic T_s rather than U_s because of the increased sample sizes) reveals statistical differences between L and S ($p<0.01$) and between M and S ($p<0.02$). That the tests should yield such variable results makes their interpretation difficult, and probably provides good reason to repeat the mesh size comparisons at a later date. It does, nevertheless, indicate that catch rates from nets fitted with 30 mm, 50 mm and 75 mm webbing are not homogeneous.

Table 11. Values of the Mann-Whitney statistic U_s and associated probabilities for comparisons of the catch per net between the three mesh sizes, by trip and for all trips pooled.

TRIP	COMPARISON	N_1	N_2	U_s	T_s	P
97	L x M	8	8	42.5	—	>0.05
	M x S	8	8	38.0	—	>0.05
	L x S	8	8	45.5	—	>0.05
98	L x M	16	16	202.5	—	<0.05*
	M x S	16	16	173.5	—	>0.05
	L x S	16	16	223.0	—	<0.002***
99	L x M	4	4	11.0	—	>0.05
	M x S	4	4	11.5	—	>0.05
	L x S	4	4	13.5	—	>0.05
100	L x M	16	14	126.0	—	>0.05
	M x S	16	16	179.0	—	>0.05
	L x S	16	14	152.0	—	>0.05
101	L x M	10	6	41.5	—	>0.05
	M x S	10	8	61.0	—	>0.05
	L x S	8	6	41.5	—	<0.05*
POOLED	L x M	54	48	1451.0	1.058	>0.05
	M x S	54	52	1779.5	2.392	<0.02**
	L x S	52	48	1745.0	3.464	<0.01**

3.8 Net Design Trials

When the Project commenced, inverted dillies were in general use amongst commercial spanner crab fishermen. Shortly after, however, Hawaiian-type flat nets appeared, gained acceptance among the fishermen, and eventually replaced the slack-hung conical nets altogether. During this transition phase experiments were carried out to evaluate the relative effectiveness of the two net designs. The trials took place during Trips 12 - 17 incl. (4.6.81 - 23.7.81), and included comparisons of catch rate, size composition of the catch, and net-clearing time.

3.8.1 Effect of net design on size composition

Size frequency data from the inverted (conical) dillies and flat nets (pooled over Trips 12 - 17) were first compared visually by plotting their cumulative distributions (Fig. 28). This figure shows that crabs smaller than 90 mm C.L. comprised 50% of the inverted dilly catch, but only about 34% of the flat net catch. In other words, crabs caught in the dillies are, on average, smaller than those caught in the flat nets. This hypothesis was tested using the Kolmogorov-Smirnov two-sample test (Siegel

1956, Conover 1980), which demonstrated that the two frequency distributions were significantly different (D=0.174, $p<0.001$), and that, with a one-tailed test, the difference was in the expected direction (χ^2 = 15.338, $p<0.005$ with 2 d.f.).

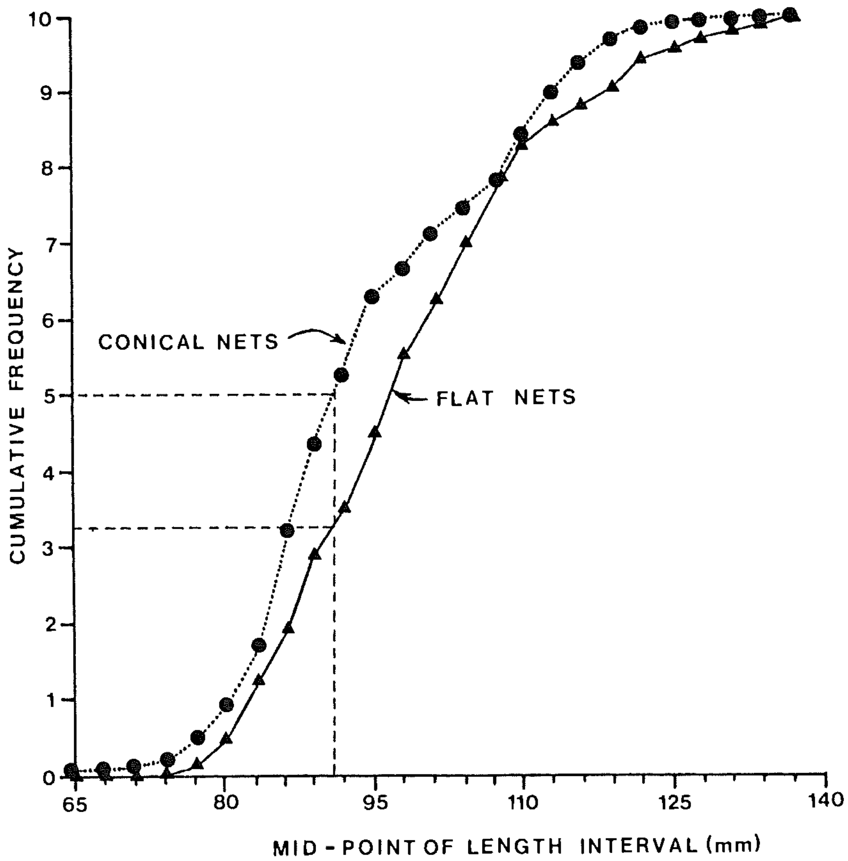

Figure 28. Cumulative relative frequency distributions of carapace length in spanner crabs caught in conical dillies and flat nets.

From the commercial fisherman's point of view, it is of interest to know whether this difference is manifest as a real difference in the proportions of legal sized to undersized crabs between the two net designs. Once again, this was tested by computing χ^2 from a 2 x 2 contingency table of observed and expected values. The resulting value (χ^2 = 7.79) indicated a highly significant difference at the 0.01 level. When Yates' correction for continuitywas applied, χ^2 was slightly reduced (to 7.28), but this had no appreciable effect on its probability level. In other words, there is a statistical difference in the ratio of legal to undersize crabs caught by the two gear types.

3.8.2 Effect of net design on catch rate

The catch rates (total numbers of crabs per drop) of conical and flat nets were compared using the Wilcoxon test. Data from two sets in which neither type of net caught any crabs were excluded from the analysis, as were all data from Trip 16 (Hervey Bay). Statistics including the size of the catch and the average numbers of crabs per drop during each of the six sampling trips are shown in Table 12 below.

Table 12. Total catch (number of crabs,M+F), numbers of drops, and average catch rate (crabs per drop) for flat and conical nets by trip.

TRIP No.	Number of SETS	FLAT NETS Drops	ΣX	$\bar{X}$	CONICAL NETS Drops	ΣX	$\bar{X}$
12	3	14	103	7.4	15	134	8.9
13	4	16	2	0.1	20	29	1.5
14	3	12	21	1.8	15	55	3.7
15	4	16	34	2.1	16	33	2.1
16	3	12	3	0.3	15	7	0.5
17	3	12	54	4.5	12	54	4.5
TOTAL	20	82	217	2.6	93	312	3.4

While the data in Table 12 suggest that conical nets outfish flat nets, the Wilcoxon non-parametric rank test (large samples) produced a t-value of 0.933, which is less than the computed test statistic for N_1=69 and N_2=62. Thus, statistically speaking, the observed differences in catch per net between the two net types are not significant, and could have been due to chance.

3.8.3 Effect of net design on clearing time

Experiments were carried out during Trips 13 and 14 (17 and 23 June 1983) in the Cape Moreton and Yellowpatch regions to establish whether the time required to clear crabs from conical dillies and Hawaiian-type flat nets is significantly different. Three inch (76 mm) 210/9 ply synthetic webbing was used in both types of net, and thawed sea mullet was used as bait throughout. Clearing time was measured with a stop-watch for each individual crab, since the number of crabs in the catch varied considerably, both between and within net types. Inspection revealed that the time-frequency data were not normally distributed, so a logarithmic transformation was applied prior to testing the results statistically.

The back-transformed (geometric) mean clearing time for crabs caught in the conical nets (20.5 sec) was somewhat greater than that for crabs caught in the flat nets (15.4 sec), but a t-test showed that the difference between means was non-significant ($t=1.93$; $p>0.05$ with 110 d.f.).

Clearing times of up to 20 sec/crab may seem excessive to a practised commercial operator, but it should be pointed out that crabs were untangled with great care to avoid breaking appendages, and that the flat nets were fitted with a double layer of webbing in line with the typical Hawaiian design (Brown 1985). It is highly probable that clearing time from a flat net with a single layer of monofilament webbing would be significantly less than for a multifilament conical dilly, especially if less consideration was given to avoiding leg and spade breakages.

3.9 Bait Trials

During Trips 87-90 incl. (February-March 1984) a series of trials was conducted to test the relative effectiveness on catch rate of two types of bait - mullet and tuna. In the course of the experiment, 66 mullet-baited and 54 tuna-baited nets deployed among 10 sets yielded 132 and 176 crabs respectively. Statistics relating to the catch (number of crabs) and effort (number of net drops) are shown in Table 13.

The untransformed catch rate (c/e) was, in all but one of the ten sets, greater for tuna than for mullet bait (Table 13), strongly suggesting that the former is more attractive to spanner crabs. To test this, pooled catch rate data from each individual trip and from all trips combined, were compared using the Wilcoxon technique. The results of these tests also appear in Table 13, as U (for small samples) and t (for large samples), together with the associated probability values.

In three of the four individual trips the differences in catch rate between bait types were shown by the Wilcoxon test to be non-significant; only in Trip 89 were they statistically different ($U=124$; $p<0.01$ with 14 and 10 d.f.). Notwithstanding, when the entire data set was treated as a single sample, the test statistic $t=2.74$ was significant at the 99% level of confidence (Table 13, bottom line).

Thus the non-parametric test appears to support the observation that there is a substantial difference in effectiveness between the two baits. While it is tempting to attribute this to a biochemical difference between the two species, it is important to recognise that (because of the vast size-difference between longtail tuna and sea mullet) split mullet would expose a far smaller cut surface area than a piece of tuna of equivalent weight. It is possible that the area of exposed flesh is the significant factor, rather than interspecific chemical differences, but to establish the precise cause would require very carefully-controlled experiments.

Table 13. Comparative catch, effort and catch-rate data between mullet-baited and tuna-baited flat nets, with results of the Wilcoxon test for individual trips and total (pooled) data.

Trip No.	Set No.	Bait: mullet drops	Bait: mullet catch	Bait: mullet c/e	Bait: tuna drops	Bait: tuna catch	Bait: tuna c/e	test statistic	p
87	1	6	11	1.8	6	16	2.7		
	2	6	9	1.5	6	24	4.0		
	pooled	12	20	1.7	12	40	3.3	U=95.0	>0.05
88	1	6	26	4.3	6	32	5.3		
	2	6	13	2.2	6	20	3.3		
	pooled	12	39	3.3	12	52	4.3	U=91.5	>0.05
89	1	7	2	0.3	5	10	2.0		
	2	7	8	1.1	5	19	3.8		
	pooled	14	10	0.7	10	29	2.9	U=124.0	<0.01
90	1	6	10	1.7	6	17	2.8		
	2	6	8	1.3	6	7	1.2		
	3	6	9	1.5	6	21	3.5		
	4	10	36	3.6	2	10	5.0		
	pooled	28	63	2.3	20	55	2.8	t=0.14	>0.05
Total		66	132	2.0	54	176	3.3	t=2.74	<0.01

3.10 Larval Rearing

Attempts were made during the 1981/82, 1982/83 and 1983/84 spawning seasons to extend the work of Sakai (1971) and rear a larval series of **R. ranina** through to the presumed megalopa stage. The megalopa of this species is undescribed and has evidently never been observed. At the same time, observations and measurements were made on the eggs and zoeal stages to enable morphometric comparisons between Queensland and Japanese stocks. Maternal crab holding and larval rearing conditions (including salinity and temperature in the experimental tanks) were documented in an endeavour to determine optimum environmental conditions for larval survival.

Larvae used in these experiments were obtained exclusively by hatching the eggs of ovigerous females obtained from commercial spanner crab fishing grounds either by the Project team or by cooperative professional crab fishermen.

Basic details of the origin, size and fate of these females and their eggs are presented in Table 14. Each crab (or group of crabs) involved in the study is identified by a unique code number which relates it to a particular experiment or set of observations. The three consecutive spawning seasons are represented by Series A, B, and C respectively.

Table 14. Details of ovigerous females held in the SFRC aquarium system for larval production. "Days" refers to the number of days after capture.

SEASON	CODE	C.L. (mm)	CAPTURE DATE	ORIGIN	COMMENTS
81/82	A1	80	26.10.81	* Mooloolaba	Eggs lost @ day 31
	A2	86	27.10.81	* Mooloolaba	Eggs lost @ day 31
	A3	82	30.11.81	E. Tempest	Eggs hatched @ day 30
	A4	100	2.12.81	Dog's Leg	Eggs hatched @ day 14
	A5	87	2.12.81	" "	Eggs hatched @ day 15
	A6	87	2.12.81	" "	Crab died @ day 4
	A7	99	2.12.81	" "	Crab died @ day 15
82/83	B1	78	6.11.82	* Mooloolaba	Eggs hatched @ day 26
	B2	94	7.11.82	Dog's Leg	Eggs hatched ca day 31
	B5	80	23.1.83	* Sth Passage	Eggs hatched @ day 10
	B6	?	28.1.83	Sth Passage	Eggs hatched @ day 10
	B7	?	9.2.83	" "	Eggs lost @ day 12
83/84	C1	75	7.11.83	Dog's Leg	Eggs hatched @ day 22
	C2	103	1.12.83	Dog's Leg	Eggs hatched @ day 6
	C3	93	16.12.83	Sth Passage	Eggs hatched @ day 15

* crabs captured and supplied by commercial fishermen.

3.10.1 General observations

Berried crabs captured during routine sampling operations were placed in 15 l black plastic drums containing a sand substrate and clean aerated sea water for transport to the laboratory. There they were transferred to larger (750 l) holding containers. Individuals supplied by fishermen were generally delivered under less well-controlled conditions in buckets of sea water, and the elapsed time between capture and introduction to the aquarium system was considerably longer (e.g. by 24 hours or so) than it was with crabs captured by Project staff. Resultant stresses took their toll on the survival of both the female crabs and their offspring.

The first two commercially-caught females in Series A both lost their eggs after about four weeks. Of an initial batch of 21 crabs caught by a fisherman off South Passage, seven of the healthiest were selected for experimental work. These ranged in size from 79 to 92 mm C.L., but all were in comparatively poor condition. One developed a fungal infection in the egg sponge, and all but one of the remainder suffered high egg mortality and/or complete egg loss within the first few days. The only eggs which hatched (at day 10) were from an 80 mm female (B5), and these showed morphological abnormalities presumably resulting from post-capture stress.

Operational problems with the the SFRC aquarium system, including power failure and breakdowns in the seawater circulating system, also very likely affected the outcome of some experiments, with sudden changes in temperature inducing premature hatching and subsequent high larval mortality. Figure 29 provides details of the salinity and temperature regimes which prevailed during the holding periods of all major trials.

By and large, healthy ovigerous females remained buried beneath the sand surface with only the eye-stalks and extended abdominal flap (with associated egg sponge) protruding. When food was introduced into the tank, the crabs would swim or creep out, seize the food, and retreat back into the substrate where ingestion would take place. The experimental animals quite obviously fed during the pre-hatch period, which seems to conflict with the hypothesis proposed previously to account for significantly decreased catches of females in the post-ovulation phase. However, the fact that berried crabs can be caught at all in the baited nets suggests that there is at least some feeding activity going on, albeit at a reduced level. No comparative experimental data are available to test the theory that ovigerous females feed less frequently than non-ovigerous individuals.

Crabs A1 and A2 (which both lost their eggs after 31 days) and A5 and A6 (which died within a fortnight of capture) made no attempt to feed during the holding period. Whether the lack of food intake was causally related to egg and maternal death is not known; the possibility exists that all three effects were the result of an independent stress-related cause.

In most cases the main hatch took place at night, although sometimes a small proportion of the eggs began to hatch during the previous day. On the only two occasions when the process was observed, it commenced at 1910 hr and 1915 hr (on 7.12.83 and 16.12.83 respectively) and was completed within about 45 minutes. Newly emerged Zoea I larvae aggregated near the water surface, and exhibited a degree of positive phototaxis. Larvae from B1, which hatched on 3.12.82, had experienced some sudden changes in water temperature during their embryonic development, and were morphologically abnormal, with crooked rostral and dorsal spines. These larvae suffered particularly high mortality rates during Zoea I.

Generally speaking, the larvae appeared to feed well on the rotifers, copepods and brine-shrimp nauplii offered. Zoea III and IV stages, when deprived of an adequate food supply, were seen to bite the tips of each others' dorsal and rostral spines.

3.10.2 Egg and embryonic development

Observations on impregnated non-ovigerous female crabs which ovulated in a holding tank prior to the first of this series of experiments indicated that (at least under laboratory conditions) embryonic development takes about five weeks. While gonad development studies have shown that the south Queensland spanner crab stock has a relatively well-defined spawning period, ovulation is not completely synchronous, and embryos in contemporaneous samples of crabs will not be at exactly the same stage of development. Late-term embryos are obviously preferred for larval work, as this reduces the risk of disease, developmental aberrations, and premature hatching during the holding period. However the egg sponges obtained from

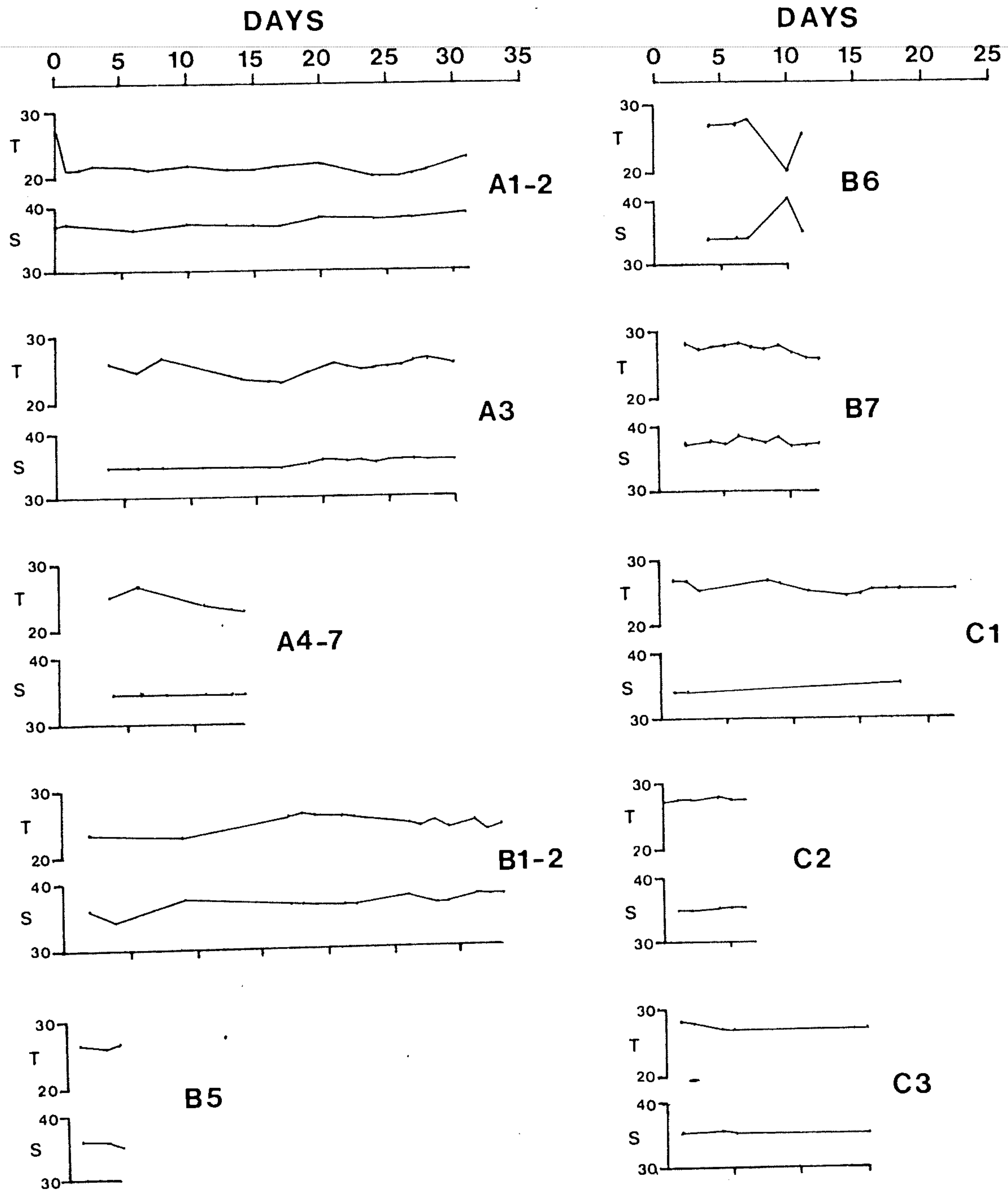

Figure 29. Temperature (T, °C) and salinity (S, ppt) conditions in aquarium tanks in which ovigerous females were held prior to egg hatching.

the field tended to be in a rather early stage of development, as can be seen from the number of days between capture and hatching in Table 14. Only one female was carrying eggs that where anywhere near full-term.

