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BRACKISH WATER FISH

CULTURE RESEARCH STATION

CLARENCE RIVER PRAWN FARMING PROGRAMME

FINAL REPORT

Greg B. Maguire Geoff Allan

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Department of Agriculture New South Wales

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C O N T E N T S

C H A P T E R 1

Progress on major programme objectives and implications for the N.S.W. prawn farming industry

The aims of this section of the final report are to provide an overview of the objectives of the programme, to assess progress on these objectives and to discuss the implications for the N.S.W. prawn farming industry which has emerged during and partly as a result of this project. The detailed descriptions of methodology and results are presented in the accompanying and complementary second National Prawn Seminar (NPS2) paper.

The project was largely carried out at a field site adjoining Lake Wooloweyah, a part of the Clarence River system near Brooms Head in northern N.S.W. The land and pond were provided by a private farmer, Mr. Max Carson, without whose help and foresight this project may never have been initiated. His staff, Mr. Tony Massingham and Mr. Gordon Eggins, also made most valuable contributions to the project. Support for the programme was also provided by management and staff at the Brackish Water Fish Culture Research Station at Port Stephens. In particular, Mr. Bob Martin, Mr. Bill Bennett, Mr. Bob Litchfield, Mr. Steve Hopkins and Mr. Wayne Wallace provided invaluable assistance with technical problems and with stocking and harvesting operations.

The research programme was largely comprised of farming trials in a 1 ha prawn farming pond and in swimming pools on the pond bank at the field site. Juvenile school prawns (Metapenaeus macleayi) were collected by commercial trawlers in Lake Wooloweyah, transported by punt to the pond where they were stocked and farmed for 2 to 3 months before harvest and marketing at the Sydney Fish Market.

The first objective of the project was to establish a functional prawn farm which entailed the following facilities:

* A 1 ha excavated earthen pond
* Pond drainage and overflow systems with screens
* Weatherproof road beside the pond
* Fencing around the pond to exclude cattle
* Electricity and water supply
* 2 pumping systems for filling and final emptying of the pond
* 2 paddle wheel aerators
* Caravan accommodation
* A water quality laboratory
* A feed storage area with shed
* Prawn cleaning and cooking area with facilities

* Boat wharf
* Punt with stocking, sampling and harvesting equipment
* Bird deterrant equipment
* An experimental area with a set of 16 swimming pools with aeration, water supply and drainage systems.

The site proved to be a logistically difficult one and some delays were experienced before all these facilities operated reliably.

The remaining objectives related to the actual operation of these facilities.

For several reasons it was decided that a pilot-scale study should be conducted in a 1 ha pond in the Clarence River area.

* Production data was required from a larger scale system than small experimental units so that realistic economic analyses could be carried out.
* It was necessary to see if the promising growth rates already obtained could be achieved in larger ponds.
* When trials had been carried out in whole ponds at Salamander Bay, survival rates had often been disappointing. It was hoped that locating the pilot-scale pond closer to a convenience source of juveniles would reduce handling stress and improve overall survival rates in ponds.
* The Salamander Bay ponds receive abundant tidal water exchange but commercial ponds are more likely to rely on pumping for water exchange. It was considered necessary to obtain experience in managing non-tidal ponds where water exchange is usually carefully controlled to reduce costs.
* Finally, if an extension service was to be provided to farmers it is clearly necessary to have first hand experience with the range of problems which farmers are likely to experience e.g., predator control.

The prawn production results were used as the basis for an independent economic analysis of school prawn farming. The first version of this analysis is discussed in the accompanying NPS2 paper and a revised version presented at the N.S.W.

Department of Agriculture Prawn Farming Open Day (a compilation of the papers delivered at this Open Day is attached). Both versions predicted attractive returns on capital but it should be noted that the extrapolation from pilot scale to commercial scale must necessarily be in part hypothetical until it is supported by consistent commercial success.

The growth rates obtained in the pilot-scale pond were somewhat disappointing in comparison to those obtained on a smaller scale at Port Stephens. More promising growth rates have at times been obtained in the commercial ponds beside the Clarence River near Yamba. The pilot-scale results may have been influenced by progressive deterioration (chemical reduction) of the pond bottom sediment. The pond bottom was difficult to manage because of the increasingly deep silt layer which developed within the pond. Despite the sub-optimal growth rates, overall prawn production was approximately 900 kg per ha for each pilot-scale pond trail and the product generally fetched excellent prices.

The survival rates obtained in the Clarence River pilot trials were often better than those recorded in whole pond trials at Port Stephens. Regardless of these successes considerable doubt must be expressed about the suitability of collecting juvenile school prawns from the Clarence River. Survival rates in commercial ponds have not usually been as high and while this may be in part attributable to insufficient pond management experience, initial post-stocking mortality is probably a major factor. The experimental pools were more convenient for observing mortality than was the pilot pond and mortality could continue for up to a week after stocking. These losses were presumably due to stress experienced during capture and stocking despite careful handling. When stocking large commercial ponds it is usually necessary to simplify handling procedures and hence the risk of post-stocking mortality increases. Collection of wild juveniles has enabled scientists and commercial farmers to readily obtain farming experience but it is likely that reliable commercial operations will usually be based on a hatchery-reared supply of juveniles. Major constraints with stocking from the wild are posed by the fluctuations in supply and price of juveniles from estuarine fisheries. The move towards hatcheries will also allow diversification into the use of larger penaeid prawns (eastern king prawns <u>Penaeus plebejus</u> and Australian tiger prawns <u>Penaeus esculentus</u>). These larger species would be acceptable on the export market and their use would reduce the risk of the emerging prawn farming industry oversupplying the domestic market.