The stage of embryonic development was gauged roughly by estimating the fraction of egg volume occupied by the yolk. Initial yolk volumes greater than 95% were recorded in crabs A1-A3, indicating recent ovulation. At about two weeks the yolk volume had decreased to 80%, and by a little over three weeks less than 50% of the egg volume was occupied by yolk material. At that stage the embryo's eyes had become prominent, chromatophores were beginning to appear, and the heart was visibly beating. Yolk consumption rate increased with the size of the embryo; in crab A4 (whose eggs contained 75% yolk at capture), 20% of the yolk was still present at day 11, but by day 15 it was almost entirely consumed, and the larvae hatched.

Spanner crab eggs are ovoid in shape, and are stalked and attached to the female's pleopods rather like bunches of grapes. As embryonic development progesses, egg dimensions increase slightly from about 0.65 x 0.60 mm soon after ovulation to 0.80 x 0.76 immediately prior to hatching (Fig. 30).

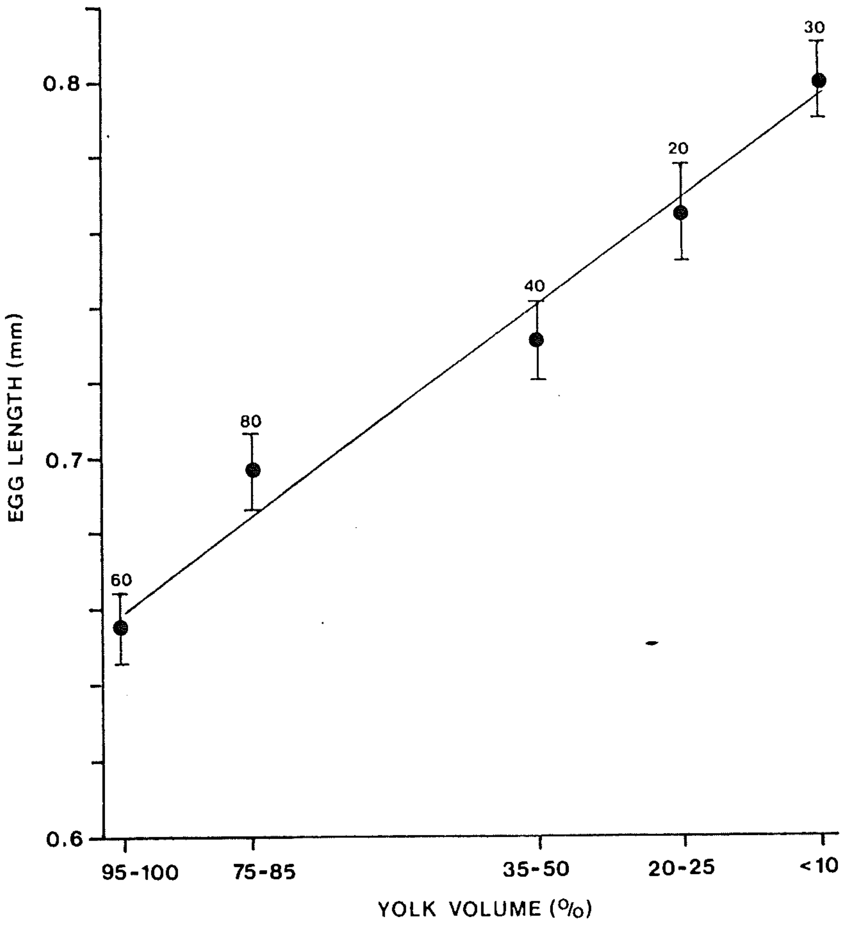

Figure 30. Relationship between egg dimension (long axis) and estimated percentage yolk volume.

3.10.3 **Larval morphometry**

Five zoeal stages were observed and documented during the larval culture experiments. Each stage, on average, lasted for about five to seven days. As might be expected, earlier moults were more highly synchronised than those later in the series (see Fig. 31). Measurements of the following morphological structures were made on zoeae from the C-Series experiments:

- CL (carapace length): anterior edge of eye to posterior carapace margin
- RL (rostrum length): rostral tip to anterior margin of eye
- DSL (dorsal spine length): dorsal spine tip to base (abdominal side)
- LSL (lateral spine length): lateral spine tip to base
- R-DSL (rostrum-dorsal spine length): rostral tip to dorsal spine tip

These measurements, presented in Table 15, appeared to be in close accordance with those of Sakai (1971), indicating that the larval stages of two widely separated spanner crab stocks are morphologically very similar.

Table 15. Spanner crab zoeal morphometrics: mean lengths (mm), standard deviations and ranges of five somatic dimensions (see text for explanation) during larval stages ZI - ZIV inclusive.

STAGE	SOURCE	STATISTIC	CL	RL	DSL	LSL	R-DSL
ZI	C1	mean	1.11	3.45	2.98	0.53	7.32
		s.d.	0.026	0.055	0.048	0.026	0.103
		range	1.08-1.13	3.35-3.50	2.90-3.05	0.50-0.55	7.2-7.5
	C2	mean	1.04	3.01	2.66	0.50	6.62
		s.d.	0.030	0.091	0.107	0.001	0.140
		range	1.00-1.08	2.90-3.20	2.50-2.80	0.48-0.50	6.5-6.8
	C3	mean	1.13	3.20	2.73	-	6.91
		s.d.	0.033	0.128	0.123	-	0.268
		range	1.10-1.18	3.00-3.40	2.60-2.95	-	6.7-7.3
ZII	C3	mean	1.42	4.60	3.76	-	9.49
		s.d.	0.069	0.135	0.117	-	0.250
		range	1.33-1.50	4.45-4.75	3.65-4.00	-	9.0-9.7
ZIII	C3	mean	1.77	6.41	5.23	-	13.26
		s.d.	0.058	0.374	0.362	-	0.546
		range	1.68-1.83	6.00-7.10	4.7-6.0	-	12.6-14.5
ZIV	C3	mean	2.36	8.76	6.94	0.38	18.14
		s.d.	0.166	0.270	0.230	0.040	0.477
		range	2.18-2.53	8.4-9.1	6.7-7.3	0.33-0.43	17.6-18.9

3.10.4 Larval development and mortality

The results of the main experimental rearing series are presented in Figures 31-33. These show temperature and salinity regimes, cumulative percentage larval mortality, initial sample size, and duration of each zoeal stage in days, for each particular trial or replicate.

The success of the experiments, as measured in terms of larval survival, varied considerably. One of the earliest trials (Fig. 31[i]) continued for about five weeks, and produced a small number of ZV larvae, while in others (e.g. Fig. 32 [i] and [ii]; Fig. 33 [v]), initial mortality rates were so high that no larvae survived the moult to ZII. In the majority of experiments, however, at least three of the zoeal series were observed.

Fluctuations in salinity and temperature as a result of aquarium system failure were probably responsible for high mortality in some of the trials but the pattern was not consistent. Temperatures were generally maintained between about 24° and 30°C, and rarely changed by more than three or four degrees in any one experiment. Even in trials where the temperature was essentially constant (e.g. Fig. 32 [iii], [vi] and [vii]), more than half the ZI larvae died within the first couple of days, and well before any had started to moult. In nearly all trials the 50% cumulative mortality point was reached before the first moult, and within the first five days. This occurred regardless of sample size or rearing tank volume.

Earlier moults were more highly synchronised than later moults, with the duration of ZI spanning a moderate range of four to seven days. Each of the first three stages lasted approximately five days, but the range increased as development progressed. As ZV larvae appeared in only one experiment, it is difficult to ascertain the duration of ZIV. In this instance the fourth moult (to ZV) was protracted, spanning a 13-day period from day 22 to day 35. The data in Figs 31-33 do not suggest a significant relationship between temperature and larval stage duration, at least over the range of temperatures recorded in these trials.

From ZII onward, the greatest mortality appeared to occur just before or after the moult, and after the periodic change of rearing tank water. Newly-hatched larvae are active swimmers, tending to aggregate near the water surface. However by ZIII they seemed less active, spending more and more time on or in close proximity to the bottom. This may well have resulted in detritus adhering to their appendages, and contributing to mortality by interfering with feeding and swimming mechanics, and perhaps by increasing the risk of bacterial infection. However it is unlikely that such a situation would arise in the animals' natural environment, since temperature profiles indicate that the surface layers of the water column are well mixed.

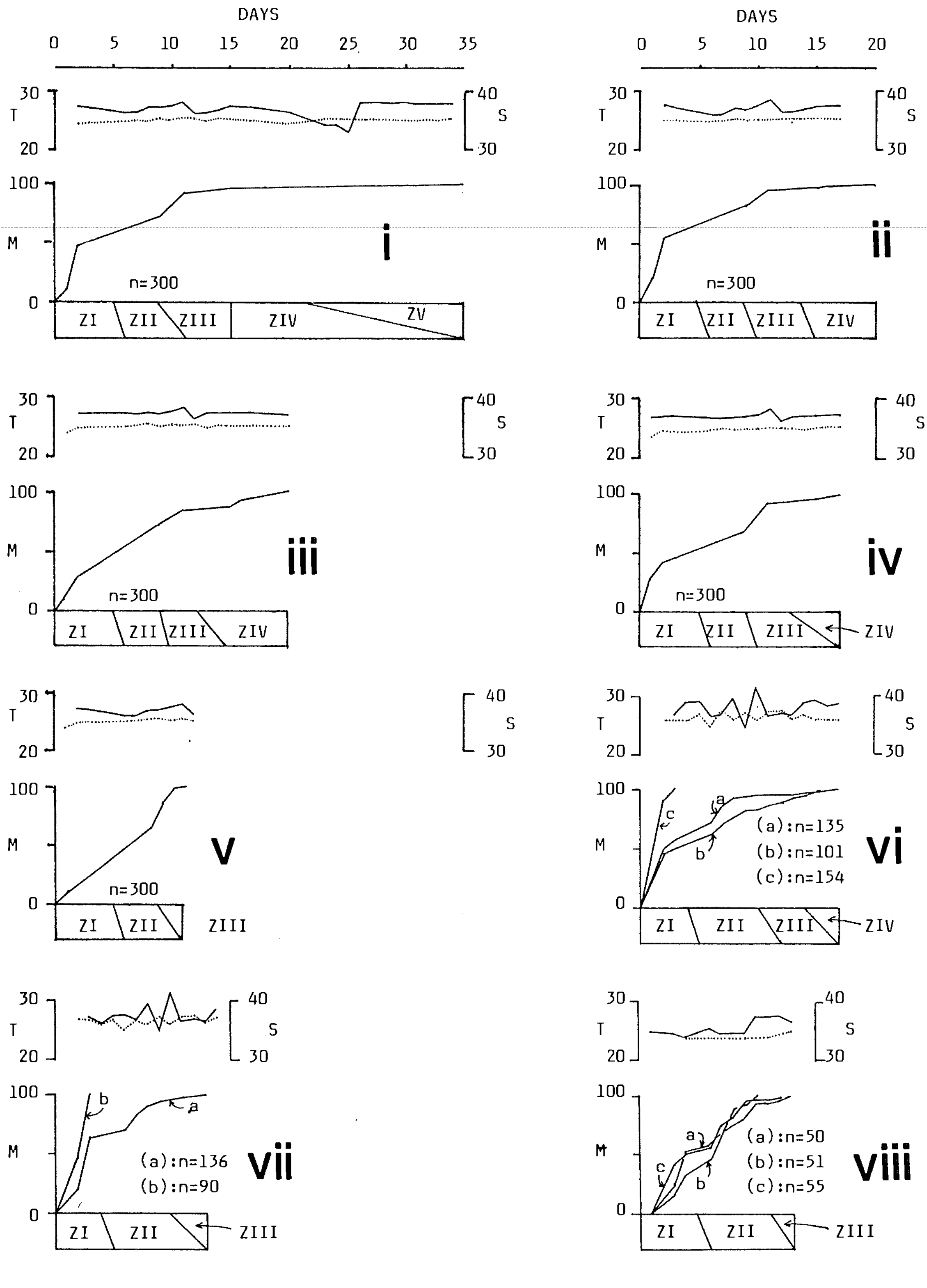

Figure 31. Percentage cumulative mortality in larval spanner crab rearing trials: A4/A5 in 40 l glass tanks (i)-(v); B2 in 3 l plastic bowl waterbath replicates (vi),(vii); B5 in plastic bowl replicates (viii). Temperature (T, °C) and salinity (S, ppt) regimes are shown above the mortality curves.

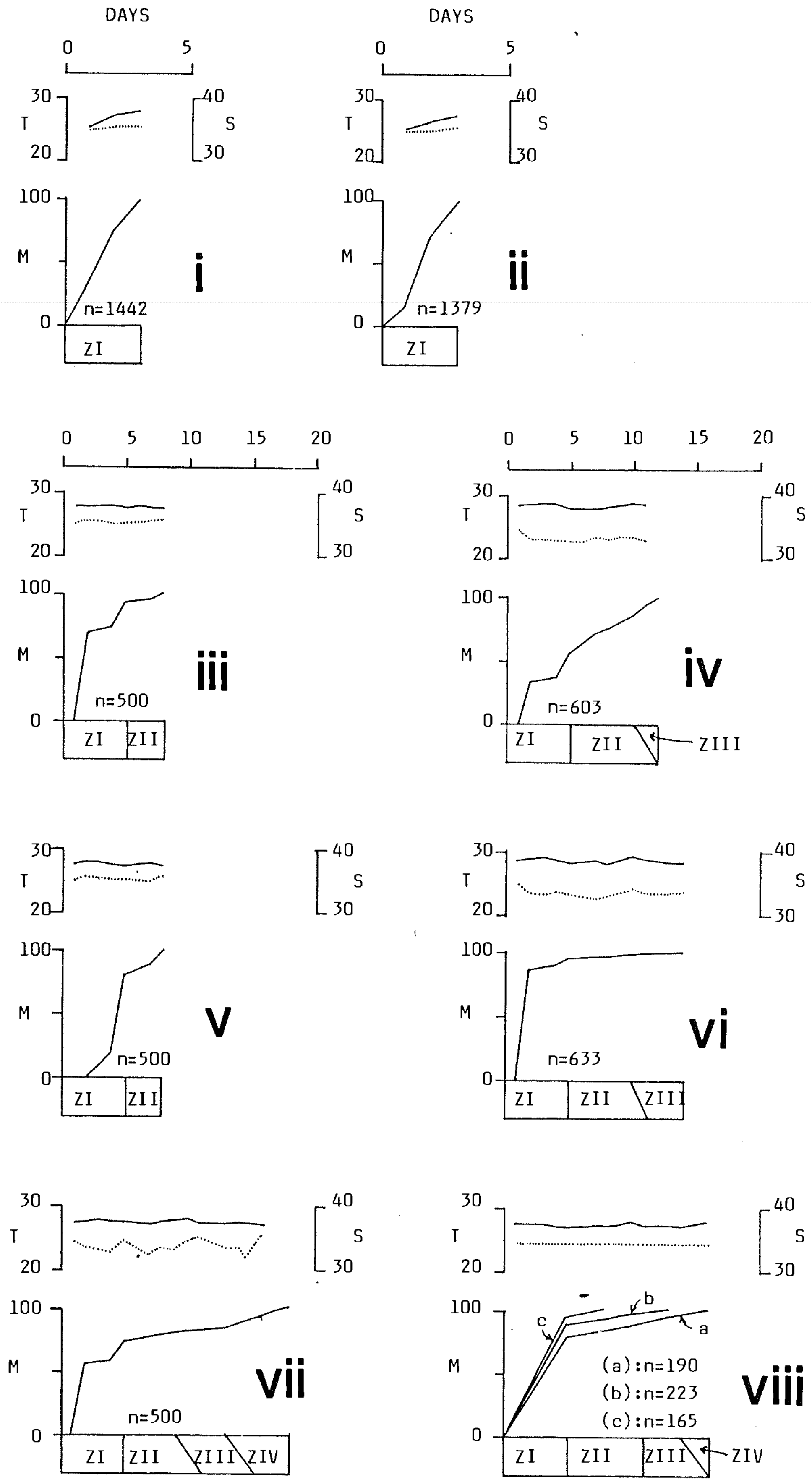

Figure 32. Percentage cumulative mortality in larval spanner crab rearing trials: C1 in 40 l glass tanks (i),(ii); C2 in 40 l glass tanks (iii)-(vii); C2 in 3 l plastic bowl replicates in water-bath (viii). Temperature (T, °C) and salinity (S, ppt) regimes are shown above the mortality curves.

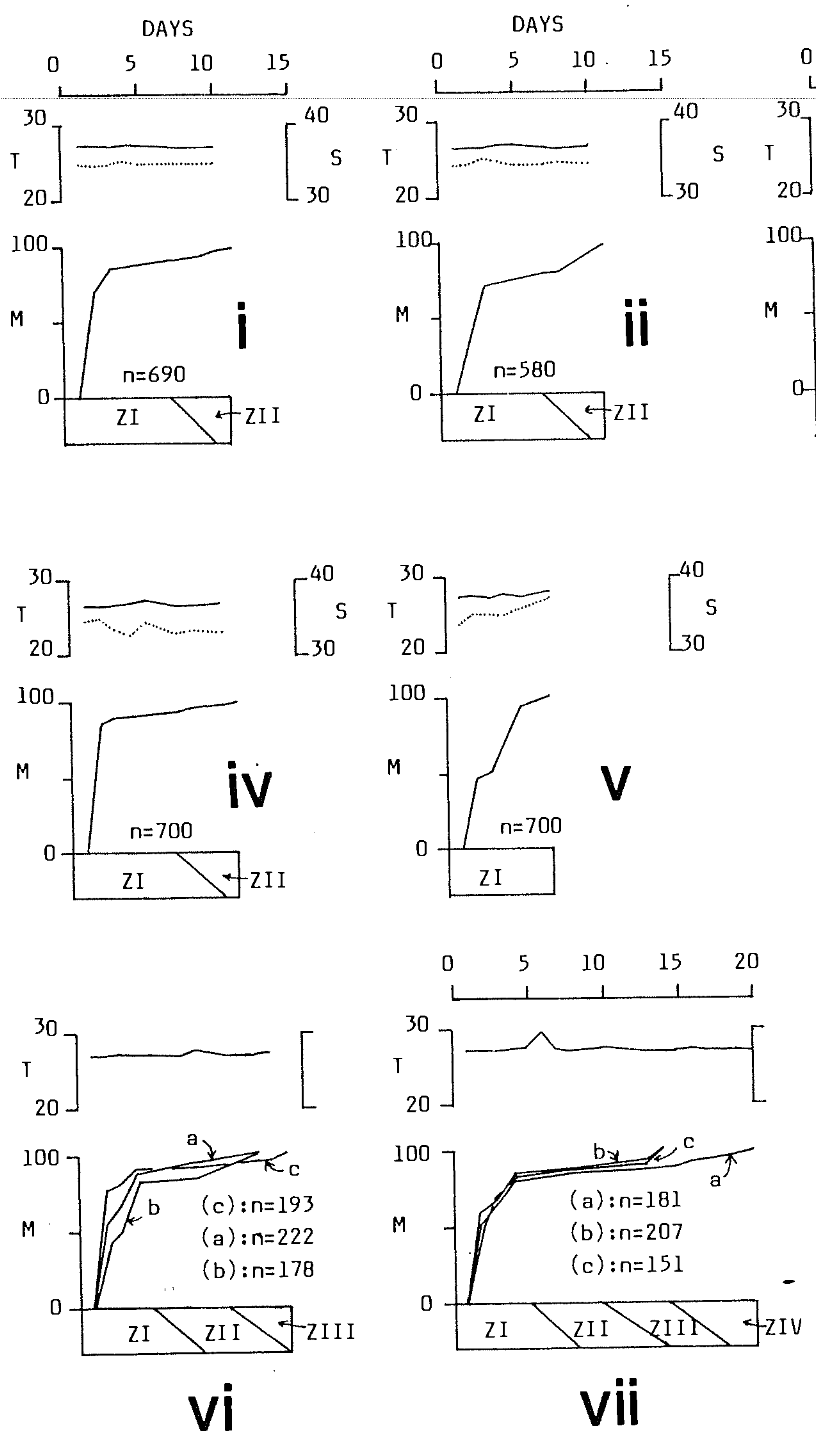

Figure 33. Percentage cumulative mortality in larval spanner crab rearing trials: C3 in 40 l glass tanks (i)-(v), and 3 l plastic bowl replicates in waterbath (vi),(vii). Temperature (T, °C) and salinity (S, ppt) regimes are shown above mortality curves.

3.11 Growth

Initial estimates of the growth parameters of male and female spanner crabs were obtained by analysis of monthly length-frequency data, using a slightly modified version of the computer program ELEFAN I of Pauly and David (1981).

Length-frequency tables were generated for each sex and month, using all of the carapace length data collected during the Project field operations. The paucity of data during some months required pooling over several years. Although carapace lengths were measured to the nearest millimetre, it was necessary to regroup the frequencies, in accordance with the strategy advised by David et al. (1984), such that the tabulated class interval sizes were 5 mm for males and 6 mm for females.

Examination of the individual monthly length-frequency tables revealed some multi-modality, but the peaks and troughs were not consistent, nor was there a distinct modal progression. Apparently differences in growth rate between individuals were, to a great extent, obscuring the expected modal separation, and output from ELEFAN I therefore needs to be interpreted with caution.

As coastal water temperatures in the study area range seasonally from about 19°C to 27 °C (unpublished CSIRO data) growth is unlikely to proceed at a uniform rate throughout the year. Moulting activity peaks (Section 3.1.3) suggested that the seasonally-oscillating von Bertalanffy growth model might be the most appropriate option.

The results produced by ELEFAN I are neither definitive nor strictly objective. They are the product of an iterative optimisation procedure, where the test for goodness of fit is the ratio of explained to available "sums of peaks" (ESP/ASP). The optimum set of parameter estimates for a particular run depend on a variety of factors including the parameter seed values, starting point sample number and mid-length, the number of parameters allowed to vary, the magnitude of the increments of variation, and whether or not the starting point is iterated. This means that the program must be run many times, using different seed values and increment sizes, to maximise the probability of locating the data set's true optimum growth parameters. Moreover some subjective assessment is required, as very high ratios of ESP:ASP can result from biologically impossible values of K and t_0.

Data sets for both males and females were subjected to a large number of trials using a wide variety of parameter seed values and starting points. The highest R values for female spanner crabs were associated with estimates of K ranging between 0.8 and 1.0, and L_∞ = 122 and 125 mm (Table 16). In each case the computed monthly length table indicated growth in the early part of the first year (January - May) to only 22 - 38 mm. According to the model, growth ceases during winter (June - August) but resumes again in September, with sizes typically increasing to 50 - 60 mm C.L. by the beginning of summer (December), and 85 mm by the beginning of the following non-growing (winter) season. These estimates suggest that females reach sexual maturity in their second year, and attain the minimum legal size around the start of their third year.

Table 16. Estimates of growth parameters in female spanner crabs using the seasonally-oscillating von Bertalanffy model in ELEFAN I. R = (ESP/ASP) x 1000.

K	L_∞	T_{max}	R
0.80	122.0	3.15	314.16
1.00	122.0	2.70	352.19
0.94	125.0	2.62	303.19

The "best" ESP/ASP ratios for male crabs occurred with K values between 0.9 and 1.1, and L_∞ ranging from 157 to 163 (Table 17). In all cases T_{max} was rather lower than expected (2.5 - 3.4), which suggests that although L_∞ is attained at approximately the same rate in males as in females, growth is more rapid in males because of their greater asymptotic length. In fact, with K = 1.1 and L_∞ = 158, the model predicts that males hatching in November/December would reach an average carapace length of 93 mm at the end of their first year, and legal size a couple of months later.

Table 17. Estimates of growth parameters in male spanner crabs using the seasonally-oscillating von Bertalanffy model.

K	L_∞	T_{max}	R
0.90	157.0	3.4	245.41
0.90	162.0	2.7	294.84
0.95	163.0	2.5	251.00
1.10	158.0	2.5	273.18

The parameter etimates for both male and female spanner crabs are considered somewhat suspect for two reasons. First, the model accounts for a relatively low proportion of the available sum of peaks (at most 35% in females and 29% in males). Second, the estimate of T_{max} is suspiciously low, especially for male crabs. In other words, the model appears not to fit either of the available data sets very well. This is not to suggest that the model is necessarily inappropriate or lacking in power; a more likely explanation is that the data do not provide the necessary degree of resolution.

It became apparent during the course of the Project that the commercial gear rarely captured spanner crabs smaller than about 60 mm C.L. This was initially believed to be due to mesh selectivity, but the fact that small calappid crabs (<30 mm C.W.) were captured at certain shallow-water sites suggests that mesh selection may not be the entire answer, and that other factors such as behavioural and/or dietary differences between juvenile and adult crabs may also be implicated. Whatever the reason for the paucity of small spanner crabs in the catch, it was clear that a different fishing technique would be required if the sub-adult sector of the stock was to be sampled effectively.

Initial trials with a small benthic dredge failed to capture any spanner crabs, although a variety of other benthic invertebrates and bottom-dwelling fish species was taken. Subsequent operations with a scaled-down trawl net in shallow water near Cape Moreton and Mooloolaba met with a little more success, producing small catches of crabs ranging in size from 32 to 63 mm C.L. Unfortunately it was not possible to establish a regular sampling schedule with this gear because of vessel availability and other project commitments.

The restricted size distribution of these trawl-caught female crabs indicated that they all probably belonged to the same year-class, and, assuming a November spawning, would not have been much more than three months old at capture. Their carapace lengths ranged from 33 to 54 mm, which is considerably greater than that predicted by the growth model on the basis of data for all size-classes. The data for trawl-caught males are also inconsistent with predicted length values, particularly with regard to the chronology of settlement and early growth.

Two other independent observations- one relating to the result of juvenile moulting activity and the other to the collection of two exceptionally small crabs - do little to clarify this confusing situation. In response to reports of small spanner crabs appearing on some of the beaches at the northern end of Fraser Island, Project staff visited the area in mid-December 1982. With the aid of a 4-wheel drive vehicle the beach was searched westwards from Sandy Cape to Rooney's Pt, then south as far as Wurtumba Creek, and 31 juvenile spanner crabs (16 males and 15 females) were collected. Some of the crabs were exposed, walking on the moist sand, and others were either partly or completely buried in the intertidal zone of the beach. The latter were detected from the presence of a mound or a circular cake of wet sand above the animal. While the females included a broader size range than did the males (Fig. 34 a and b), the modal carapace lengths (around 48 mm) were very similar.

The only data available on spanner crab reproduction in the Fraser Island - Hervey Bay area were obtained in 1981-2 during the course of a FIRTA-funded exploratory project aimed at identifying offshore crab resources in south-east Queensland waters (Jones and Brown 1983), when three ovigerous crabs were captured north-west of Rooney's Pt between 10 and 24 November 1982. Even assuming that these females were carrying late-term embryos on the point of hatching, it is unlikely that the progeny could have grown to 48 mm by December 12, given the known duration of their planktonic larval phase. There are two possible explanations of this paradox:

1. The "post-larval" (supposed megalopa) phase is greatly attenuated and initial growth rate quite slow, which would mean that the juvenile crabs collected from the beach were in fact slightly more than 1 year old.

2. The peak spawning period in northern Hervey Bay occurs significantly earlier than November; early growth is rapid, and the juveniles were of the order of 1 - 2 months old.

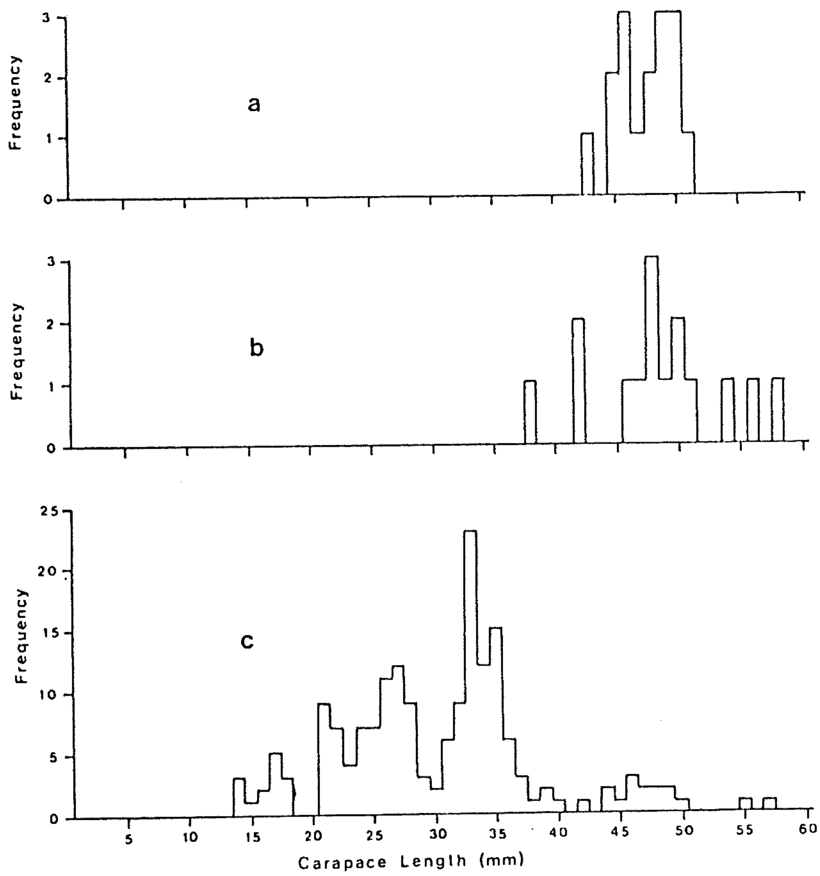

Figure 34. Length-frequency distributions of live male (a) and female (b) spanner crabs, and moult carapaces (c), collected from northern Fraser Is beaches on 12 - 13 December 1982.

The lack of any information (published or otherwise) about the nature, duration, or even the existence of a megalopa stage makes any objective consideration of the above alternatives rather difficult, and there is some evidence (albeit very limited and circumstantial) to support both. The rapid growth hypothesis is supported by the quite fortuitous discovery of numerous juvenile moult shells (carapaces) on the northern Fraser Island beaches at the same time as the live crabs were being collected. Nearly 180 intact carapaces, measuring between 14 and 57 mm, were collected from the tide-line. Findings of large numbers of juvenile spanner crab moult shells have not been reported elsewhere, and this represents the first substantiated evidence of the possible location of a larval settlement area. It is unlikely that the shells could have been more than a few weeks old, because of their frailty and the fact that many still retained their natural pigmentation. If this conclusion is valid, the carapaces must all have derived from animals belonging to the same year-class, and it suggests that there may be a nursery area in close proximity to the northern end of Fraser Island. Comparison of the frequency distribution of the moult carapace lengths (Fig. 34 c) with that of the live juveniles (Fig. 34 a and b) reveals a substantial overlap, further indicating that the live crabs could well represent the same statistical population as that which produced the exuviae somewhat earlier. In other words, if it is accepted that juveniles which hatched during the latter part of 1982 could attain a carapace length of 15 mm by, say, the middle of November, then the evidence presented above must lead to the conclusion that spanner crabs are capable of growing to half their minimum legal size in a matter of 2 - 3 months.

The alternative hypothesis (of slow initial growth) is supported by another unexpected observation - the discovery of two very small but reasonably intact spanner crabs in the stomach of a bar-tailed flathead (**Platycephalus indicus**). The fish had been captured by the DPI research trawler "Bar-ea-Mul" in the vicinity of Bribie Island on 10 April 1985. Both spanner crabs measured 11 mm C.L., the smallest seen by any of the Project team. If these individuals are assumed to be representative of the population, there would appear to be very little growth during the animal's first year of life. It is possible that, if the megalopa stage extends until the end of summer, growth during much of the remainder of the year could feasibly be depressed by the effect on metabolic processes of reduced water temperatures. Rising temperatures during late spring (towards the end of the year) might then trigger a burst of moulting activity such as possibly resulted in the exuviae found on Fraser Island.

The available data are insufficient to provide a reliable account of the pattern of growth in this species. More information is needed on the early stages, and particularly the megalopa, which will require the development of specialised sampling equipment. However localities where such work could be carried out with some chance of success have been identified.

3.12 **Recruitment and mortality**

First-order estimates of the recruitment pattern and instantaneous rate of total mortality (Z) for male spanner crabs were derived using the program ELEFAN II of Pauly, David and Ingles. This routine requires input of growth parameters (in this case as estimated by ELEFAN I), as well as the original length-frequency data set. A catch curve is generated, which allows an estimate of Z from the slope of the descending limb (e.g. Ricker 1975). A visual assessment of the curve is first required so that only age-groups that are considered to be fully recruited are included in the computation.

If independent estimates of natural mortality (M) are unavailable, ELEFAN II will provide an approximation from an empirical relationship involving L_∞, K and mean environmental temperature (Pauly 1980). Since Z = F + M, fishing mortality (F) can then be calculated by subtraction, and exploitation rate (E) determined as the ratio of F on M. Finally, a graphical representation of percentage recruitment by month is generated to show the number of recruitment peaks per year and, if t_0 is known, the absolute seasonal recruitment pattern .

Figure 35 shows the catch curve for male spanner crabs using growth parameter estimates of L_∞ = 157 and K = 0.9 from Table 17. On the assumption that crabs older than about 1.4 yr are fully recruited to the fishery, total mortality (Z) was estimated at 3.98.

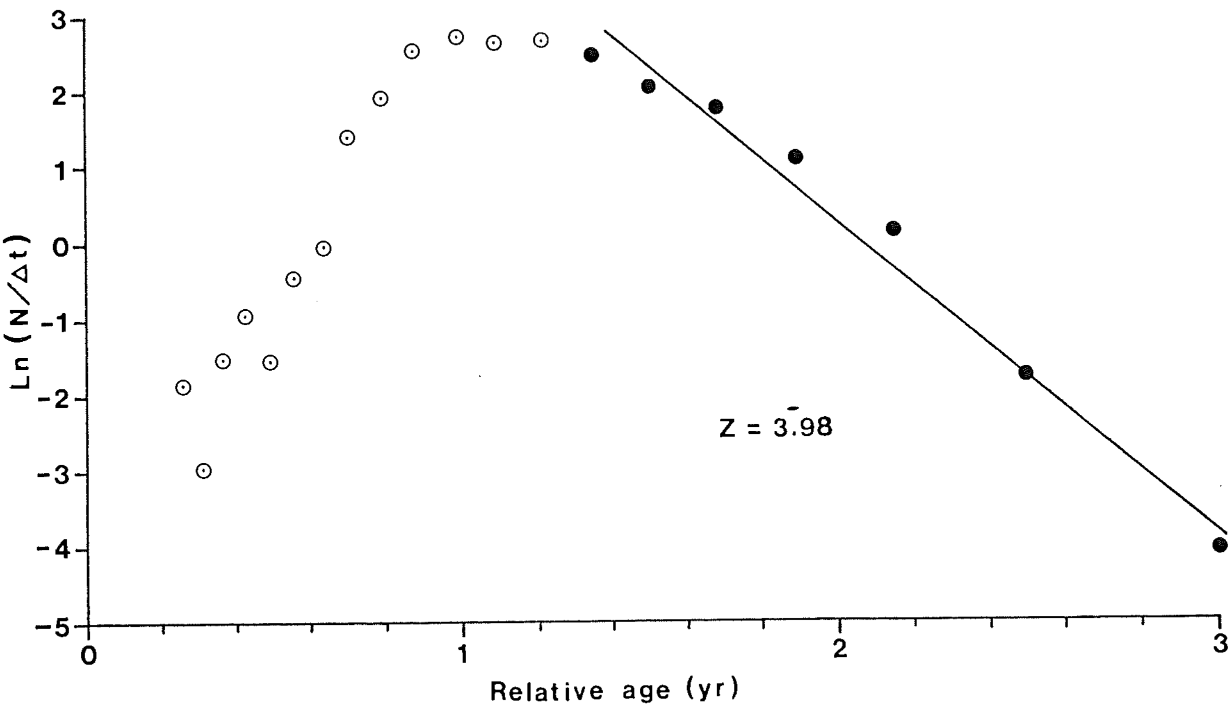

Figure 35. Catch-curve for male spanner crabs (L_∞ = 157, K = 0.9) showing estimate of total mortality from fully recruited age-groups.