While problems were experienced with pond sediment condition, it proved to be reasonably easy to monitor the algal bloom which was maintained within the pilot pond. These blooms sustained dissolved oxygen levels and accumulation of dissolved nitrogenous wastes was rarely a problem while a bloom was active. This experience suggests that large amounts of water exchange are probably unnecessary unless stocking densities are very high. This conclusion was supported by the results of water exchange rate experiments in the experimental pools at the field site. Overall this augers well for the cost efficient operation of commercial ponds which would not usually be located at sites affording generous tidal exchange in the ponds. The water quality component of the project is considered in greater detail in Chapter 2 of this final report.

The pilot scale trials did allow Departmental staff to obtain pond management experience which has proved to be most useful in extension work with existing and prospective prawn farmers. The Prawn Farming Open Day held at Wollongbar Agricultural Research Station provided an opportunity to present results of this project to a diverse group of people interested in prawn farming. A main problem which had been anticipated was predation by diving birds, specifically by several species of cormorants (Phalacrocorax sp). The devices tested so far, e.g., the gas-powered scare guns and high-frequency (ultrasonic) deterrant systems have not proved to be totally effective, however, it is hoped that further development especially with the ultrasonic device will be successful. Certainly persistent predation by large numbers of cormorants would make prawn farming unprofitable especially in larger ponds where the birds can fish undetected. The experience obtained during the pilot scale trials tended to confirm the belief that emergency aeration is an integral part of sound pond management.

The industry that has emerged is quite large with approximately 130 ha of ponds in various stages of construction. Additional requests for prawn farming permits are being received and more pond construction is imminent. The future prospects for the industry will depend on sound management, high product quality and adequate returns on capital and also on the acquisition of suitable land which is not affected by potentially harmful contamination, e.g., by agricultural pesticides, and which is not in environmentally sensitive areas. The supply of hatchery reared juveniles will expedite the development of a prawn farming industry.

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CHAPTER 2

Development of methods for growing juvenile school prawns, *Metapenaeus macleayi*, in estuarine ponds

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Development of methods for growing juvenile school prawns, *Metapenaeus macleayi*, in estuarine ponds

Abstract: Research using small scale experimental systems has identified the optimum conditions for growing school prawns, *Metapenaeus macleayi*, in terms of a wide range of environmental, nutritional and pond management variables. These include temperature, salinity, substrate, dietary protein and mineral levels, supplementary feed type and feed rate, stocking density, effects of predators and competitors, water exchange rate, polyculture and product quality. A pilot scale (1 ha) farming program provided prawn production data (825-930 kg ha^{-1} harvested from each two to three month trial) which supported some of the assumptions made in a favourable economic analysis of school prawn farming (up to 27% annual return on capital). These pilot scale trials also provided information on water quality management in non-tidal ponds and on other aspects of pond management, eg predator control. The school prawn farming industry in northern New South Wales has grown to the point where approximately 130 ha of large (3 to 9ha) ponds have been completed or are under construction. Future research and developments in commercial prawn farming technology will probably be directed towards improving supplementary diets, improving pond water and sediment quality management, and enhancing natural food levels within ponds. In addition, estuarine juvenile stocks will tend to be replaced by hatchery reared juveniles for pond stocking purposes. Diversification into the farming of larger penaeid species, eg eastern king prawns, *Penaeus plebejus*, is also likely to occur.

Introduction

The school prawn, *Metapenaeus macleayi*, is endemic to temperate, east coast Australian waters with a geographical range extending from Tin Can Bay, Queensland, to Corner Inlet, Victoria (Fig. 1). This species has a typical penaeid life cycle with an estuarine nursery phase followed by migration to oceanic waters where mating, spawning and larval development take place (Ruello 1973a). According to Ruello (1977) there are large populations of school prawns associated with five New South Wales (NSW) estuaries (Fig. 1) as evidenced by average annual commercial catches in each estuary exceeding 40t. Electrophoretic studies indicated that NSW school prawn populations south of and including the Clarence River are genetically homogeneous (Mulley and Latter 1981). However, the Clarence River, which supports the state's largest school prawn fishery, produces school prawns which are usually smaller than those from other estuaries and as a result fetch only a relatively low market price (Glaister 1976).

The Fisheries Division, NSW Department of Agriculture (formerly NSW State Fisheries) considered that the Clarence River would be a convenient source of juvenile school prawns for aquaculture, at least for pilot studies. A research program was initiated to develop a technology for growing school prawns in estuarine ponds. The initial studies were carried out in small scale experimental systems at the Brackish Water Fish Culture Research Station at Port Stephens and were aimed at optimising environmental, nutritional and pond management variables. Subsequently these results were applied in a series of farming trials in a 1 ha pilot scale farming pond adjacent to the Clarence River.

The major aim of this paper is to present an overview of this research program and the future prospects for the NSW prawn farming industry. Rather than presenting the large

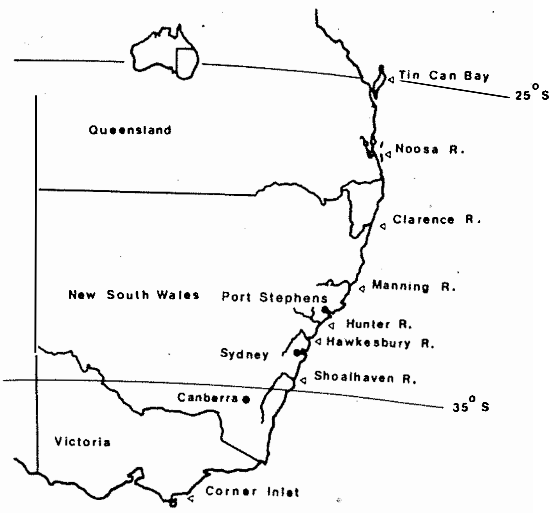

Figure 1. The geographic range of the school prawn, *Metapenaeus macleayi*, and the locations of Port Stephens and the river systems which support substantial school prawn fisheries.

amount of growth, water quality and specific methodological data arising from numerous small scale experiments, it was considered preferable to describe and evaluate these experimental systems and to provide a comprehensive summary of the major conclusions. Priority has been given to a detailed presentation and discussion of the pond management methods, growth, survival and production results, and the economic analysis pertaining to the pilot scale Clarence River farming trials.