The statistical significance of the slope estimate (used to derive Z) was very high ($R^2 = 0.97$ with 5 d.f.; $p<<0.01$), but this is more a reflection of how well the catch curve data points fitted the regression model than an indication of the estimate's accuracy, which itself is a function of the reliability of the original growth parameter estimates. Given Z = 3.98, M was estimated to be 1.82 and (by subtraction) F = 2.16, producing an exploitation rate E = 0.54. These figures should be regarded with extreme caution, since they assume not only accurate initial estimates of L_∞ and K, but also that Pauly's (1980) algorithm, which was based on data for teleost fish, applies equally to crustacean species. The latter has by no means been adequately demonstrated.

The typical annual recruitment pattern for male spanner crabs is shown in Fig. 36, on the basis that t_0 approximates zero. The figure's unimodality is indicative of a single major recruitment each year, between August and November, and supports the independent observation (from gonosomatic index analyses) of a single discrete spawning season.

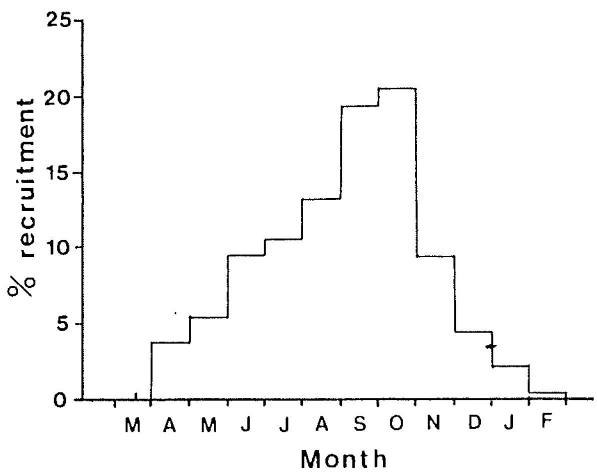

Figure 36. Seasonal recruitment pattern for male spanner crabs in the south-east Queensland fishery.

3.13 The commercial fishery

3.13.1 Availability of statistics

As there is no general state-wide system in Queensland for collecting and compiling fisheries statistics from the catching sector, descriptive assessments of the status of most fisheries can be made only by piecing together incomplete information from diverse sources. The Queensland Fish Management Authority's data-base is theoretically capable of providing details of the numbers of fishermen engaged in the various types of fishing activities, but unfortunately no distinction is made between sand, spanner, or mud-crabbing operations. The Queensland Fish Board (QFB), a major purchaser and wholesaler of seafood, maintains a computer record of the quantity and price of individual species or groups of species purchased by its regional depots. However neither the origin of the landings, the level of fishing effort, nor the quantity of product marketed outside its own system can be assessed from this source.

The absence of such important data required the introduction of a voluntary logbook programme which was field-tested in the latter half of 1982, and ran until December 1984.

3.13.2 The spanner crab fishing fleet

When fishermen were initially contacted about participating in the logbook programme, they were also asked to provide some details of their vessels and gear. The responses showed that the "typical" spanner crab boat was a fibreglass mono-hull runabout approx. 6 m in length, and powered by a single outboard motor between 60 and 150 hp. Details of the size ranges, engine types and horsepower ratings are set out in Table 18.

Table 18. Characteristics of a sample of vessels involved in the south-Queensland spanner crab fishery.

Size range	No.	Hull type		Construction			Power unit*				Total horsepower			
(metres)		Mono	Multi	GRP	Alloy	Steel	O	OO	IO	I	50-99	100-149	150-199	>200
4.0 - 5.9	11	7	4	9	2	-	6	5	-	-	5	4	2	-
6.0 - 7.9	5	4	1	5	-	-	3	-	2	-	-	3	1	1
8.0 - 9.9	3	2	1	1	1	1	-	1	-	2	-	1	-	2
> 10.0	2	2	-	2	-	-	-	-	-	2	-	-	-	2

* O: single outboard
OO: twin outboards
IO: inboard-outboard (stern drive)
I: inboard

The ease with which small boats can enter the fishery means that the fleet comprises a high proportion of transient operators. Structural modification to the vessel is not required, the gear is inexpensive and easily fabricated, and even the pot-hauler (while desirable) is by no means essential. Most vessels working in the Moreton Bay sand crab fishery are capable of switching to spanner crabbing at short notice, and in fact many do when sand crab abundance declines seasonally. The number of fishermen involved in spanner crabbing is thus extremely difficult to estimate with any accuracy. In 1982 the then Queensland Fisheries Service undertook a survey of applicants for commercial fishing licences to gain some idea of State-wide fishing operation patterns during the previous year. Of the 146 fishermen claiming to have worked spanner crabs in 1981, five ranked this fishery (in terms of personal importance) as top priority, 27 indicated priority 2, 36 indicated priority 3, and the remainder (78) gave it a priority rating between 4 and 8. Estimates provided by QFB regional depot staff suggest that there are probably around 10 full-time spanner crabbers and 40 - 50 part-timers operating in the Mooloolaba/Moreton region at the present time.

The adaptability of the fleet is apparent from Figure 37, which shows seasonal variation in the mean number of days per fisherman (averaged over 1983 and 1984) spent fishing for spanner crabs and other species. These data were derived from logbook returns which requested, inter alia, information on fishing, lay-day and maintenance activities. during the first six months of the year logbook programme participants spent an average of 5 days/month working spanner crabs, and about 10 days/month in alternate fishing activities such as sand crabbing, beach seining and reef handlining. Between July and August, and to a lesser extent during the remainder of the year, a considerably greater effort was directed towards spanner crabs at the expense of other fisheries.

The effect of weather on offshore small-boat fishing activities can be seen in Fig. 37 (c), which shows the mean number of potential fishing-days each month lost because of adverse conditions. The least down-time occurred in summer and winter (4 - 8 days/month), while during late autumn and spring (particularly November) conditions were apparently less favourable, with between 12 and 17 unworkable days per month.

3.13.3 **Trip characteristics**

Because of constraints imposed by the weather as well as the size, capacity and range of the vessels, spanner crab fishing is done almost exclusively on a day-trip basis. According to the logbook data, fishermen typically leave port in the early morning and return mid-afternoon with an average trip duration of 7.6 hr. The catch is cooked on-shore, sorted into size categories where appropriate, and taken to market either the same afternoon or early the following day.

3.13.4 **Gear characteristics**

While fishermen have their individual preferences with regard to minor details of size, shape, and type of webbing used, the commercial tangle-nets are identical in basic structure to those used during the Project (see section 2.2). Square or rectangular frames are preferred by some because of ease of construction and/or stowage, but the surface area of net is normally between 0.5 and 1 m^2. The trot-line system, with several nets attached to the one buoy-line, is commonly used, although some fishermen favour the flexibility of having only one or two nets on each line. Weights are rarely (if ever) used by the commercial operators, because currents are generally rather weak in the areas where most of the fishing activity is concentrated.

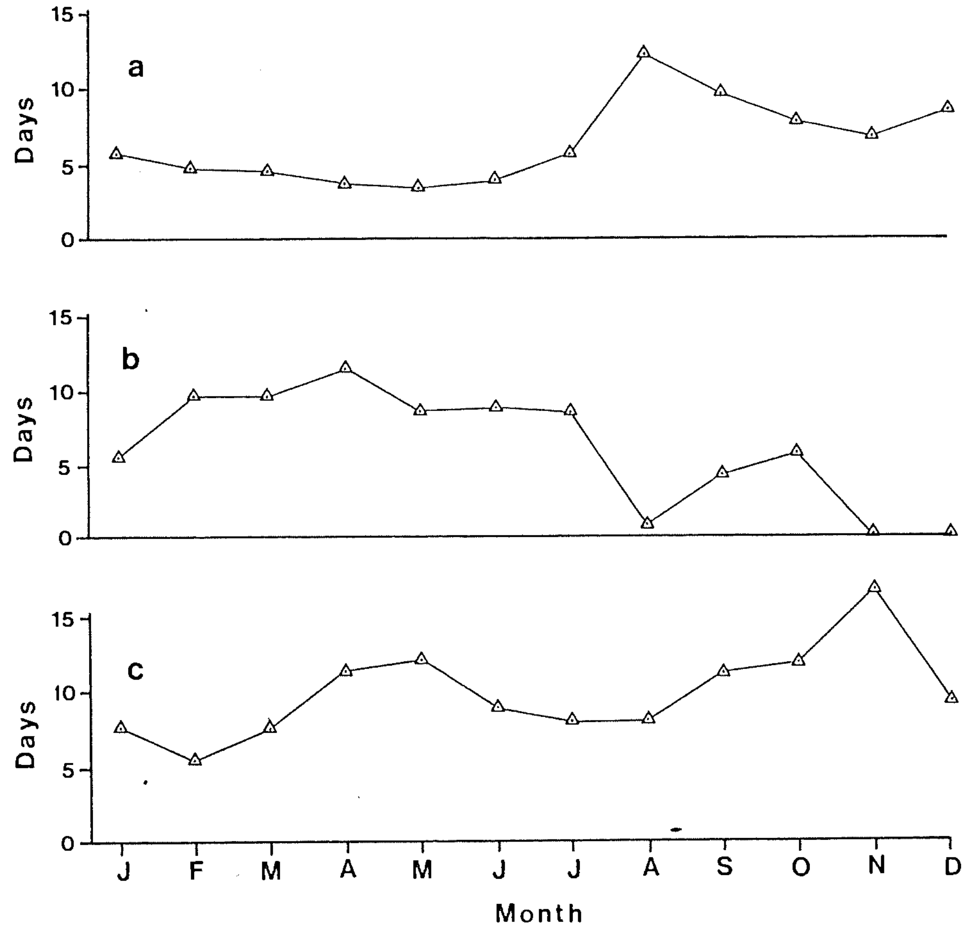

Figure 37. Average number of days per month on which logbook contributors fished for spanner crabs (a), other species (b), and were unable to work because of inclement weather (c).

3.13.5 **Marketing**

During 1983-4 participants in the logbook programme indicated that slightly more than half their total catch was marketed through the Fish Board, and the remainder was divided approximately equally between fishermen's cooperative organisations (primarily at Mooloolaba and Sandgate) and "other buyers" which include commercial processors and seafood dealers (Table 19). A slightly higher proportion of the catch was directed to "other buyers" in 1984 than during the previous year. This seems to have been at the expense of cooperatives, as the QFB-directed fraction remained much the same.

It is difficult to know whether this situation is typical of the entire fishery, since the reticence of some fishermen towards involvement in the logbook programme may well have been related to their less orthodox marketing arrangements. Some crabbers, for example, periodically freight their catch directly interstate, and others are known to have investigated alternative markets overseas. On balance, it seems likely that the 59% indicated in Table 19 might be an overestimate of the proportion of the actual total catch sold through the QFB network.

Table 19. Percentage distribution of annual spanner crab catch amongst markets (data from logbook programme participants).

MARKET/OUTLET	1983	1984	TOTAL
Queensland Fish Board	57.7	59.9	58.9
Fishermens Cooperatives	24.5	19.2	21.5
Other buyers (e.g. processors)	12.6	19.4	16.4
Not specified	5.2	1.5	3.2

Of the spanner crab catch handled by QFB by far the bulk is landed and sold at the Mooloolaba and Scarborough depots (Fig. 38). Minor landings at other depots (Tin Can Bay, Wynnum, Southport) probably include crabs caught incidentally by prawners, who are beginning to realise the economic benefit of marketing certain components of their by-catch. The post 1981-82 decline in the proportion of catch sold at Scarborough may not entirely reflect the proportion actually landed at that port, since an increasing number of fishermen opt to have their catch road-freighted to QFB's main Brisbane market (at Colmslie) for auction, rather than sell it locally at a set price.

Fig. 38 also shows that the quantity of product handled by the Board increased from around 100 000 pieces in 1980-81 to over 200 000 in 1982-83, but has declined somewhat in subsequent years. The initial increase probably reflects a general rise in effort during the developmental phase of the fishery, and is thus indicative of the trend in total annual catch during that period. However there is some evidence that more recent entrants into the fishery may be utilising alternative marketing outlets

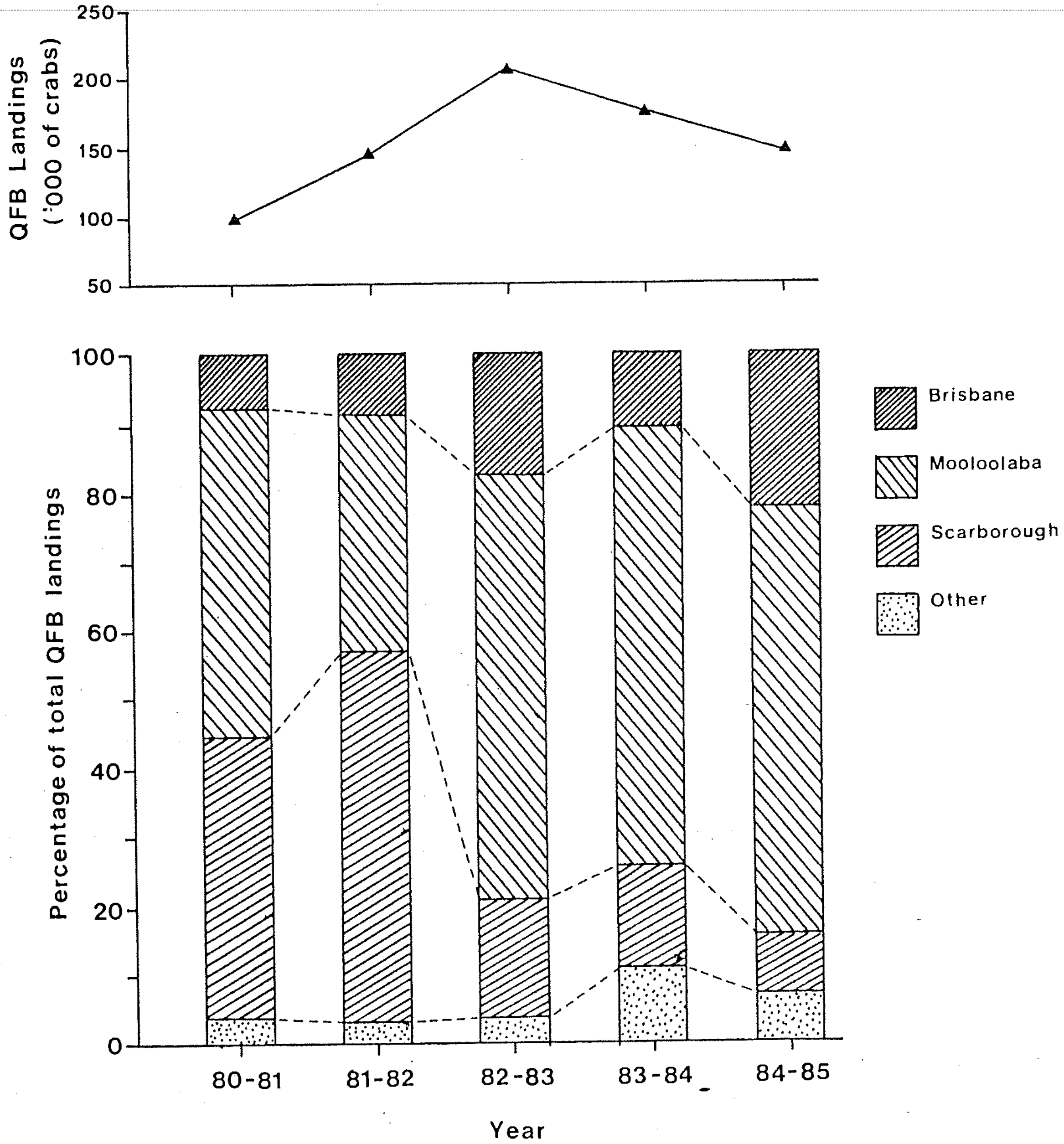

Figure 38. Total sales of spanner crabs at all Queensland Fish Board depots by year (a), and the the proportion attributable to each of the major depots (b).

(i.e. outside the QFB system), so the decline in QFB "landings" since 1982-83 should not be interpreted as being representative of trends in the total south-Queensland commercial catch.

The pricing structure for spanner crabs was determine from analysis of data kindly provided by the QFB management. Crabs are frequently graded prior to sale, and it would be expected that the different size-grades would command different prices. The Board's quarterly and annual summaries make no distinction between grades, so the more detailed "accounting period" (approx. monthly) summaries of landings by depot during 1984-85 were examined. Table 20 presents the total landings and value of each grade, and shows that the price to the fisherman averaged \$1.37 per body for large, \$0.83 for medium, and \$0.51 for small crabs. The overall (weighted) mean price was \$1.05 per body.

These values were converted to prices per unit weight on the assumption that all marketed crabs were above the minimum legal size. The total expected length range (100 - 145 mm) was subdivided equally into three intervals, and the expected weight corresponding to the midpoint of each interval was calculated with reference to weight/length regression parameters for males (see section 3.4). The numerical landings figures were then converted to weights, and the mean values per kg calculated accordingly (Table 20).

Table 20. Wholesale market prices for graded spanner crabs sold at QFB Scarborough, Brisbane and Mooloolaba depots during 1984-85.

STATISTIC	GRADE			TOTAL or MEAN
	LARGE	MEDIUM	SMALL	
Number of bodies	39020	24488	12637	76145
Total value ($)	53353	20367	6423	80143
Mean value ($/body)	1.37	0.83	0.51	1.05
Est. length range (mm)	130-145	115-129	100-114	—
Mean weight/body (g)	895	616	404	—
Total weight (kg)	34923	15085	5105	55113
Mean value ($/kg)	1.53	1.35	1.26	1.45

The market price for spanner crabs is known to fluctuate considerably. To test whether classic supply-demand effects were responsible for the observed variation, the relationships between total quantity and corresponding price of crabs marketed at the Board's Scarborough and Colmslie depots for each accounting period during 1982-83 were examined. Neither coefficient of correlation (r= 0.04 and 0.43 respectively, each with 11 d.f.) was statistically significant at the 95% confidence level. This indicates that the price of spanner crabs is not appreciably affected by the quantities currently being marketed.

A similar analysis, however, between spanner crab price and the quantity of sand crabs marketed (over the same period) resulted in a highly significant inverse correlation (r= -0.56 with 22 d.f.; p<0.01). The data are presented as a scatter-graph in Fig. 39, which clearly demonstrates the adverse effect which increasingly large sand crab landings have on the price of spanner crabs.