Materials and methods

Port Stephens facilities

The experiments carried out in the aquaria, pen and pond (0.01 and 0.1 ha) systems were conducted at the Brackish Water Fish Culture Research Station at Port Stephens (32° 45′ S, 152° 04′ E). The prawns stocked into these various experimental systems were collected by otter trawling in the Port Stephens, Hunter River and Clarence River estuaries. While being transported from fishing grounds to the research station, prawns were held in a multilayered system of timber and 1.5 mm plastic flyscreen trays (0.9 m x 0.45 m x 0.05 m) immersed within 400 l, continuously aerated tanks. For lengthy road transport, the trays were placed in a 2000 l insulated tank with continuous aeration and water recirculation.

Aquarium experiments

Clear perspex 60 l aquaria were used for experiments on salinity, temperature, substrate and nutritional requirements. Each aerated aquarium usually contained a 25 mm deep layer of coarse beach sand and a plastic subsurface biofilter plate covering most of the aquarium floor area. The water temperature and salinity levels were usually in the ranges 24 to 26° C and 28 to 36‰. Fluorescent light tubes illuminated the aquaria (4.2 micro Einsteins m^{-2} s^{-1} at sand surface level) for the diurnal light: dark cycle of 12:12 h in a room without natural light. The water exchange rate was usually at least 60 l day^{-1} with sand or diatomaceous earth filtered seawater. Each aquarium was stocked with 10 juvenile prawns (1 to 5g) individually tagged with saturn yellow fluorescent pigment in petroleum jelly injected into the musculature of one abdominal segment (Klima 1965). Freshly shucked beach pipi meat (*Plebidonax deltoides*) was fed daily to slight excess shortly before the onset of the dark period. Initial and final prawn weights were obtained by weighing all prawns individually.

Pen experiments

Steel framed pens with netting walls (2.5 mm or 6 mm mesh) were positioned in 0.1 ha ponds so that they enclosed 3.3 m^2 of pond bottom and gave the prawns (usually 15 to 20 juveniles m^{-2}) access to natural benthic food items. Prior to each experiment, ponds were usually fertilised with 50kg ha^{-1} of urea ($N:P_2O_5:K$ ratio of 46:0:0) or nitram (ammonium nitrate 34:0:0) as a source of nitrogen and 20kg ha^{-1} of superphosphate (single superphosphate 0:21:0) as a source of phosphorus. After fertilisation ponds received no water exchange until the pens were stocked. A restricted tidal water exchange regime ensured that the flyscreen lids of the pens were not regularly submerged. Pens were continuously aerated. A more detailed description of the pens and the colonising macrofauna is given by Maguire (1980) and Maguire and Bell (1981). Initial and final average prawn weights were determined by weighing in bulk all prawns for each pen (sexes separate).

Pond experiments

The 0.01 ha round ponds used in the earliest experiments have been described by Maguire (1980). Water exchange in these non-tidal, continuously aerated ponds was achieved by pumping. Three whole-pond experiments (Maguire 1980) were also conducted in fertilised 0.1 ha square ponds. The continuous aeration system, tidal water exchange patterns, biota and sediment temperature and salinity characteristics for these ponds have been described by Maguire and Bell (1982) and Maguire et al (1981, 1984). The diets used in the pen and pond trials were usually either pelleted poultry diets eg chicken broiler grower diets (20 to 25% protein) or pelleted trout diets (35 to 40% protein). The feed rate was usually 5% of the estimated daily biomass reduced to 2.5% by the end of each trial. Some experimental water-stable prawn diets varying in dietary protein or mineral levels (see Maguire and Hume 1982 for composition) or pipi meat were used in pen experiments. Prawns which died due to stress during capture or handling were replaced in the aquaria, pens and 0.01 ha pond experiments.

Clarence River facilities

Pool experiments and pilot scale prawn farming trials were conducted using a 1 ha pond adjoining the southern shoreline of Lake Wooloweyah, a shallow (usually <1 m deep) lagoon near the mouth of the Clarence River in northern NSW (29° 31′ S, 153° 17′ E).

Pool experiments

A total of 16 steel swimming pools with plastic liners (3.4 m diameter x 0.9 m) were positioned on two banks of the 1 ha pilot scale pond. The pools contained an 80 mm deep sand layer and water from Lake Wooloweyah was supplied to the pools via the main seawater supply line to the pond. The pools were continually aerated and two water exchange rate experiments (Table 1) were conducted. The rates were 0 to 80% of pool volume exchanged every second day by partial drainage and refilling (0 to 40% day^{-1}) and 0 to 60% every third day (0 to 20% day^{-1}). Stocking, feeding, initial fertilisation and water quality monitoring were similar to those used in pond trials, although uneaten food could be more readily observed in the pools, and feeding rates adjusted accordingly. The extent of initial mortality was estimated in each pool and extra prawns were stocked as required. Initial and final biomass values were obtained by weighing in bulk all prawns stocked into each pool (sexes separate).

Pilot scale pond

Four farming trials were conducted in a 1 ha pond (200 m x 50 m x 1 m deep) oriented north to south to maximise circulation and aeration by prevailing winds. The flood-proof walls were constructed of densely compacted silt containing calcareous bivalve shell deposits. A centrifugal pump drew water through a PVC pipeline from below the lake surface level but above lake bottom level to minimise the intake of silt and dilute seawater after heavy rain. Incoming water was sprayed over the pond water surface to improve aeration. The pond could be filled in 20 h. Water exchange usually involved the pumping in of water and passive overflow from the pond through a 1 m wide concrete raceway at the opposite end of the pond. Where possible water was pumped in only when lake water turbidity levels were low. Despite these precautions an increasingly deep layer of silt developed over most of the pond bottom. This layer (0 to 100 mm deep) may have resulted in part from a loosening of pond bottom soil due to immersion and netting activites.