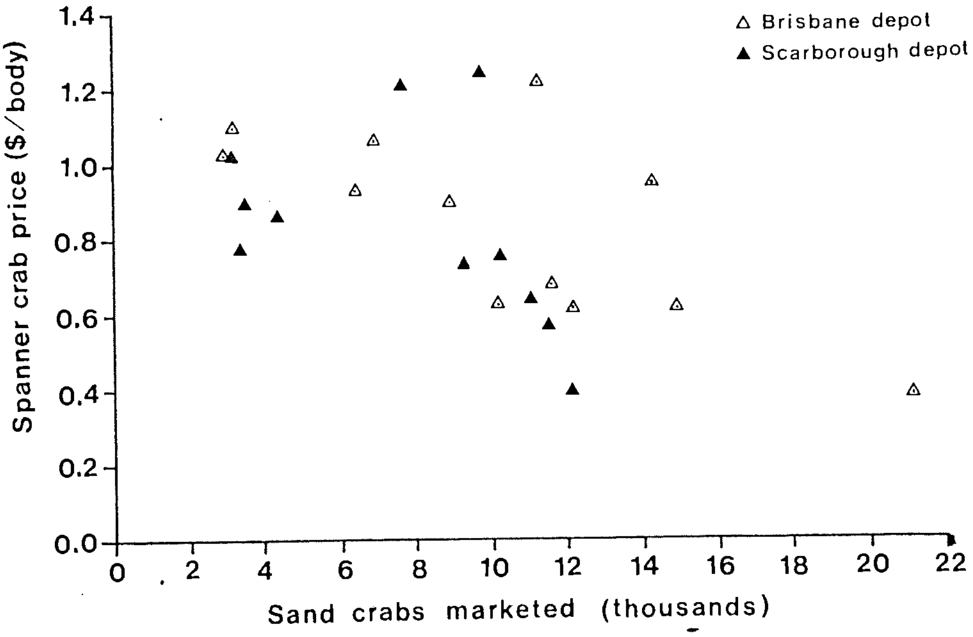

Figure 39. Relationship between sand crab landings and spanner crab market price at two QFB depots during 1982-83.

3.13.6 **Distribution of fishing effort, catch and CPUE**

Logbook programme participants were provided with a reference chart with a 10′ x 10′ grid (block area approx. 309 km^2), covering the expected maximum operational range of spanner crab fishermen based at Mooloolaba and around Moreton Bay. The trade-off between information content and format simplicity meant that fishermen were unable to partition their daily catch and effort statistics between blocks, even though provision was made on the log sheets for recording up to three block numbers per day (see Appendix 1). The logbook analysis computer program was therefore designed to allocate catch and effort equally amongst blocks in situations when more than one block was fished on a particular day. Errors resulting from this simplifying assumption are, however, probably of only limited significance.

Figure 40 shows the geographical distribution of nearly 72 000 net-drops during the currency of the programme, and includes data collected from one fishermen during the trial period in the latter half of 1982. It is immediately clear that a large proportion (30%) of the total effort was expended in Block 1302 offshore from Mooloolaba, and nearly two-thirds between the latitudes of Mooloolaba and Cape Moreton. Very little fishing activity took place in depths greater than about 80 metres.

The number of keepers (legal-sized crabs) in the day′s catch could be determined with reasonable accuracy, either directly or by estimation from the number of baskets of crabs cooked at the end of the day. Estimates of the number of discards (sub-legals) are less reliable, as the fishermen could not be expected to maintain a direct tally of these. One technique employed was to determine the ratio of discards to keepers from several drops throughout the day, then multiply the number of keepers by this fraction. In some cases the final figure was probably little more than an educated guess, but analysis of trends in the non-marketable component indicates a surprising degree of uniformity in the estimates provided by different fishermen. Notwithstanding the method′s imprecision, the numbers of keepers and discards were summed and plotted by grid block (Fig. 41) to show the approximate geographical distribution of total catch.

Of somewhat greater potential interest to the commercial operator is the way in which the catch rate of only marketable crabs is distributed. Figure 42 shows that the CPUE for keepers varied considerably between localities, from 0.8 crabs/drop in Block 0902 to 7.0 in Block 1603. The weighted mean over all blocks amounted to 4.3 crabs/drop. Lower than average catch rates were recorded from the deepest areas fished (Blocks 1304, 1404, and 1504), and, judging from the limited amount of effort applied, the results were evidently enough to discourage much further activity in those areas.

Monthly mean catch rates throughout the logbook period were also quite variable (Fig. 43, solid line). While the overall estimated mean number of crabs (of all sizes) per net was 7.4, individual monthly averages ranged from 3.5 in February 1983 to 13.4 in November the same year. Figure 43 suggests a strong seasonal cycle in total catch rate, with peaks during spring (August-December) and troughs from late summer (January/February) through autumn to early winter (June/July).

Partitioning the total catch rate between keepers and discards (Fig. 43, dashed and dotted lines respectively), reveals that most of the seasonal variation can be attributed to small crabs. Monthly mean CPUEs for large crabs varied from 2.7 to 7.5 (mean = 4.3), but there was little conformity to a recognisable seasonal pattern. On the other hand, monthly catch rates for discards showed a marked seasonal trend and a much wider range of variation (0.7 - 7.8; mean = 3.1).

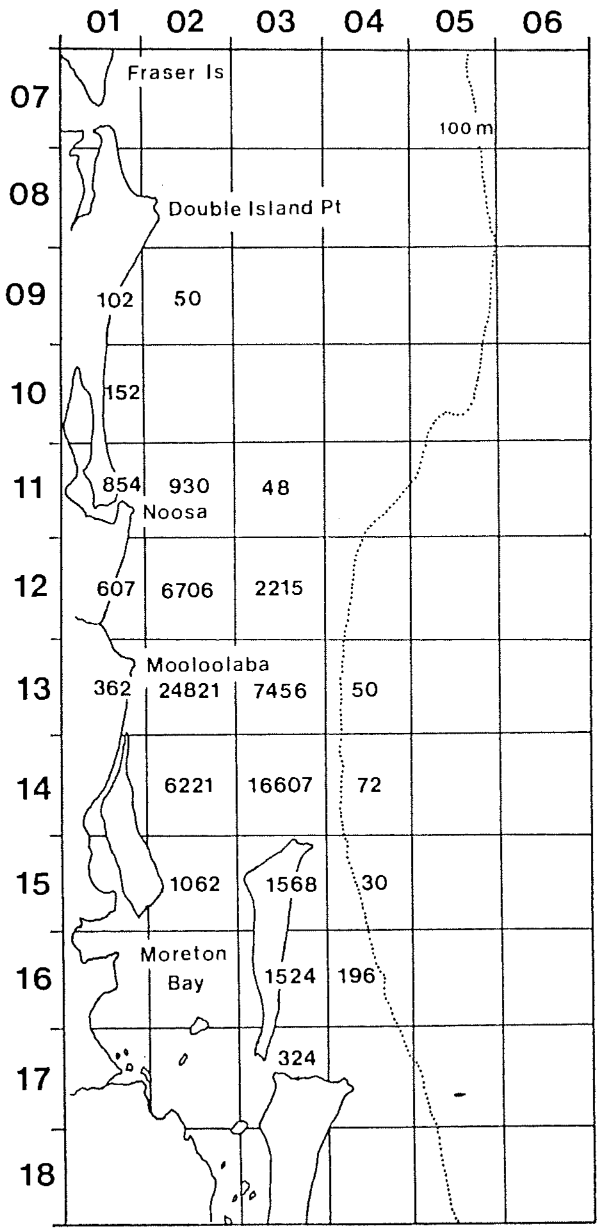

Figure 40. Geographic distribution of total fishing effort (net drops) during the logbook programme period from June 1982 to December 1984. Block numbers comprise 2 row digits followed by 2 column digits.

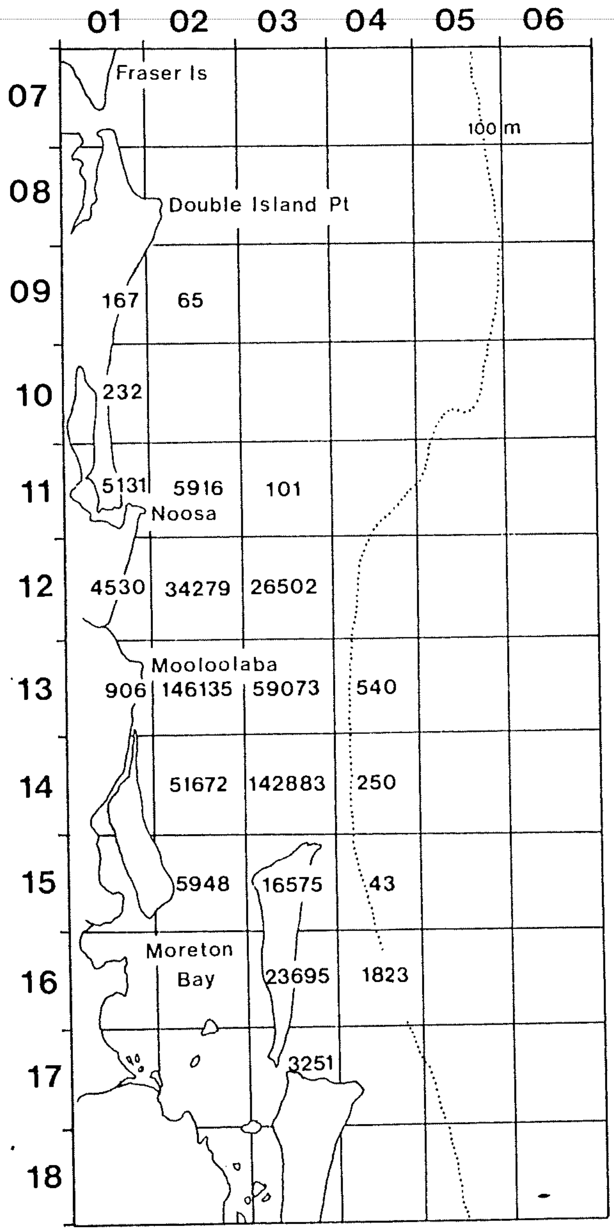

Figure 41. Geographic distribution of total catch (including discards) during the period June 1982 to December 1984.

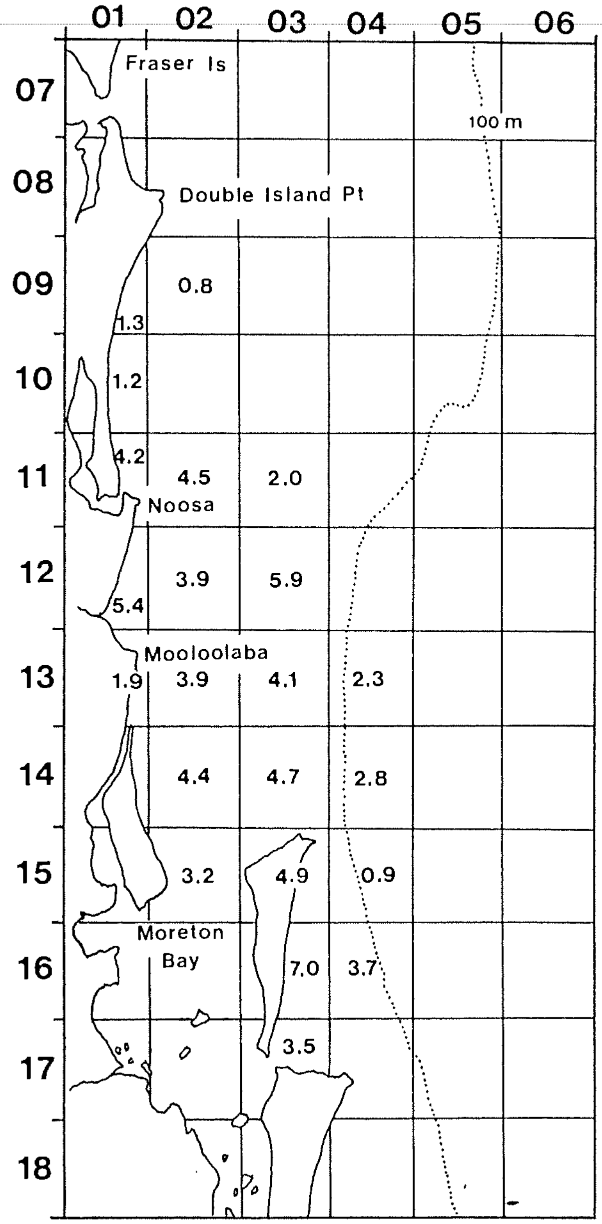

Figure 42. Geographic distribution of the catch rate (crabs/drop) of marketable crabs during the period June 1982 to December 1984.

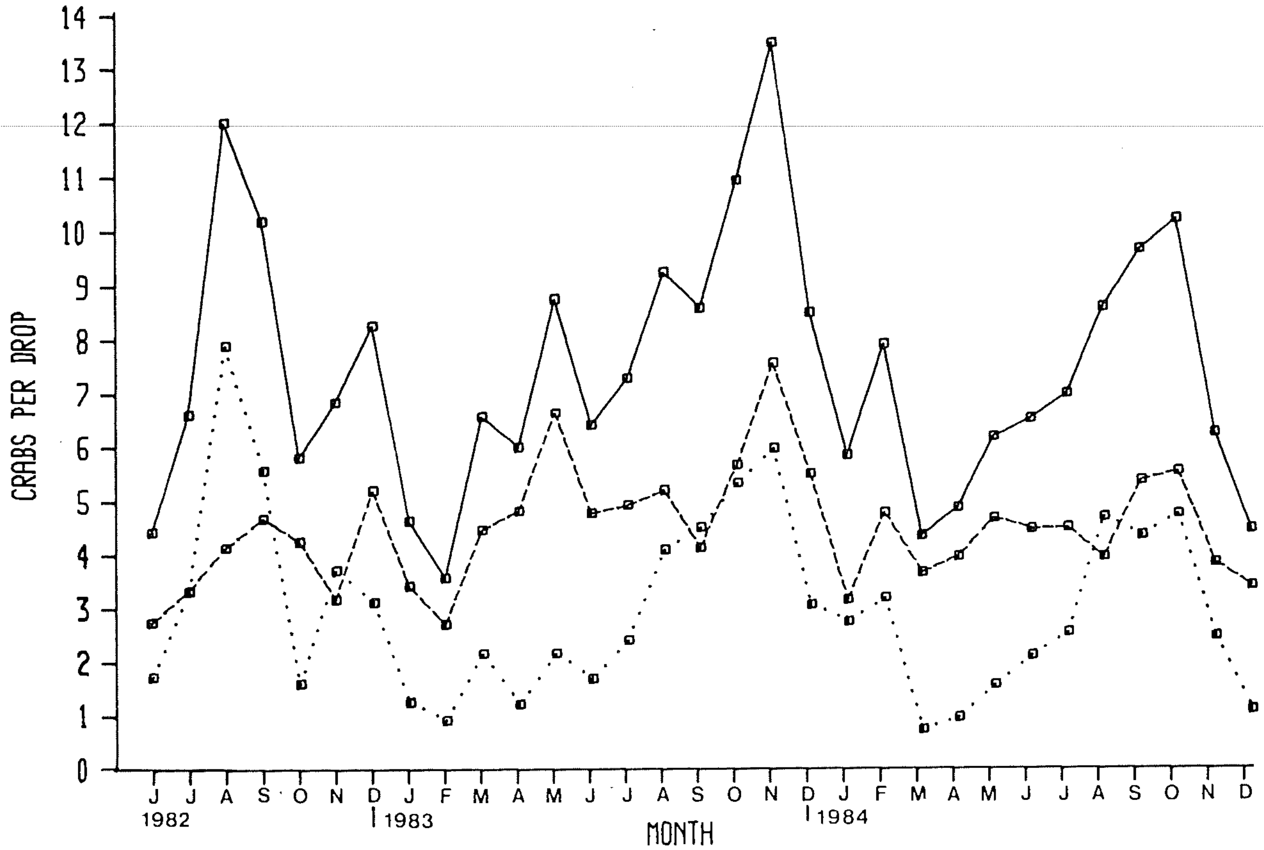

Figure 43. Seasonal changes in the catch rate of discards (dotted line), keepers (dashed line), and all crabs (solid line) throughout the logbook programme period.

In Fig. 44 year-to-year differences in CPUE have been smoothed by pooling the data, and the seasonal influence of small crabs on the total catch rate is even more apparent. There is a slight general tendency for the catch rate of legal-sized crabs (dashed line) to increase throughout the year, perhaps as a result of small recruits attaining marketable size, but the significance of this trend after about May is doubtful. The catch rate of crabs below marketable size increased throughout-winter to a peak in late autumn, indicating a progressively increasing rate of recruitment to the commercial fishery between about April and August. Little additional recruitment appears to take place after August, and from October to April the relative abundance of undersize crabs decreases, partly as a result of growth into the exploitable sector of the stock and (to probably a much lesser extent) the effects of natural mortality. This interpretation of the recruitment process is in general accordance with that presented in Fig. 36 (Section 3.12) based on an entirely different data set.

Provided there is little change in the fishing power of the standard unit of gear, CPUE time series can provide managers with a valuable guide to changes in the size of the stock. Such indices are a necessary parameter in most population dynamics models.

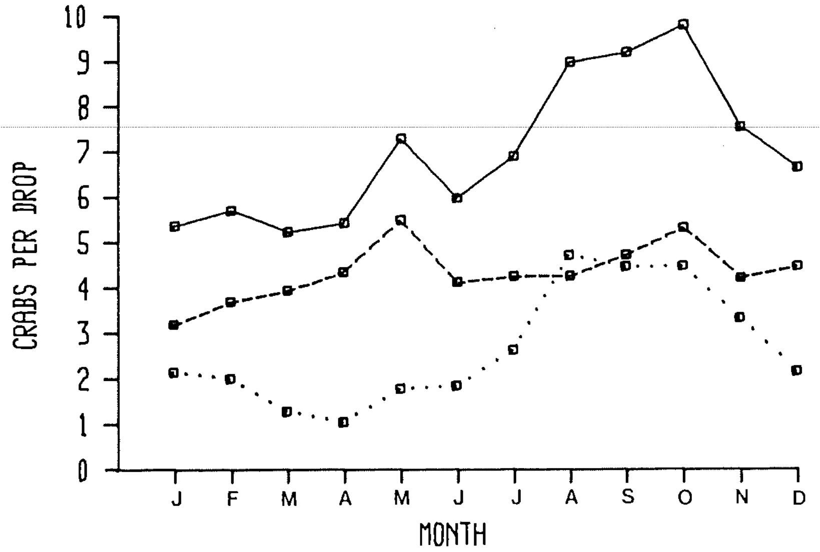

Figure 44. Seasonal variation in CPUE (number of crabs per net-drop) for discards (dotted line), keepers (dashed line), and total crabs (solid line), using pooled data.

It is therefore of interest to examine year-to-year changes that occurred during the logbook programme period. Yearly catch, effort and CPUE data are shown in Table 21. It should be noted again that the 1982 data represent only seven months, and were collected from one individual fisherman. Considering the differences in technique used to estimate the size of the "discard" component, CPUEs for non-marketable crabs were surprisingly consistent, particularly between 1982 and 1983. The CPUE for keepers during

Figure 21. Annual catch, effort and CPUE derived from commercial logbook data over the period 1982-84.

	1982	1983	1984	TOTAL
CATCH (# keepers)	28625	123902	156178	308705
(# discards)	29045	80205	111762	221012
(total #)	57670	204107	267940	529717
EFFORT (net drops)	7616	26356	37983	71955
CPUE (keepers)	3.8	4.7	4.1	4.3
(discards)	3.8	3.0	2.9	3.1
(total)	7.6	7.7	7.1	7.4

1983 probably approximates that of the virgin (unfished) stock, although it might be slightly elevated due to the fact that minimum size legislation was not introduced until May in the following year. Differences between fishermen in their individual assessment of what constituted a marketable-sized crab may therefore account for some of the reduction in CPUE from 4.7 in 1983 to 4.1 in 1984. However, as the catch rate of discards did not increase accordingly, at least part of the change is likely to be attributable to a real decline in accumulated stock.

4. DISCUSSION

4.1 Biology and Life History

4.1.1 Reproduction

Spanner crabs in southern Queensland spawn in the warmest part of the year, between November and February. There are no other data on the species' reproductive cycle in the south Pacific, but the observations of Rice and Ingle (1977) suggest that reproductive chronology is very similar in southern Indian Ocean stocks. Due to seasonal reversal, the spawning cycle in northern hemisphere populations is out of phase with that in the southern hemisphere by six months. Spanner or kona crabs in Hawaiian waters become ovigerous between May and the end of August (Onizuka 1972; Fielding and Haley 1976), and in Japan, Sakai (1971) obtained ovigerous crabs caught off the Pacific coast of Susaki towards the end of July.

Slight differences in spawning chronology were observed within the study area, apparently related to differences in latitude. Although the mean distance between sites north and south of Cape Moreton was very small, a phase lag of about 4 weeks was observed both in ovary development (as measured by the gonosomatic index) and in the appearance of berried females in samples from the southern part of the study area. Fielding and Haley's samples, from the Penguin Banks, indicated peak ovulation in May, while very few females collected by Onizuka from higher latitudes near the coast of Oahu were in berry before June. This may have been the result of year-to-year differences, as the two sets of data were not taken concurrently, but it is pertinent that the trend was in the same direction (earlier spawning in lower latitudes) as in southern Queensland.

Although ovigerous females may form small local aggregations, there is no evidence of any mass migration to specific spawning "grounds". Berried crabs were caught at many sampling sites throughout the study area, and neither Onizuka (1972) nor Fielding and Haley (1976) made mention of preferred spawning areas in Hawaiian waters.

The sex ratio in the south Queensland spanner crab population favours males by a factor of about 3 to 1. According to Onizuka (1972) and Fielding and Haley (1976) there are also apparently more males than females in the Hawaiian crab population, although in both of those studies the ratio was very much closer to unity. Prolonged exploitation of a stock where the sexes have a different L_∞ may well result in an altered sex ratio, and this appears to be the case in Hawaii. Data collected in 1980-81 by the National Marine Fisheries Service (NMFS) during fisheries stock assessment cruises in the relatively unexploited North-Western Hawaiian Island group revealed a M:F sex ratio of 2.8 (J. Prescott, personal communication).

Skinner and Hill (1985) suggest that the skewed sex ratio in commercial catches may be due to behavioural patterns in which the presence of a large male may inhibit access to the food on the part of (smaller) females. However the authors also observed in their aquarium populations that females tended to respond more rapidly than males to the presence of food, which would presumably reduce (or perhaps negate) the effect of behavioural exclusion.

The number of eggs per clutch or "sponge" varies with maternal body size. A moderately large female (100 mm CL) would produce a clutch of about 150,000 eggs. The fecundity data of Onizuka (1972) and Fielding and Haley (1976) (derived by volumetric and gravimetric methods respectively), show that egg production in the Hawaiian stock is similar to that in the south Queensland stock. Multiple ovulation was observed in aquaria both during this project and by Onizuka (1972), who relates that the second egg mass was somewhat smaller than the first. Since the length of the spawning season probably limits the number of ovulation cycles in any individual to two, total annual fecundity in spanner crabs is very much less than in either of the commercially exploited portunids **P. pelagicus** (Potter et al. 1983) and **S. serrata** (Fielder and Heasman 1978), both of which are characterised by more protracted spawning periods and a vastly greater number of embryos per sponge.

The spanner crab's comparatively low fecundity probably reflects lower rates of larval mortality in oceanic waters than in shallow estuarine habitats where much of the portunids' early post-larval life history is centred. This has implications for future management of the spanner crab resource, since it increases the likelihood that moderate overfishing could result in stock recruitment problems.

Female crabs as small as 64 mm CL were observed to be carrying an egg sponge, and other (indirect) evidence suggests that the size at first maturity is around 70 mm. None of the females below 58 mm orbital C.L. examined by Onizuka (1972) were either ovigerous or showed signs of ovarian development. Fielding and Haley (1976) believed 65 mm (orbital) CL to be the smallest length at which females may ovulate, but the average size at which 50% of the females are ovigerous (during the spawning season) was between 70 and 75 mm CL. Estimates of length at first maturity from the two widely separated spanner crab populations thus agree very closely.

Onizuka's (1972) supposition of promiscuous mating has been validated by Skinner and Hill (1986 b), who described the copulatory activity of animals in aquaria. Spanner crabs mate throughout the year, and because of spermathecal structure, copulation is not tied to the moulting cycle. However Skinner and Hill (1986 b) found that mating activity increased threefold immediately prior to ovulation, and decreased again at the end of the spawning season. Females may mate prior to their second ovulation of the season, but apparently this is not necessary; observations in the present study revealed that females which had spawned once were able to produce a second batch of fertile eggs without being re-inseminated. Spermatophores can clearly remain viable for extended periods, perhaps from the pre-spawning moult until ovulation, but because of the architecture of the spermathecum (described by Hartnoll 1979), spermatophores would be lost with the exuvium after moulting.

Askawa (1941) and Rice (1970) described the first zoeal stage of **R. ranina**, and this was followed by a description by Sakai (1971) of the full zoeal series. Sakai (1971) failed to produce a megalopa, and believed that the eight zoeae he reared constituted the complete series. During the present project it was hoped that, by using a more sophisticated and better controlled rearing system, larval survival would be enhanced, and some useful knowledge of the megalopa stage could result. However high mortality amongst the early zoeae (due in part to technical problems with the aquarium system and also to the unavailability of females carrying near full-term eggs) meant that in none of the trials did any of the larvae survive past the fifth stage. The duration of the first four stages (each about 5 days) was consistent with Sakai's (1971) data, and thus is probably reasonably close to the natural situation. It may therefore be assumed that the planktonic phase of the spanner crab's life history lasts for about 5-6 weeks, during which time the larvae can be transported (depending on the strength and direction of ocean currents) a considerable distance.

An intriguing insight into the potential for such dispersal is given by Rice and Ingle (1977), who describe the fortuitous collection of about 50 stage VIII zoeae washed aboard an oil tanker during heavy seas in the Mozambique Channel on February 15, 1976. The vessel's noon position on that day placed it at least 100 km from the nearest land (east coast of South Africa) in a depth exceeding 1000 m. The zoea must have been swarming at or very near the surface for such a large number to have been brought on board by spray and "occasional light water". This dispersal potential is of great significance in terms of the pattern of spanner crab distribution along Australia's eastern seaboard when one considers that larvae entrained in the East Australia Current could feasibly be transported 500-1000 km down the coast before settlement.

It may not be surprising that the main concentrations of spanner crabs are found in broad northerly-oriented "embayments" where (presumably) permanent localised eddy systems trap the pelagic larvae. Nevertheless, a proportion of the larvae undoubtedly becomes entrained in the EAC; it seems quite likely that many postlarvae which ultimately recruit into the northern New South Wales fisheries are actually derived from spawning stock in southern or even central Queensland waters. This implies that the future of New South Wales spanner crab fisheries may be at least partly dependent on how well the Queensland stock is managed. However in view of the lack of knowledge about possible longshore countercurrents, and the ability of spanner crab larvae to take advantage of different current systems by vertical migration, it is impossible to estimate the extent of this dependence at the present time.

Settlement presumably occurs at the metamorphosis of Zoea VIII to megalopa. The megalopae of other raninids, such as **Lyreidus tridentatus** and **Raninoides benedicti** have been described by Williamson (1965) and Knight (1968) respectively; these no doubt bear morphological similarities to **R. ranina**'s megalopa and probably occupy a comparable habitat. Evidence concerning the likely duration of the megalopa stage is conflicting; the size distribution of early crab stage exuviae found on Fraser Island beaches suggests that it may be very brief, while the discovery of intact 11 mm crabs in the stomach of a fish captured during April indicates otherwise.

4.1.2 Growth

The question of the species' overall growth pattern remains unresolved: Onizuka (1972) reported average pre- to post-moult growth increments of 9.9 mm for males and 7.5 mm for females in aquaria, but made no mention of the number of moults observed for each individual over a period of time. In crabs larger than 40 mm CL the proportional increment (ie, as a function of pre-moult carapace length) of males appeared greater than that of females, to which fact Onizuka (1972) attributed the greater average size of adult male crabs. A similar differential in moult increment was found by Skinner and Hill (1986 a), who reported means of 13.6 and 8.0 mm for males and females respectively. While these figures provide evidence for different growth rates between the sexes, they are unlikely to be of much help in establishing absolute growth patterns because of differences in environmental conditions between the aquaria and the animals' natural habitat.

Estimates of growth rate parameters made during the present study (using length-structured data in the seasonally-oscillating von Bertalanffy model) indicate a Brody growth coefficient of between 0.9 and 1.0, and a longevity of around 3 yr for both males and females, and asymptotic lengths of 160 mm and about 122 mm for males and females respectively. Although these figures should certainly not be considered definitive (for reasons outlined in section 3.11), they do reinforce the hypothesis that the observed sexual dimorphism in body size is a function of divergent growth rates rather than differential mortality.

4.1.3 Population structure

The largest male crab caught during course of the project measured 148 mm and the largest female 113 mm CL: in both cases the observed maxima were approximately 1 cm short of the predicted asymptotic lengths. A reduction in mean size is to be expected when a previously unexploited stock is subjected to fishing pressure, and such an effect has been reported in Hawaii by Fielding and Haley (1976) who compared size frequency distributions between the Penguin Banks and the more intensively fished Waimea and Waialua Bay sub-populations. Anecdotal reports from fishermen involved in the very early stages of the south Queensland and northern New South Wales spanner crab fisheries indicate that initially crabs weighing as much as "about 2 kg" were captured periodically. Male crabs of this weight would have a corresponding length of 176 mm. In the lightly fished North-Western Hawaiian Islands population individual males have been recorded with carapace lengths up to 168 mm, and around 25% of the catch taken during the NMFS survey comprised animals exceeding 130 mm C.L. (Brown 1985).

The unimodal size frequency distribution for female crabs compares closely in location to that of Fielding and Haley's (1976) Penguin Banks samples, with a mode at about 90 mm (rostral) CL. Males from the Penguin Banks, however, exhibited an irregularly flattened size distribution, with minor modes at the equivalent of 81 and 112 mm (rostral). This differed conspicuously from the uniform, almost Gaussian, length frequency pattern for south Queensland males, with a distinct modal peak at 110 mm CL. In other words, the Queensland catch (at the present time) comprises a far greater proportion of crabs larger than 100 mm CL than does the Hawaiian catch. Whether this reflects actual differences in size composition between the two stocks is unclear, for although both studies employed nets with the same sized mesh (50 mm), the Hawaiians used two layers of webbing which undoubtedly reduced the effective mesh size and may therefore explain the larger proportion of small crabs in the catch. Continuous fishing pressure over many years has, nonetheless, reduced the abundance of large male crabs on the Penguin Banks, albeit less markedly than at the sites studied by Onizuka (1972).

4.2 Commercial Fisheries

Despite the relatively recent development of spanner crabbing in Australian waters as a moderately important fishery, annual production figures (as far as they can be assessed on the basis of available data) are substantially greater than in other areas where the species is exploited commercially. The size of the south Queensland catch was initially estimated at around 250 tonnes per annum (Brown 1984), but subsequent information suggests that 300 t would be a much more realistic (and probably still conservative) figure. By way of contrast, official statistics indicate an average annual catch of only 10-15 t from Hawaiian waters, where the fishery dates back at least 40 years (Brown 1985).

Spanner crabs are also caught commercially off the southern coast of Japan (Sakai et al. 1983; Sakai 1971), and around the Philippines where they are normally marketed live and command a higher price than mud crabs (W.M. Sanguila, personal communication). Catch statistics from these areas are not available, but total landings are believed to be quite small. Indirect evidence presented by Rice and Ingle (1977) implies the existence of substantial local stocks along the east coast of southern Africa, but there appear to be no published reports of spanner crab exploitation anywhere in the western Indian Ocean. Since the commencement of this Project the fishery has expanded north to the Bundaberg area, and south into northern New South Wales waters. The total annual NSW catch is not yet known, but an indication of its significance can be gained from the fact that in the year to June 1985 some 200 t were landed at the Ballina cooperative alone (A. Vallance, personal communication).

The history and current status of the Hawaiian kona crab fishery was examined by Brown (1985) to discover why the Queensland landings are so much greater than those in Hawaii, and to gain some insight into possible long-term trends which might be expected to occur in the Queensland fishery. Differences between the production figures were attributed to under-reporting of landings by Hawaiian fishermen, lower levels of fishing effort, and differences in the size and density of the stock.

Not only are the Hawaiian crabbing grounds much less extensive than those in Queensland, but judging from reported catch rates the animals appear more sparsely distributed. Catch rates calculated from the Queensland logbook data averaged 4.3 marketable-sized crabs per net drop, which equates to approximately 5.7 crabs per net-hour (since soak-times are typically around 45 min). The average weight of marketable male crabs has been estimated at 725 g, which means that, in terms of weight, the catch rate was roughly 4 kg/net-hour. This is more than ten times the mean CPUE reported by Vansant (1978) for a single vessel which worked the Penguin Banks consistently between January and July 1974. The tangle-nets used in Hawaii are similar to those used by Queensland spanner crab fishermen, but there are marked differences in gear deployment techniques, particularly in the Hawaiians' preference for the long trot-line system where up to 100 or so nets may be attached to a single ground line (Vansant 1978). That a similar system is also used in Japan (Sakai et al. 1983) is not really surprising, considering the strong historical and cultural links between the two countries. It is of interest to note that fishermen both in Queensland and Hawaii believe that soak times greater than about one hour are counter-productive, especially if the presence of skarks or turtles is suspected.

These differences in the way the fishing gear is deployed may partly explain observed differences in apparent stock density. Whereas Hawaiian fishermen locate "suitable" crabbing grounds on the basis of echo soundings then set a large number of nets in a rather lengthy operation, their Australian counterparts tend to move around, initially setting a few nets in different areas until they find a patch of crabs, then working the patch intensively. The latter would seem to be a more effective mode of operation, in which case the measures of fishing effort are not strictly comparable. Nevertheless, there is little doubt that there are significantly more crabs per unit area along the coast of south Queensland and northern New South Wales than on the Penguin Banks.

The annual catch per trip of a vessel working the Penguin Banks between 1967 and 1974 varied slightly around a mean of 426 lb (=193 kg), and showed no evidence of a decline (Vansant 1983), which the author interpreted as meaning that the crab population had remained stable over that period (during which it had been relatively lightly fished). The low apparent stock density is thus unlikely to have been the consequence of overexploitation. Alternative explanations involve the possible effects of environmental factors such as depth and substrate type, or to naturally low levels of larval recruitment (Brown 1985).

4.3 Factors Affecting Local Abundance

4.3.1 Food availability

Provided abiotic conditions are favourable, populations of animals will aggregate and prosper in areas where food is plentiful. In terms of stock assessment, this may have unpredictable consequences when the only viable capture/sampling method relies on attracting hungry animals to a baited fishing apparatus: such gear in fact selects against replete individuals. The point has been made by Brown (1984) and again by Skinner and Hill (1986 a) that the main spanner crab grounds in Queensland occur where there is an intensive nocturnal trawl-fishery for penaeid prawns, and that trash fish and crustaceans discarded by the trawlers may well constitute an important source of food for the spanner crabs.

Crab fishermen are acutely aware of the distributional patchiness of their quarry, a feature which has been demonstrated statistically for the catch figures obtained during this Project. It may be that crabs congregate locally to feed on trawl trash, and rather than dispersing immediately, tend to remain in the same general area for a day or so. They may then be located as a "patch" by the crab fisherman. Aquarium studies have shown no evidence of territoriality amongst spanner crabs, and even large adult crabs can coexist at quite high densities without exhibiting much aggressive behaviour. Considering the relative uniformity of their demersal habitat, it is improbable that the distribution of their natural prey would be sufficient to account for the crabs' local patchiness.

Because of the nature of the sampling technique, spanner crabs containing recently ingested (and therefore easily identifiable) natural prey items are rarely encountered. A small proportion of the fore-guts examined opportunistically during the course of this Project contained the remains of polychaete worms, echinoderms (primarily heart-urchins), small bivalve molluscs, and skeletal fragments of fish. This observation is generally confirmed by Skinner and Hill (1986 a), who listed echinoderms, polychaetes and fish as the natural prey organisms most frequently encountered in the intestinal tract of spanner crabs. Grant's (1965) supposition that the crabs probably feed on live fish such as whiting is almost certainly erroneous, as various small live fish and prawn species remained untouched after being held for extended periods in aquaria with un-fed spanner crabs.

4.3.2 Temporal factors

In an effort to determine whether catch rates could be influenced by changes in activity levels resulting from seasonal cycles in ambient water temperature, Skinner and Hill (1986 a) compared variations in CPUE obtained from one individual fisherman with the duration of emergence periods in a group of aquarium-held crabs. They concluded that there was a direct correspondence between the seasonal timing of high and low levels of emergence and the time of high and low CPUE, but this was not tested statistically. However they did report that emergence and temperature were negatively correlated, and that no significant relationship existed between temperature and CPUE. The CPUE data presented by Skinner and Hill showed peaks between July and September, which the authors attributed to changing behavioural (emergence) patterns. Field data collected from deeper parts of the main commercial crabbing grounds during the present study also showed a gradual rise in catch rates throughout the latter half of the year. However commercial fishermens′ logbook returns clearly demonstrated that the post-July increase in CPUE is due to a seasonal recruitment pulse of small crabs (i.e. effectively an increase in the density of the vulnerable population), rather than an increase in the vulnerability of the population as a whole. The commercial CPUE for large (marketable-sized) crabs actually varied little throughout the year.

Spanner crabbing is an exclusively day-time operation in Queensland and Hawaii, but in Japanese waters, where the set line is left fishing for much longer periods (8 - 12 hr), there appears to be no preference between day and night sets (Sakai et al. 1983). Although no definitive study of diel variation in CPUE has been done, incidental night sets carried out during the Project period yielded catch rates only marginally greater than zero, and similar results have been obtained by one or two fishermen curious as to whether spanner crabs can be captured at night.