Juvenile school prawns otter trawled by professional fishermen in Lake Wooloweyah were quickly sorted from live fish, jellyfish, bivalve shells and filamentous algae and then loaded into trays before being transported directly by punt to the pond. Each bound stack of wooden trays was drained and weighed with and without prawns to estimate the total weight of prawns stocked taking into account residual water within the stacks. Stocking activities were suspended if excessive muscle necrosis (Lakshmi et al 1978) was observed. This usually happened only if lake water temperatures or wave action were excessive. Initial mortality was difficult to estimate because of high pond turbidity levels. Estimates of the total weight of prawns stocked in each trial (Table 2) have been reduced by the relatively minor number of prawns which were actually moribund at time of stocking, but not by the subsequent initial mortality. The estimated optimum stocking density (20 juveniles m^{-2}) for school prawns in ponds (Maguire and Leedow 1983) was used as a guide. Stocking densities for pilot trials 1, 2 and 4 ranged from 17.4 to 21.3 juveniles m^{-2} but an unexpectedly large component of very small juveniles (an estimated 49.4% of prawns stocked weighed $\leq$1 g) made accurate stocking difficult for trial 3 and swelled the estimated initial density to 27 juveniles m^{-2} (Table 2). Stocking operations were usually completed within two to four days but in trial 4, prawns were stocked on two occasions two weeks apart.

In trials 1 and 2 and the second phase of the trial 4 stocking, initial prawn samples for average prawn weight and sex ratio determinations were taken directly from the stocking trays. Similarly samples from tubs of harvested prawns were taken prior to cooking to estimate these parameters for trials 1 and 2. All other initial, final and intervening samples for prawn size and sex ratio estimates were taken with a 1.8 m beam net (10 mm mesh) towed by punt through the pond the day after stocking was completed, the day prior to harvest and at intervening biweekly periods. A correction factor was determined to take account of weight losses caused by frozen storage of some of the prawn samples prior to weighing. Daily feed rates were initially set at 5% of biomass reducing by 0.5% decrements every two weeks to 2.5% of biomass. For the purpose of biomass and feeding rate estimations high overall survival rates (approximately 70%) were assumed. The feed was spread evenly over the pond at dusk. A pelleted trout diet (Allied Feeds) was used in pilot trials 2 and 3, and pelleted poultry diets were used in trials 1 (Steggles) and 4 (Supastok Products). This last diet had been modified by the inclusion of a water-stable binder. Feeding was suspended for up to three days prior to harvest to minimise the risk of discoloration of prawn heads caused by the use of these artificial diets.

The pond was harvested using a hand drawn seine net approximately 70 m long (23 mm mesh) with a 10 m centre pocket (17 mm mesh). Prawns were usually held alive in aerated seawater to remove silt particles which adhered to exoskeletons and gills, drained, weighed, cooked in a commercial gas prawn cooker, cooled, stored with ice and salt and transported by road to rail to the Sydney Fish Market for sale as 'cultured prawns'.

Prior to each stocking the 1 ha pond was fertilised to increase natural food levels by stimulating an algal bloom and hence increasing benthic detrital deposits. The fertiliser inputs were 100 kg ha^{-1} each of superphosphate and nitram for trial 1, 1 500 kg ha^{-1} dry cow manure spread out over the dry pond bottom for trial 2, and 700 kg ha^{-1} and 1 100 kg ha^{-1} of fresh, wet cow manure in trials 3 and 4 respectively. The wet manure was mixed into a slurry with water and pumped evenly over the pond water surface. Chemical fertilisers were largely dissolved before being dispersed in pond water during pond water exchanges.

Subsequent additions of fertilisers were used in each trial to maintain an algal bloom so that dissolved oxygen (DO) levels could be maintained and levels of dissolved nitrogenous wastes (ammonia and nitrite) minimised. Only one additional input of fertiliser was required in both trials 1 and 2 (25 kg ha^{-1} of superphosphate and 100 kg ha^{-1} of wet cow manure respectively). In trials 3 and 4 fertiliser input was needed at approximately biweekly intervals. The trial 3 inputs were 25 kg ha^{-1} each of superphosphate and nitram or 60 kg ha^{-1} wet cow manure and for trial 4 they were 10 to 25 kg ha^{-1} each of superphosphate and nitram. Indicators of decreasing algal levels were the small diurnal variations in DO levels, low morning DO readings ($<$4.0 mg l^{-1}) or a decline in afternoon pH values over several days despite sunny weather.

Pond water exchange was used to replace minor evaporative losses, provide circulation and aeration and to dilute excessively dense algal blooms (afternoon DO levels $>$15 mg l^{-1} and pH levels $>$9.0). Water exchange during the first four weeks of trial 1 was minimal, but DO levels were adequate (range 4.0 to 11.4 mg l^{-1}) and unionised ammonia levels were low ($\leq$ 0.17 mg NH_3-N l^{-1}) relative to those considered by Wickins (1976) to be lethal to penaeid prawns (1.29 mg NH_3-N l^{-1}). However when stressed or dead prawns were noticed at the pond edges or in the biweekly prawn samples a deleterious algal bloom was suspected and daily water exchange rate was increased to 6 to 60% ($\bar{x}$ = 23%) of pond volume. To avoid a recurrence of this situation in trials 2 to 4, a more liberal routine water exchange regime of 6 to 16% day^{-1} (usually $<$10%) was used. Pumping took place every second or third day so that an 8% day^{-1} regime could involve the pumping of 24% of pond volume every three days.