The experimental work of Skinner and Hill (1986 a) showed that the amount of time the animals spent on top of the substrate (rather than buried) rose dramatically from mid-afternoon to a peak at dusk. Overall, the duration of emergent periods was surprisingly small. For example, male crabs emerged from the substrate for an average of a mere 2 min each hour between mid-night and 1600 hr, and for a maximum of 6 min/hr at the dusk peak, and corresponding activity amongst females was significantly lower. This pattern of behaviour is in clear contrast not only to the diurnal nature of the commercial fishery and the fact that trawlers working at night catch very few spanner crabs, but also to Project results which indicate an apparent (but not statistically significant) decline in catch rates throughout the day, with the lowest mean CPUE from sets after 1400 hr. This paradox may be due to the fact that the experimental animals were fed every second day, while emergence observations were made only on non-feeding days, a situation unlikely to parallel natural conditions experienced by animals in the wild.

Several spanner crab fishermen believe that catch rates are influenced by the lunar cycle. Project results have confirmed this theory, demonstrating that CPUE is greatest on the "dark" of the moon (i.e. around new moon), and least during the period between 1st quarter and full moon. Trawlermen favour dark nights for catching prawns in southern Queensland waters, presumably because prawns are more active at that time. However it is not at all clear whether spanner crabs are affected directly by lunar periodicity, or whether increased day-time catch rates are somehow the result of more intense trawling activity on immediately preceding moonless nights.

4.3.3 Depth

Spanner crabs have been found in a wide range of depths along the south Queensland coastline, from the intertidal zone on sandy beaches down to depths in excess of 80 m. Onizuka (1972) cites a report of Stebbings (1893) that members of the family Raninidae occur in depths to 300 fathoms (550 m). In Hawaii the species inhabits waters from less than 20 ft (6 m) to more than 300 ft (91 m) deep, and the Waialua and Waimea Bay crabbing grounds range from 90 to 300 ft (27 - 91 m) (Onizuka 1972). Personal observation of the latter areas indicates that heavy wave action in the inshore parts of the bays would severely limit fishing operations, if not the crabs' distribution. Fielding and Haley (1976) consider the Penguin Banks, with an average depth of 60 m, to be "shallow", and report that large numbers of kona crabs were caught along the outside edge of the banks in depths of 100 - 200 m. Vansant's (1978) experimental sets were carried out in a small depression 3 km in diameter and between 65 and 90 m deep, on the northern edge of the Bank.

The bulk of the Queensland catch, therefore, is taken from areas which are only about half the depth of the Hawaiian commercial crabbing grounds. There is no obvious physiological reason why depth **per se** should limit the animals' distribution: bathymetric variations in population density are most likely related (indirectly, via depth) to factors such as food availability, bottom current velocity, substrate suitability, and (perhaps in deeper areas) temperature.

Analyses of the Project catch-rate data indicate significant "depth related" trends, with highest CPUEs being recorded from the intermediate (30 - 50 m) range. However more detailed calculations revealed that the relationship is far from straight-forward, and may be significant only during the period of increasing reproductive activity (September - December). Seasonal trends depicted in Fig. 14 could feasibly indicate a general movement of mature crabs from shallow to deeper water (30 - 40 m) as reproductive development progresses prior to spawning. While it was not possible to carry out definitive analyses of the relationship between depth and the logbook CPUE data, the gross catch rates (presented by grid block in Fig. 42) certainly tend to be higher at intermediate depths than in either shallow inshore or deep offshore areas.

4.3.4 **Substrate type**

Assuming that catch rate is a reasonably consistent indicator of population density, results of this study show that spanner crabs prefer substrates comprising a high proportion of medium-fine sediments, in the +2 to +3 Φ (125 - 500 μ) range. Few of the sediment samples examined contained a significant amount of very fine (clay or silt) fractions. Sediments which comprised a low proportion of medium to fine sand, and which generally yielded low catch rates, thus consisted mainly of fractions with a larger mean particle size (coarse sands and shelly gravels). Areas such as the western and deep central parts of Moreton Bay where silty substrates predominate are essentially devoid of spanner crabs. It could be postulated that this species, in contrast to the commercial portunids, may lack the mechanism needed to keep its gills from becoming clogged with very fine particles. On the other hand, its apparent avoidance of very coarse substrates is probably due to the mechanical difficulty of digging into a rubble or gravelly bottom.

In view of the low catches experienced in areas where the substrate comprised a high proportion of very coarse material, it is interesting to note Vansant's (1978) comment that "most commercial (kona crab) fishing effort (in Hawaiian waters) was observed to be between 50 and 150 m in coarse sand and coral rubble". It has been pointed out elsewhere (Brown 1985) that Vansant did not present any sediment data, and that perhaps there is, in fact, very little fine sand substrate available for spanner crab settlement in the Hawaiian region. If this is the case, it may explain why the Penguin Banks appears to support such a sparse crab population. The most likely explanation for low crab densities in such areas is that the animals (particularly the juveniles) have difficulty in burying themselves in the substrate, and thus become more vulnerable to predation.

Sharks and turtles are known to prey on spanner crabs trapped in the tangle nets. As a result, they are probably the major cause of gear damage in the Queensland fishery. Hawaiian fishermen claim that large stingrays are the main natural predators in that area, but they also blame the introduced blue-banded sea perch (**Lutjanus kasmira**) which is believed to consume juvenile kona crabs in large quantities (Brown 1985). There may well be some truth in this, as fishermen handlining on some of the offshore reefs in south Queensland have periodically reported finding the remains of small spanner crabs in the stomachs of other percoid species such as the snapper (**Chrysophrys auratus**).

4.3.5 Stock movement

Indirect evidence for the possible movement of crabs from shallow inshore areas to slightly deeper regions offshore has been alluded to above. Mean catch rates at deep (> 30 m) and shallow (< 30 m) sites were very similar during the period January - April when (according to Skinner and Hill 1986 a) subsurface water temperatures are at a maximum. CPUEs at deep sites subsequently increased, but shallow water catch rates remained at their previous level. If there had been a substantial offshore movement of the population, the catch rate in shallow areas would be expected to have decreased at much the same rate as the deep-water CPUEs increased.

A similar analytical approach was used to test whether cycles of "availability" related to lunar periodicity could have been due to short-term inshore-offshore migration, but the patterns of change in catch rate from deep and shallow sites were parallel rather than inverse, indicating that no population movement was involved.

Limited results from the aborted tagging exercise suggest that adult spanner crabs tend to remain in the same area even for quite long periods. Corroborative evidence is presented by Onizuka (1972) who observed no exchange of tagged crabs between two adjacent embayments on the north coast of Oahu, and concluded that migration is not part of the behavioural repertoire of this species. Onizuka's surprisingly high tag return rate (16.2%) was presumably due to heavy fishing pressure concentrated in a very small geographic area.

4.4 Gear Selectivity

During the early days of the south Queensland fishery, spanner crabbers used inverted dillies (witches' hats) consisting of a slack conical net attached to a circular metal frame. However the introduction of the Hawaiian flat nets rapidly led to the abandonment of the dillies. Comparative trials involving the two types of gear showed that differences in catch rate were insignificant. A slightly greater proportion of the flat-net catch comprised marketable-sized crabs, because of the slack dillies' greater potential for trapping small animals. An additional advantage of the flat nets is that they easier to clear, which undoubtedly results in less damage to the nets and to the crabs themselves. The latter is an important conservation consideration, as Onizuka (1972) found that although crabs in aquaria could survive the experimental removal of 2 or 3 dactyli (spades), any greater leg damage than this caused significant mortality. Onizuka's mortality figures may be somewhat higher than would be expected in the wild, because of the greater risk of bacterial infection under aquarium conditions. Nevertheless, any developments which enhance the survival of undersize crabs should clearly be encouraged.

Mesh selection experiments showed that the size-composition of crabs caught in 30 mm and 50 mm mesh nets was very similar, but that 75 mm mesh caught a significantly greater proportion of large crabs (particularly at the upper end of the size-range). Curiously, crabs less than 80 mm C.L. comprised an almost identical fraction (33%) of the catch from all three mesh sizes, which indicates that the selectivity exhibited by the large (75 mm) mesh does not operate on the smallest vulnerable size-classes. Catch rates, on the other hand, varied inversely with mesh size, the mean number of crabs (of all sizes) per 30 mm net being more than double that obtained from the 75 mm nets. Thus it appears that large mesh catches a moderately greater proportion of large crabs, but small mesh catches a substantially greater total number of crabs.

Similar experiments were conducted by Vansant (1978), who compared size-frequency composition of the catches from nets with 50, 76 and 100 mm mesh. No significant difference was found between either the 76 mm or the 100 mm mesh and the 2" (50 mm) control. Perhaps the reason for this non-significant result was that the nets he used were covered with two layers of webbing. This could potentially reduce the mesh size by as much as 50%, which would effectively have invalidated the entire exercise. Unfortunately Vansant did not provide comparative catch-rate data for the three mesh sizes, but he did observe that the smaller the mesh, the greater the damage it could sustain while maintaining its physical integrity.

The question arises periodically as to whether spanner crabs can be caught in pots and traps. Vansant (1978) reports that during his study "various pot designs were set from time to time ... and were completely avoided by the kona crab", but provided no design details. On the other hand, fishermen in the northern part of Moreton Bay sometimes catch spanner crabs in their sand crab pots. Moreover many of the crabs taken during the National Marine Fisheries Service stock assessment cruises in the North-Western Hawaiian Island chain were captured in lobster pots, and at least one Hawaiian crab fisherman prefers to use traps (Brown 1985), although he was reluctant to divulge design details to the author.

Clearly an appropriately-designed trap or pot can be an effective means of capturing spanner crabs. However the use of such gear in Queensland waters would be impractical because the vessels currently operating in the fishery are too small to carry an adequate number of traps to and from the fishing grounds each day, and the activity of trawlers in the area precludes their deployment overnight.

4.5 Management

4.5.1 Justification for existing legislation

While arguably less than significant in comparison to Queensland's important prawn-trawling industry, the spanner crab fishery has provided seafood consumers in this State with a new, high quality and very modestly priced product. It represents a livelihood for a small number of full-time comercial fishermen, and has provided many fishermen involved in pulse fisheries with an additional source of income at times when their main target species are at a seasonal ebb. One of its main attractions is the minimal capital outlay required to suitably equip a vessel, and the ease with which existing small boats can be modified to enter the fishery. There is probably scope for expansion north to the southern end of the Great Barrier Reef (possibly further), and the value of the fishery will increase as the product becomes better established in the marketplace, both domestic and overseas. The present modest level of production should not be seen by management authorities as an excuse to ignore the fishery.

The work outlined in this report was carried out at the initial request of industry representatives. At an early stage the resource was recognised as a potentially valuable one, and one of the few remaining offshore marine stocks in Queensland accessible to the small-boat operator. Some information relating to the species' biology and exploitation around Hawaii was available at the time, but nothing at all was known of the Australian stock. Initial marketing problems were experienced as a result of large quantities of very small crabs being landed, and frequent instances of poor quality control during the handling and cooking processes. These problems were of concern to the bona-fide fishermen, who attributed much of the blame to unlicenced amateurs "cashing in" on the abundant new resource. There was also a high level of interest in the possible effects of current levels of fishing pressure on the long-term future of the fishery. Several of the more conservation-conscious fishermen exercised a degree of self-regulation in an attempt to stabilise the market, by voluntarily imposing a limit on the size of the crabs they landed, but unfortunately the practice was not widely adopted.

The apparent paucity of female crabs in the population was also a cause of some concern. This was heightened by the fact that (at the time) few fishermen had ever seen a female spanner crab in berry, while evidence from Hawaii suggested that over a period of a third of a year as many as 80% of the females in a typical commercial catch could be expected to be carrying eggs (Fielding and Haley 1976).

There was a perceived need to provide a more uniform marketing environment for the product, and better quality control on handling and processing. The strongly male-biased sex ratio, infrequent capture of ovigerous crabs, and their relatively low fecundity indicated that (at least until more comprehensive data became available) the spawning stock should be afforded some protection. Legislation to achieve these objectives would have to be formulated in such a way as to ensure that it was enforcable (from the practical viewpoint), and most importantly that the fishermens' activities were not restricted to the extent that their spanner crabbing operations became financially non-viable.

In this context, Project data on hand at the time were critically evaluated, and various possibilities were canvassed among individual fishermen, industry representatives and relevant State Government bodies. Finally three interim management regulations (involving a size limit, a restriction on taking ovigerous female crabs, and an amateur bag limit) were agreed upon.

A minimum legal length of 10 cm C.L. was recommended on the basis that it would prevent the sale of crabs of a size considered by seafood dealers to be unsuitable, and would thus improve the market situation. Even if not immediately reflected in a better overall price for the product, this would reduce the likelihood of consumer resistance developing further in response to fluctuations in quality (i.e. size and appearance).

At the same time, a cut-off at 10 cm would potentially protect around 43% of the total number of male crabs taken in the typical catch. The effect on potential landed weight would be much smaller, in the region of 25%. It would, however, help prevent the establishment of a crab-meat market heavily reliant on a supply of small animals. Because of the observed sexual dimorphism in growth and L_{∞}, this limit would also provide protection to over 90% of the females.

The lack of egg-bearing crabs in the catch suggested either 1) that the spawning season was exceptionally brief and embryonic development equally rapid, 2) that ovigerous crabs were aggregating in areas not presently subject to fishing pressure, or 3) that they become less vulnerable to capture (perhaps for behavioural reasons) when carrying eggs. Hypotheses 1 and 3 were not consistent with the data from Hawaii, where large numbers of berried females are caught over a period of at least three months. The balance of evidence available at the time supported hypothesis 2. If this were true, large spawning aggregations of female crabs would eventually be located in certain areas, and judging from the Hawaiian experience, would be highly susceptible to capture. The possibility thus existed for serious depletion of the spawning stock with consequent deleterious effects on recruitment levels in subsequent years.

It could be argued that there should be little cause for concern as the 10 cm size limit actually exposed less than 10% of the females to fishing mortality. However Vansant (1978) estimated that, because of the relationship between body size and fecundity, and the fact that large females are capable of multiple ovulation, the small vulnerable sector of the female stock may in fact be responsible for more than 30% of the total egg production. Such a contribution to the future of the resource must be regarded as significant. The designation of spawning grounds (if and when identified) as seasonally closed areas was dismissed because of the difficulty of ensuring adequate surveillance. A general prohibition on the taking of ovigerous crabs was thus considered the best option available for maximising the species' reproductive potential.

Recreational fishermen in Queensland can, for a small fee, obtain a permit which allows them to sell catches in excess of their personal needs. The basis of this arrangement is largely a philosophical one, and has been the cause of much debate within the industry. Unfortunately many sport fishermen have abused the system to such an extent that the recreational pursuit is replaced by a desire for financial gain, and permits are frequently ignored. Many such "weekend professionals" apparently involved themselves in the spanner crab fishery, and paid little regard either to the size of the crabs they landed or to the finer details of handling, cooking and storing the catch. This resulted in some rather poor-quality product being sold, which was not conducive to the creation of a marketing niche in the face of competition from the two other well-established crab species.

It would be difficult on any grounds to justify the complete exclusion of amateurs from this fishery: a compromise was needed which would on the one hand allow for legitimate sport-fishing, while on the other, discourage the marketing of recreationally-caught crabs. A bag-limit was seen as probably the only viable method of achieving these objectives, and discussions with the Queensland Amateur Fishing Council resulted in a recommendation that recreational fishermen be allowed 40 crabs (in possession). It should be added that, for reasons unclear to this author, the figure was subsequently reduced to 20. Recommendations were presented in the form of interim precautionary measures (rather than part of a formal management plan) to the relevant State authorities in 1982. Following this, discussions were held with the Commonwealth DPI regarding the introduction of complementary legislation, as a significant proportion of the south Queensland spanner crab fishing ground is in Commonwealth-controlled waters. The Queensland regulations were announced in May 1984.

4.5.2 **General assessment**

It is now appropriate to consider (in light of the Project results as a whole) whether these pieces of legislation are still justifiable, and what may need to be determined or done with respect to future management of the fishery.

In the absence of accurate information on turnover rates and natural mortality (i.e. the population's inherent genetic potential for increasing biomass) it is impossible to make use of dynamic models designed to predict any sort of yield function (e.g. Beverton and Holt 1957). Virtual population and cohort analyses (e.g. Pope 1972) are useful only in situations where it is possible to identify successive year-classes in the population; this requires well-documented growth and length-at-age data. The recent development of the spanner crab fishery obviously means that historical data are non-existent, which precludes the application of production models such as that of Schaefer (e.g. Schnute 1977) based on a time series of reliable catch and effort information.

The growth parameters K, L_∞ and T_{max} have been estimated from the length-frequency data but (for reasons discussed previously) they are not considered to be particularly reliable. The value of Z (3.98) computed on the basis of these estimates is suspiciously high, as it would indicate that annual survivorship amongst recruited age-classes is only about 2%. The implication here is either that M or F (or both) are unusually high, or that T_{max} is underestimated. The biology and behaviour of the species is not consistent with values of M which exceed many of those reported even for small, short-lived fish (Pauly 1978). On the other hand, an elevated F would imply a very high exploitation-rate. An indication of exploitation rate could be derived by comparing total annual catch with an estimate of stock size, if it were possible to estimate the latter.

From first principles it could be argued that a gross non-dynamic assessment of standing stock biomass might be derived from the formula

$$P' = \frac{CPE \times A \times \overline{W}}{\pi \times R^2 \times q}$$

where P' = weight of the exploitable stock in metric tonnes
CPE = weighted mean catch per unit effort (legal crabs/net drop),
A = total area of fishing grounds (km^2),
$\overline{W}$ = average weight of legal-size crabs (g)
R = effective radius of the fishing unit (m), and
q = coefficient of catchability.

Realistic values for CPE (4.3) and A (3 000) have been obtained from the logbook data, and $\overline{W}$ is calculated at 724 g. The parameters R and q are unknown. However, assuming conservatively that the effective fishing radius R (i.e. the maximum average distance from which crabs can be attracted to a typical baited net) is 30 m, and that 60% of the crabs within that radius are actually captured, P' equates to about 5 500 t. This is an order of magnitude greater than the annual catch, suggesting that the "true" F is not, in fact, excessive. It is interesting to note here that the logbook CPUE figures for marketed crabs showed a 12.7% drop between 1983 and 1984.

If the 1983 figure is taken as being representative of a virtually unfished stock (where Z = M), then the magnitude of the catch rate in the following year (when Z = M + F) is not inconsistent with this interpretation.

Thus it appears that the growth parameter estimates from ELEFAN I may be inaccurate, possibly as a result of poor contrast in the size-frequency data and the paucity of information about the small juvenile stages. In particular, T_{max} may actually be somewhat greater than 3, in which case Z would be forced towards an intuitively more realistic level. Should the above assumptions ultimately prove anywhere near correct, the fishery may well be able to sustain somewhat higher levels of fishing pressure than it is currently experiencing. Unfortunately, as the logbook programme had to be terminated at the end of 1984, no CPUE data are available for subsequent years, and there is no way of determining whether any further reduction in catch rate has occurred since that time.

Data obtained following the introduction of minimum size legislation do not provide any evidence that the limit should be altered. The stabilising effect which it has had on the market has been generally recognised and appreciated; a significant reduction in the minimum legal length cannot be supported on economic or (at this stage) biological grounds. Conversely, there does not appear, from the conservation point of view, to be any need to raise the limit. Indeed, such a change would place an undue financial burden on the fisherman, since almost 50% of the marketable component of the catch comprises animals in the 10-11 cm size group.