Two floating paddle wheel aerators powered by electric motors were moored in the pond. As a precaution against overnight dissolved oxygen crisis, these aerators were run on a timeclock for 4 to 10 hours during the night and early morning period when low DO levels were most likely to occur. The paddle wheels were also used if low DO levels ($<$4.5 mg l^{-1}) occurred at other times, to alleviate DO stratification on still days during trial 4 and to help distribute dissolved fertilisers. This stratification was probably caused by high turbidity near the silt laden pond bottom.

Cormorants (*Phalacrocorax* spp.) were common during trial 1 but did not prey upon prawns in the pond. However during trials 2 and

3, five to ten cormorants were often chased from the pond each day. A gas scare gun which regularly produced two very loud consecutive discharges was largely ineffective in deterring these birds. They could be chased away by shotgun volleys aimed near them but this was labour intensive and aesthetically undesirable. A high frequency 'Electronic scarecrow' deterrent system (Hi-Tec Control Systems) was installed during trial 3 but technical problems prevented regular operation of the unit until trial 4 during which cormorants were uncommon.

Water quality sampling was carried out regularly using calibrated recording instruments for temperature, salinity, DO, pH and total ammonia. The standard calibration techniques used are described by Strickland and Parsons (1968), American Public Health Association (1971) and Dal Pont et al (1973). Nitrite and nitrate were measured using the spectrophotometric method (Major et al 1972). Temperature and DO were measured either continuously or early morning, noon and late afternoon, salinity after water exchange or rainfall, pH in the late afternoon, total ammonia and nitrite were sampled every one to three days and nitrate recorded at least weekly. The statistical analyses usually applied to experimental results from at least three replicates involved ANOVA techniques to assess overall treatment effects and the least significant difference (LSD) method to compare individual treatments (Steel and Torrie 1960).

Results

Port Stephens research

The results of the small scale experiments at Port Stephens are summarised in Table 1. The aquarium experiments showed that school prawn growth rates are favoured by water temperatures in the range 21 to 27° C and by high salinity levels ($\geq$ 25‰) but are not affected by the type of substrate.

A wide range of conclusions can be drawn from trials in pens and whole ponds. For stocking densities up to the estimated optimum of 20 juveniles m^{-2}, inexpensive poultry diets are adequate but more nutritionally adequate diets, eg pipi meat, are advantageous if higher stocking densities are used (38 juveniles m^{-2}). Furthermore, prawn growth rates in ponds can be affected by dietary protein and mineral levels and by supplementary feed rates. The optimum levels are 25 to 30% and $\leq$ 0.5% of the diet on a dry weight basis for dietary protein and calcium levels respectively and 5% of prawn biomass as dry feed for the supplementary feed rate.

A wide variety of animals inhabit prawn farming ponds and some can be harmful to the prawns as predators or as competitors for food, eg cormorants, eels, yellowfin bream and tarwhine. Benthic macrofauna can be abundant in ponds but do not appear to be as important as detritus as a natural food source for school prawns. Sydney rock oysters which do recruit naturally to the 0.1 ha ponds at Port Stephens were grown with school prawns in polyculture trials in these ponds. The oysters did not exhibit good shell growth or survival rates (Table 1).

Clarence River pilot scale pond trials

Production results

Prawn production results from the pilot scale pond trials are presented in Table 2. The total weight of prawns stocked in each trial (range 370 to 617, $\bar{x}$=489kg ha^{-1}) varied depending on initial average prawn weight (1.5 to 3.2, $\bar{x}$=2.4g) and to a lesser extent on stocking density (17.4 to 27.0, $\bar{x}$=21.4 juveniles m^{-2}). The total weight of prawns harvested was relatively constant (825 to 950, $\bar{x}$=870kg ha^{-1}) although the average prawn weight at harvest (5.4 to 7.6, $\bar{x}$=6.6g) and the survival rate (52.1 to 71.3, $\bar{x}$=63.2%) varied considerably among trails. The average prawn size at harvest tended to increase with initial prawn size but there were no clear relationships between survival rate and initial or final prawn size.

Growth rates recorded in each pilot scale pond trial were relatively uniform except for weeks 0 to 2 in trial 1 and weeks 2 to 6 in trial 4 when rapid growth rates were evident (Fig.2). Overall weekly growth rates for the four trials were 0.40, 0.49 and 0.45g for males, females and all prawns (sexes pooled), respectively. The biweekly prawn sampling results show that growth continued throughout each of the trials and there were no indications that a growth plateau had been reached (Fig.2). Size frequency analyses showed that both initial and final prawn sizes within each trial were quite variable. There was some general tendency for the initial distributions to change from an asymmetrical type with the smaller size classes constrained by zero to a bilaterally symmetrical distribution at harvest. Size variation among prawns harvested from each trial was most acceptable to buyers at the Sydney Fish Markets with the exception of those from trial 3.

Table 1. Summary of the effects of environmental, nutritional and pond management variables on the growth, survival and pond production rates for school prawns, *Metapenaeus macleayi*. Experiments were conducted in A aquaria, B 0.1 ha Port Stephens ponds, C Clarence River pond and pools, D pens, E pools, F Clarence River pond and G 0.01 ha Port Stephens ponds. All feed composition data are expressed on a dry weight basis.

Variable and results		Comment and reference
Temperature		
*Food consumption rate increased with temperature in range 15 to 27°C. Optimum temperature for growth was 21 to 27°C. Growth rates were depressed at 18 and 30°C and very slow at 15°C. Survival rate was unaffected by temperature in the range 15 to 30°C.	A	Prawns were obtained from pond at 18°C and acclimated gradually using 3°C changes every three to five days.[1]
Survival was unaffected by extreme pond temperature readings of 6 to 32°C.	B	
Salinity		
*Within an experimental range of 10-30‰, growth and survival rates increased as salinity increased from 10-25‰.	A	Prawns were obtained from pond at 28‰ and acclimated gradually using 5‰ changes every 2 days.[1]
*Growth rates at 30 to 33‰ were better than at 15 to 18‰.	G	Survival rates were highly variable but not inversely related to growth rates in this trial.[2]
High growth and survival rates were recorded during six weeks when pond salinity was approximately 36 to 38‰.	D	[2]
Slow growth rates but high survival rates obtained despite a pond salinity of approximately 5‰ for 12 weeks.	C	[1]
Substrate *Substrate type had little consistent effect on growth and survival rates.	A	Bare perspex, mud and fine and coarse sands were tested.[3]
	G	Fine to medium sand and concrete tested.[2]
Dissolved oxygen		
Survival was unaffected by extreme pond bottom dissolved oxygen readings of 3.2 to 18.9mg l^{-1}.	F	[3]
pH		
Survival was unaffected by extreme pool water pH reading of 9.4.	C	Rapid growth (0.8g $week^{-1}$ increase in mean prawn weight) over 4 weeks in pond with high pH levels (Average = 8.7, range = 8.1-9.1).[3]
Natural food levvels		
Gut contents predominantly composed of pelleted artificial diet. Detritus is the major natural food item with macrofauna being less important. *Covariance analyses indicate that sediment organic content may be a useful index of natural food levels.	B	[4 5 6]
Supplementary diets		
*Pelleted chicken broiler diets (20 to 25% protein) adequate at a density of 15 juveniles m^{-2}.	B,D	[2 7 8]
*Chicken broiler finisher pellets (20 to 22% protein) inferior to trout pellets (38% protein) and pipi flesh (*Plebidonax deltoides*) at densities of 20 and 15 to 38 juveniles m^{-2}.	D	[1 5]
*Pipi flesh can sustain very high growth (0.9g increase in average prawn weight per week) and survival rates (80%) at elevated stocking densities (38 juveniles m^{-2})	D	Pipi flesh is intended only for use as a control diet in nutritional experiments. Growth data is from a five week experiment.[5]
Dietary protein		
*The optimum dietary protein level for supplementary diets was 25 to 30%.	D	Slow growth rates recorded during experiment.[7]
Dietary mineral levels		
*Growth rates decreased as dietary calcium levels in supplementary diets increased from 0.5 to 2.0% but were unaffected by dietary phosphorus levels from 0.5 to 2.0%.	D	No evidence of interactive effects of dietary calcium and phosphorus levels on prawn growth rates.[7]

Table 1. continued.

Variable and results		Comment and reference
Dietary binders *Incorporation of alginates as dietary binders or alternatively as encapsulation for a water-stable diet did not improve growth rates.	D,A	Further testing of the effects of physical stability of diet on pond sediment deterioration (chemical reduction) is required.[1] [7]
Effect of pipi *The growth promoting effects of pipi flesh in artificial diets are due to the lipid-free, water insoluble component.	A	This component is composed mostly of protein.[1]
Supplementary feed rate *The optimum daily feed rate using a pelleted trout diet was 5% of prawn biomass. The feed rate was reduced to 2.5% of biomass as biomass increased.	D	Overestimation of biomass levels can lead to overfeeding and sediment deterioration. The optimum feed rate is probably dependent on water temperature, natural food levels and on the type of supplementary diet.[1] [8]
Optimum water exchange rate *Water exchange rates (0 to 40% day^{-1}) had no effect on prawn growth or survival rates at a stocking density of 20 juveniles m^{-2}. At $50 m^{-2}$ and an experimental range of 0 to 20% day^{-1}, growth was unaffected but mass mortality occurred in one 0% exchange rate pool.	E	Slow growth rates recorded in the pool experiments. Prawn stress symptoms have been observed in pools and ponds after extended periods without water exchange.[3]
Fertiliser input Managing pond algal blooms by addition of fertilisers as required (eg 25 kg nitram and 25 kg superphosphate ha^{-1} at about two week intervals) allows ready management of dissolved oxygen, ammonia and nitrite levels.	C	At least two weeks prior to stocking intensive fertilisation (100 kg ha^{-1}). Up to 1 500 kg of cow manure (dry weight) ha^{-1} has been used. Fertiliser need can depend on site Aeration devices and avoidance of very dense algal blooms are desirable.[3] [5]
Stocking density *Growth rates are usually inversely related to survival rates. Optimum stocking density in terms of economic return estimated to be 20 juveniles m^{-2} using chicken broiler diets.	D	Optimum stocking density depends on the type of supplementary diet used and probably also on natural food levels.[5] [8]
Predators, competitors Cormorants are the most serious predators in ponds although eels (*Anguilla* spp.) can be troublesome. Sea mullet (*Mugil cephalus*), the most common fish in ponds, pose few problems. Yellowfin bream (*Acanthopagrus australis*) and tarwhine (*Rhabdosargus sarba*) are potential competitors for supplementary diets and the former is a potential predator.	B,C,D	Excessive numbers of sea mullet can interfere with harvesting operations. [1] [4] [9]
Polyculture *Sydney rock oysters improve meat condition rapidly in prawn farming ponds but are prone to mudworm (*Polydora* sp.) infections, high mortality, gill discoloration, overspatting and slow shell growth rates.	B	Sydney rock oysters (*Saccostrea commercialis*) were previously known as *Crassostrea commercialis.*[10]
Product quality *Taste panel studies and large scale marketing trials indicate that high product quality levels are attainable.	G,F	Mud adhesion to gills and exoskeleton can be a problem.[1] [11]

*Conclusions based on statistical comparisons between replicated treatments.