Analysis of seasonal changes in sex ratio provide a clue as to why fishermen caught berried female crabs so infrequently. During the post-ovulation period (November and December) the M:F ratio is significantly higher than at other times of the year, which has been shown to be due to a decrease in the vulnerability of ovigerous females. This feature is believed to be behaviourally-mediated, but it was reported neither by Onizuka (1972) nor Fielding and Haley (1976) with respect to the Hawaiian stock. While Project data indicate that berried crabs sometimes aggregate locally, Skinner and Hill (1986 b) observed markedly depressed activity levels for a period of 50 days after spawning amongst aquarium-held crabs, and similar evidence has been obtained from studies of seasonal patterns of energy transfer (D. Mercer, personal communication).

Spanner crabs in Queensland (if not in Hawaii) therefore exhibit a natural behavioural pattern linked to the reproductive cycle which effectively reduces the vulnerability of brooding females to fishing mortality. Consequently there may well be some justification for removing the restriction on the taking of ovigerous crabs provided, of course, that the 10 cm size limit is not reduced.

Apart from the fact that the quality of spanner crabs on the market has evidently reached a satisfactory level, there is no way of assessing the effect of the amateur bag-limit. Genuine recreational fishermen can certainly capture adequate quantities of crabs for domestic consumption, and the limit, if generally observed, is sufficient to discourage quasi-commercial activity. However it is doubtful whether much surveillance of this regulation has been carried out to date. The possible impact of recreational fishing on the stock will be better appreciated after the QDPI Fisheries Management Branch has conducted its planned boat-ramp survey.

4.5.3 **Market influences**

Presently spanner crabs represent exceptionally good value for money to seafood consumers, particularly in the Brisbane metropolitan area. The reason for this is demonstrably related to the abundance of sand crabs on the market. Most consumers still prefer to buy sand crabs, even when spanner crabs are available at a lower price per unit weight. A minor price differential (due to the slightly lower meat yield from spanner crabs) is to be expected, but there is nonetheless considerable scope for improving the return to the fisherman. The value of the fishery could probably be increased through an intensive multi-media consumer awareness programme providing recipes as well as hints on cleaning, cooking and meating the animals. Such a campaign was conducted (but on a very limited scale) during the course of the Project, with the distribution of leaflets of the type illustrated in Appendix 4.

Any significant increase in wholesale price would naturally make the fishery more attractive, and probably result in increased fishing effort. There is, however, another way in which fishermen and dealers are circumventing the problem of competition from locally-produced sand crabs, and that is through the development of interstate and overseas markets. Precise figures are difficult to obtain, but it is known that trial shipments have been sent to Hawaii, Japan, Hong Kong, and possibly the U.S. west coast, as well as to various southern-state markets in Australia. One processor estimates that at least 80 t of whole cooked spanner crabs have been exported to Japan in the recent past, and one dealer is attempting to establish a market for live crabs in south-east Asia. Fishermen supplying crabs destined for such markets presumably obtain a significantly better and more consistent price for their product than they would locally. It is not beyond the bounds of possibility that ultimately the bulk of the catch (including the best quality crabs) will be exported, leaving an unpredictable residual supply of less than top-quality product for the home market.

4.5.2 **Future requirements for management**

If the fishery is to be managed effectively in the future, there will need to be some sort of formal monitoring system established to ensure the collection and assessment of appropriate information. Without an adequate data base, fishery assessment is impossible, and even to talk about management is a waste of time. Ideally, in the opinion of this author, serious consideration should be given to the implementation of a state-wide data base specifically designed to acquire at least the minimal information needed to perform a meaningful assessment of any of its fisheries. The complexity and cost of such a scheme is fully appreciated, as is the fact that it may take a long time (perhaps decades) before it produced consistently useful results. In the shorter term, all that can realistically be hoped for (in terms of commercial spanner crab fishery statistics) is a reasonably accurate measure of total annual catch and a corresponding estimate of catch-per-unit-effort.

The QDPI Fisheries Management Branch is currently developing a system for the collection of species-specific information from seafood dealers and processors throughout the state. If sufficiently comprehensive, this database should be able to provide an adequate estimate of total commercial catch, preferably broken down by regional subdivision. If total effort statistics are unavailable (which is usually the case except in fisheries where logbook returns are mandatory), the most effective way to arrive at a realistic CPUE figure is via a voluntary logbook scheme involving a representative cross-section of the fleet. Assuming constancy of fishing power, this would, over a period of years, provide the bare minimum of information required for input into a simple production model.

Experience during this Project suggests that at least 20% of the "regular" operators would need to participate, and that the scheme should be run for a period of not less than four months per year. It would not be necessary to run the logbook scheme every year, but it stands to reason that the more frequently the information is obtained, the greater its value in terms of detecting and analysing trends in the fishery. It would not be too difficult to institute such a periodic programme, since a substantial number of (non-date-specific) logbooks is still on hand, and comprehensive analytical software is available on computer file at the Southern Fisheries Research Centre. In view of the fact that the southern Queensland and northern New South Wales spanner crab fisheries are contiguous, it would be extremely advantageous if fisheries organisations in both of these states could work in collaboration to ensure that the fishery is covered in its entirety.

Although the research effort directed towards **Ranina ranina** in Australia has been comparatively modest, there now exists a significant body of knowledge about the animal's biology, life-history, behaviour and population structure. This information can (and should) be utilised by those reponsible for overseeing the exploitation of the spanner crab resource. Nevertheless, it would be very short-sighted not to admit that there are still some grey areas where additional work is needed, and where definitive results would make a considerable contribution to our understanding of the stock's dynamic processes.

Perhaps the most important of these concerns the species' growth characteristics. Research work currently being conducted by D. Mercer at Queensland University (with financial support from FIRTA) promises to yield a reliable method for estimating moult-cycle stage, which will undoubtedly be of relevance to any future studies on spanner crab growth. Any such future work would, in the opinion of this author, profit from an intensive investigation of post-larval settlement and patterns of pre-recruit distribution.

The question of larval dispersal has been briefly discussed in the context of stock management. If a significant fraction of the pelagic larvae are transported non-randomly to localities distant from the range of the parent stock, there may be no demonstrable relationship between stock size and recruitment within a particular (geographically-defined) fishery. The management implications of a situation such as this are obvious. It would therefore be of some considerable value to know more about the relationship between various spanner crab "sub-populations" along the east coast, and the extent to which one might contribute recruits to the others. Until problems such as these are sorted out, it is unlikely that any amount of population modelling will develop a significant predictive capability.

5. RECOMMENDATIONS

In view of the foregoing, it is recommended that:

i) The existing 10 cm minimum legal length be retained without change.

ii) The existing recreational bag-limit be retained without change.

iii) The existing prohibition on the taking of ovigerous females be lifted.

iv) There be no restriction placed on the size of mesh which can be used on spanner crab nets, nor on the season in which spanner crabs may be taken, nor on the areas from which they may be taken.

v) The use of any apparatus apart from ring-framed baited tangle nets or baited traps specifically for capturing spanner crabs be discouraged.

vi) Significant increases in fishing pressure be permitted only after an appropriate monitoring system has been established, and that consideration be given to the possibility of allowing additional vessels into the fishery for a specifed period of time at the end of which the permit may or may not be renewed, depending on the results of assessment of appropriate fisheries data.

vii) The Fisheries Management Branch be encouraged in its effort to establish a state-wide seafood processor/dealer data-base.

viii) Short-term voluntary logbook programmes be implemented from time to time in collaboration with NSW Division of State Fisheries to obtain reliable estimates of commercial catch-per-unit-effort from both the southern Queensland and northern NSW fisheries, and that the data so obtained be used together with total catch information from FMB and appropriate NSW sources to regularly assess the status of the fishery as a whole.

ix) More reliable estimates of the species' growth characteristics be sought through appropriate research programmes.

x) That research investigations into post-larval settlement and geographical patterns of recruitment be encouraged.

6. ACKNOWLEDGEMENTS

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APPENDIX 1

Spanner crab voluntary logbook sheet, showing format of the daily fishing record.

SPANNER CRAB COMMERCIAL LOG

yr	mo	id
		4 0

CONFIDENTIAL

YEAR 1983

MONTH JAN

ACTIVITY:
0: fishing - spanner crabs
1: fishing - other species
2: lay day - bad weather
3: lay day - maintenance
4: lay day - any other reason

Ave. SIZE:
0: mostly small
1: equal no. small & large
2: mostly large

CATCH SOLD TO:
0: Fish Board
1: Co-op
2: other buyer

DAY	ACTIVITY	TIME OF DEPARTURE FROM PORT	BLOCK(S) FISHED			MOST PRODUCTIVE DEPTH (m)		APPROXIMATE NUMBER OF CRABS		Ave. SIZE	NETS PER SET	No. SETS	TIME OF RETURN TO PORT	CATCH SOLD TO	COMMENTS
			a	b	c	from	to	KEPT	DISCARDED						
0,1															
0,2															
0,3															
0,4															
0,5															
0,6															
0,7															
0,8															
0,9															
1,0															
1,1															
1,2															
1,3															
1,4															
1,5															
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2,3															
2,4															
2,5															
2,6															
2,7															
2,8															
2,9															
3,0															
3,1															

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APPENDIX 2

Tabulated analysis of monthly commercial logbook data. Tables such as this contain information specific to individual fishermen as well as total "fleet" data, and were periodically distributed to each particular contributor.

EXAMPLE ANALYSIS

ANALYSIS OF SPANNER CRAB LOGBOOK DATA

I/d CODE: 99 FOR AUGUST 83

NUMBER OF RETURNS THIS MONTH ***** 5

STATISTIC	FLEET TOT	FLEET AVE	YOUR TOT	% OF FLEET	% DIFF
FISHING SP-CR	39	7.8	8.0	20.5	2.6
FISHING OTHER	4	0.8	2.0	50.0	150.0
BAD WEATHER	40	8.0	7.0	17.5	-12.5
MAINTENANCE	0	0.0	0.0	0.0	0.0
LAY-DAY OTHER	6	1.2	5.0	83.3	316.7
UNSPECIFIED	66	13.2	9.0	13.6	-31.8
No. DROPS	3532	706.4	842.0	23.8	19.2
# KEEPERS	18060	3612.0	3963.0	21.9	9.7
# DISCARDS	14201	2840.2	2650.0	18.7	-6.7
TOTAL CRABS	32261	6452.2	6613.0	20.5	2.5
CPUE KEEPERS	****	5.1	4.7	****	-7.8
CPUE SMALLS	****	4.0	3.1	****	-22.5
CPUE ALL	****	9.1	7.9	****	-13.2

****** NOTE: THIS IS A HYPOTHETICAL EXAMPLE- PLEASE REFER TO THE BULLETIN FOR EXPLANATION.

APPENDIX 3

Monthly catch, effort and CPUE data tabulated by fishing block. This table is typical of those circulated to fishermen participating in the voluntary logbook programme.

AUGUST 1984

BLOCK	DROPS	KEEPERS	DISCARDS	TOTAL SP/CR	CPUE1	CPUE2	CPUE3
0901	102	135	32	167	1.3	0.3	1.6
1001	102	135	32	167	1.3	0.3	1.6
1101	473	2080	950	3030	4.4	2.0	6.4
1102	346	1590	600	2190	4.6	1.7	6.3
1202	1188	4010	2667	6677	3.4	2.2	5.6
1203	874	4670	5420	10090	5.3	6.2	11.5
1302	1600	6400	9650	16050	4.0	6.0	10.0
1303	668	2335	3155	5490	3.5	4.7	8.2
1402	455	1305	5500	6805	2.9	12.1	15.0
1403	2249	8790	9395	18185	3.9	4.2	8.1
1603	120	300	300	600	2.5	2.5	5.0

NOTE: CPUE1 = Catch-per-unit-effort (catch rate) of KEEPERS
CPUE2 = Catch-per-unit-effort (catch rate) of DISCARDS
CPUE3 = Catch-per-unit-effort (catch rate) of ALL CRABS

DROPS = TOTAL number of drops (sum of nets per set x sets)

Data compiled from printout of program BLOKCPUE.BAS run 23.10.84.

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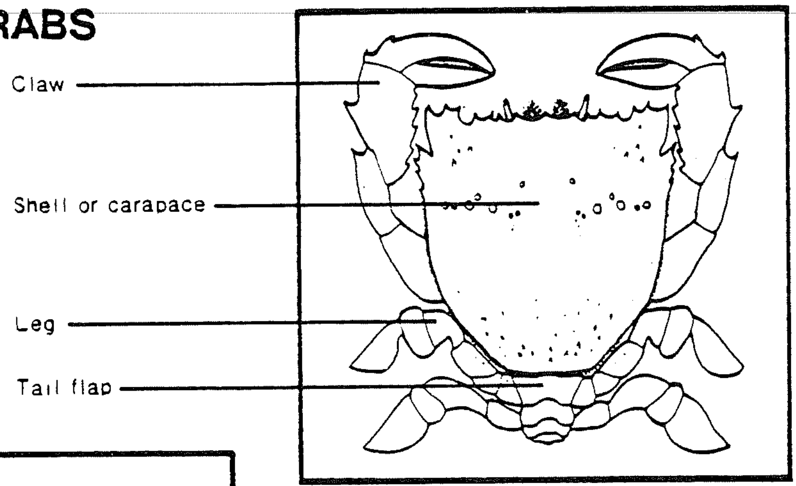
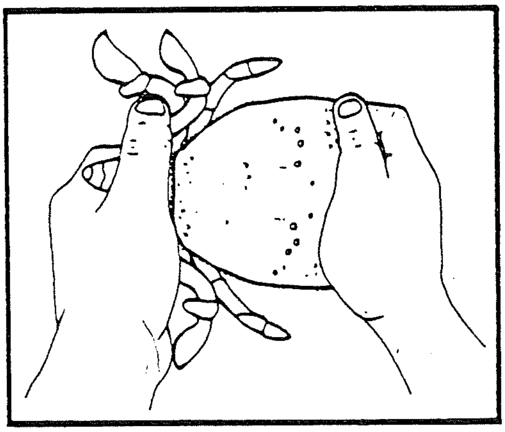
APPENDIX 4 (opposite)

Promotional leaflet produced by Project staff in collaboration with spanner crab fishermen A. McMullen and D. Jones, for general distribution to processors, dealers and seafood consumers.

COOKING with the D.P.I.

EXTRACTION OF MEAT FROM COOKED SPANNER CRABS





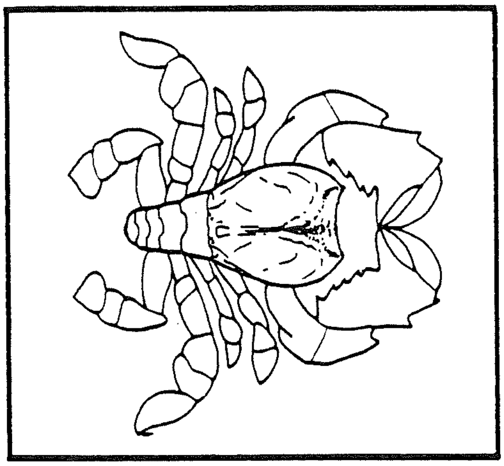
STEP 1: REMOVAL OF SHELL

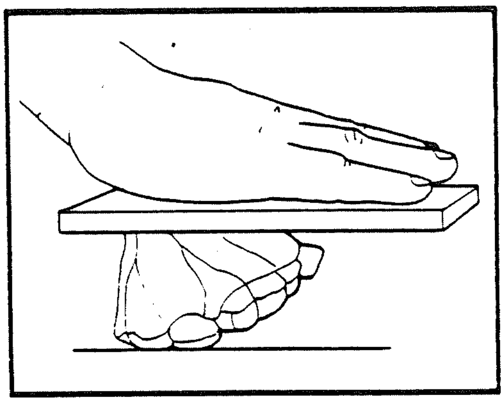
a) Lay crab in palm of left hand with thumb over tail flap.

b) Grasp front part of shell with right hand and twist until shell separates from body.

STEP 2: CLEANING

Remove gills and wash body to remove viscera.





STEP 3:

Remove legs and claws and lightly crush body using downward pressure with palm of the hand or a cutting board.

STEP 4:

Separate meat from membranous internal skeleton, crack claws and remove meat.

SPANNER CRAB STUFFED FISH (Serves 6-8)

INGREDIENTS:

3 tblspn butter
3 tblspn plain flour
1½ cups milk
1/3 cup sherry
Salt
1 cup grated Swiss cheese
1 kg fish fillets
1 medium onion (minced)
200 gm spanner crab meat
3 chopped mushrooms
½ cup cracker biscuit crumbs
Parsley

METHOD:

1. Melt butter in saucepan and carefully blend in flour. Gradually add milk, sherry and salt. Cook over low heat until thick, then add cheese and set aside.
2. Cut fish fillets into serving-size pieces and sprinkle with salt and pepper.
3. Cook onion in a small amount of butter, then add crab meat, mushrooms and biscuit crumbs. Mix well.
4. Spread crab meat mixture evenly over each piece of fish. Roll up and secure with a wooden toothpick. Place in baking dish with seam side down.
5. Cover with foil and cook until fish is tender. Transfer rolled fillets to a serving dish and cover with the cheese sauce. Return to oven to heat through. Sprinkle with parsley and serve.

SPANNER CRAB AND SWEET CORN SOUP (Serves 6)

INGREDIENTS:

6 cups chicken stock
1 cup spanner crab meat
1 cup cream style corn
½ tsp salt
½ tsp oil
1 tblsp dry sherry
½ cup finely chopped shallots
2 beaten eggs
1 tblsp cornflour
½ tsp sesame oil

METHOD: Place stock in a large saucepan and bring to the boil. Add crab meat, corn, blended cornflour, sherry, salt and oils and simmer for approximately 3 minutes. Remove from heat and slowly add egg to form egg flower. Sprinkle with shallots. Serve hot.

SPANNER CRAB AND AVOCADO COCKTAIL

INGREDIENTS:

2 ripe avocados
1 cup spanner crab meat
2 tsp sherry
1 cup mayonnaise
Salt and pepper

METHOD:

1. Cut avocados in half lengthwise and remove seeds.
2. Mix crab meat, sherry, mayonnaise, salt and pepper.
3. Place in avocado halves and chill well before serving.

SPANNER CRAB CASSEROLE (Serves 6-8)

INGREDIENTS:

1 x 440 gm tin condensed cream of mushroom soup
½ kg spanner crab meat
½ cup coarsely chopped walnuts
1 tin water chestnuts, drained and sliced (optional)
½ cup finely chopped onion
1 cup sliced celery
1 tsp Worcestershire sauce
¼ tsp Tabasco sauce
4-6 small mushrooms, cleaned and sliced
1 pkt cooked noodles
1 cup Cornflake crumbs

METHOD:

1. Place in a 2 litre casserole dish, soup, crab meat, walnuts, chestnuts, onion, celery, sauces and mushrooms.
2. Stir in noodles and spread evenly in dish. Cover with Cornflake crumbs.
3. Bake at 180°C for 30 minutes.