[1] Maguire and Allan (unpublished data) [2] Maguire (1980) [3] Allan and Maguire (unpubl. data)
[4] Maguire and Bell (1981) [5] Maguire (unpublished data) [6] Maguire et al (1984)
[7] Maguire and Hume (1982) [8] Maguire and Leedow (1983) [9] Maguire and Bell (1982)
[10] Maguire et al (1981) [11] McBride and Maguire (1979)

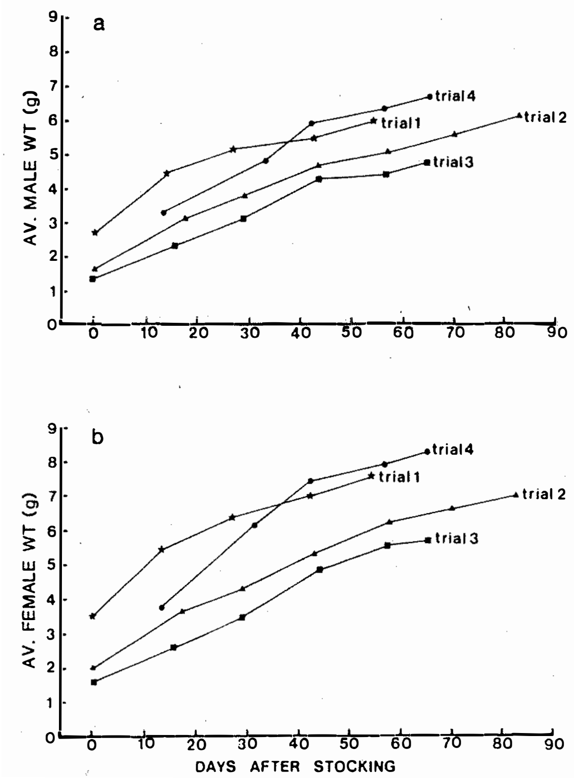

Figure 2. Growth of school prawns, *Metapenaeus macleayi*, **a.** male and **b.** female during four pilot scale (1 ha) Clarence River prawn farming trails. See Table 2 for SE values of initial and final weights.

The male and female size distributions for prawns harvested from this trial revealed that there were significant numbers of prawns of 3g or less and this adversely affected marketability.

Survival rates during the first two trials were relatively high (69 to 71%) despite the fact that prawn stress symptoms and mortality were observed in the latter part of trial 1 and that predation by cormorants was a problem in trial 2. The poorer survival rate in trial 3 (61%) may have been influenced by: (1) the difficulty of accurately assessing the true stocking density and hence survival rate because of the large number of small prawns stocked, (2) deterioration in pond sediment condition, ie chemical reduction, during the trial and (3) predation by cormorants and eels. There were approximately 100 eels ha^{-1} at harvest, mostly long-finned eels (*Anguilla reinhardtii*). The poorest survival rate (52%) occurred in trial 4 and the potential causes were: (1) further pond sediment deterioration, (2) abnormally high initial mortality (also observed in a concurrent pool trial) and (3) incidence of stress symptoms among prawns on several occasions during this trial. Biweekly sampling indicated continuing mortality during trial 4.

The average market price obtained for each crop varied widely (\$4.28 to 9.33, $\bar{x}$=\$6.67 kg^{-1}) and was not dictated solely by the average prawn size at harvest (Table 2). On two occasions the prawns were marketed at times when maximum prices for school prawns are usually obtained, ie in the one week periods prior to Christmas (trial 3) and Easter (trial 4). The trial 3 harvesting operation was complicated by retention of large amounts of silt in the harvest net and by high water temperatures. Most of the prawns were moribund by the time they were placed in the aerated seawater tank prior to cooking and the slightly muddy appearance of these prawns in combination with their relatively small and uneven size depressed their market value. Product quality was high for all other crops with the slight exception of the prawns from trial 2, which had some digestive gland discoloration after cooking which may have resulted from the trout diet used. The problem diminished in trial 2 after feeding with the trout diet was stopped and was not evident in trial 3 when the trout diet was replaced by the Supastok poultry diet for the last week of feeding. The prawns produced in trial 1 were a high quality product but were sold at a time when the market was oversupplied. Although their average market price (\$4.28 kg^{-1}) was low they did attract the highest prices for school prawns at the Sydney Fish Market on the day when most were sold.

Water quality

Water quality measurements taken during the four pilot scale pond trials are summarised in Table 3. The most variable water quality parameter among the four trials was salinity. This was usually >15‰ but declined rapidly during the last two weeks of trial 1 to 7.4‰ and remained low during all of trial 2 (4.4 to 7.1‰). Pond water temperature and DO results were characterised by progressive increases during daylight hours and the average diurnal variations were 2.8° C and 3.9mg l^{-1} respectively. Despite some quite high pond temperature readings in each trial (extreme maximum for each trial ranged from 30.8 to 31.6° C) there were no instances of widespread high temperature stress, as evidenced by muscle necrosis. Similarly, prawns in the pilot

Table 2. Summary of growth, survival, production and marketing results from four pilot scale (1 ha) Clarence River farming trials using school prawns, *Metapenaeus macleayi*. The duration of a trial is from the first day of pond stocking to the last day of harvesting.

	Farming trial number					
	1	2	3	4 (Jan to April)		
Parameter	Nov to Jan	Feb to May	Oct to Dec	First stocking	Second stocking	Combined result
Duration (weeks)	8	12	10	10	8	8 to 10
Average prawn weight (g ± SE)						
Male						
Initial	2.7 ± 0.07	1.6 ± 0.03	1.4 ± 0.06	2.6 ± 0.07	2.6 ± 0.08	—
Final	6.0 ± 0.06	6.1 ± 0.05	4.8 ± 0.07	—	—	6.7 ± 0.06
Female						
Initial	3.5 ± 0.08	2.0 ± 0.04	1.6 ± 0.06	3.2 ± 0.08	3.2 ± 0.13	—
Final	7.6 ± 0.08	7.1 ± 0.05	5.7 ± 0.08	—	—	8.4 ± 0.09
Sexes pooled						
Initial	3.2	1.8	1.5	3.0	2.9	—
Final	6.9	6.6	5.4	—	—	7.6
Number of prawns sampled						
Initial	1 371	1 494	838	822	755	—
Final	934	881	740	—	—	778
Sex ratio (male:female)						
Initial	1:1.47	1:1.27	1:1.10	1:1.39	1:0.95	—
Final	1:1.48	1:1.13	1:1.52	—	—	1:1.14
Thousands of prawns (ha^{-1})						
Initial	174	201	270	156	53	209
Final	120	144	164	—	—	109
Survival rate (%)	68.8	71.3	60.6	—	—	52.1
Total weight of prawns (kg ha^{-1})						
Initial	548	370	419	462	155	617
Final	829	950	877	—	—	825
Average market price (\$ kg^{-1})	4.28	6.77	6.31	—	—	9.33

scale pond were never observed to swim in large numbers near the pond surface during daylight hours in response to critically low DO levels as had occurred in commercial school prawn farming ponds (F. Roberts[1], pers. comm). Dissolved oxygen levels occasionally fell to 3.0 to 3.2 mg l^{-1} but never to levels approaching those considered lethal to penaeid prawns, ie <1 mg l^{-1} (Maguire 1980). High DO (>15 mg l^{-1}) and pH (>9.0) levels, indicative of dense algal blooms, were occasionally recorded but did not cause any apparent problems in terms of prawn growth or survival rates. Total ammonia readings were usually <0.1 mg total NH_3-N l^{-1} and the amounts of dissolved ammonia in its unionised toxic form were usually negligible in the pond samples. The upper acceptable level of dissolved unionised ammonia (0.1 mg free NH_3-N l^{-1}) for maximum penaeid growth (Wickins 1976) was exceeded only once and this was during a period of rapid prawn growth rates in trial 1. The amount of dissolved nitrite was always negligible (<0.02 mg NO_2-N l^{-1}) in the pilot scale pond samples.

Occasional inputs of fertilisers used to increase minimum DO levels usually stimulated an increase in algal activity as evidenced by increased daily maximum DO and pH readings. On only two occasions was a second input of fertiliser deemed to be necessary because DO levels failed to improve satisfactorily within five days of the first input.

[1] F. Roberts, School Road, Palmers Island, NSW, 2460

Table 3. Summary of pond water quality results from four pilot scale (1 ha) Clarence River farming trials using school prawns, *Metapenaeus macleayi*.

Parameter	Farming trial number			
	1	2	3	4
Water temperature (°C)				
Range	20.0-31.4	16.0-30.9	17.8-31.6	21.3-30.8
Average minimum[1]	23.9	21.2	23.2	24.9
Average maximum[1]	26.8	23.6	26.4	27.9
Salinity (‰)				
Range	7.4-19.7	4.4-7.1	16.9-23.6	14.5-27.5
Average	13.8	5.2	20.0	20.1
Dissolved oxygen (mg l^{-1})				
Minimum[1]				
Range	3.2-6.8	3.7-9.4	3.2-8.8	3.0-6.7
Average	5.0	6.0	5.3	4.9
Maximum[1]				
Range	5.8-11.4	5.5-18.9	6.1-15.2	5.0-15.8
Average	8.1	9.3	9.5	9.9
pH				
Maximum[1]				
Range	7.0-8.8	7.4-9.1	7.3-9.1	7.5-9.1
Average	8.0	8.2	8.0	8.5
Ammonia (maximum[2] for each trial) (NH_3-N mg l^{-1})				
Total	1.2	1.2	0.9	1.6
Unionised	0.17	0.07	0.09	0.05
Nitrite (maximum for each trial) (NO_2-N mg l^{-1})	< 0.02	< 0.02	< 0.02	< 0.02

[1]Readings based on continuous recordings or individual readings taken at times of day when maximum or minimum readings usually occur for each parameter.
[2]The minimum total ammonia readings for each trial were all < 0.1 mg l^{-1} and 61% of all pond total ammonia readings were < 0.01 mg l^{-1}. At these levels unionised ammonia concentrations are negligible.

Discussion

Experimental systems

The conclusions presented in Table 1 arise from research carried out in a variety of experimental systems each of which has specific advantages and limitations. Aquarium systems allow precise control of experimental variables and accurate monitoring of growth, survival, moulting and food consumption rates. The small scale of each experimental unit allows for relatively harmless forms of individual tagging, easy replication and the inclusion of expensive or inconvenient ingredients. However, the results of aquarium experiments cannot always be directly applied to practical farming situations. One general problem is that these results do not reflect the influence of other organisms which may be abundant in prawn farming ponds. Hence dietary studies in aquaria assess total nutritional requirements and do not take into account the effects that natural food items in ponds have on the required levels of nutrients, eg dietary protein, in supplementary artifical prawn feeds (Maguire and Hume 1982). Aquarium experiments at Port Stephens usually involved high stocking densities, little natural food and often restricted water exchange. School prawn growth rates in aquaria usually did not exceed 0.5g week^{-1} increase in average prawn weight even when the prawns were fed pipi meat, the best diet tested so far. In contrast growth rates in pens and 0.1 ha ponds at Port Stephens approached 1.0g week^{-1} (Table 1 and Maguire 1980). It is usually preferable to assess the nutritional requirements of rapidly growing animals.

Salinity experiments in aquaria pose quite specific problems. High survival rates (90 to 100% in each aquarium) were recorded for juvenile school prawns grown for four weeks at 25 or 30‰ but survival at 10‰ was poor (0 to 40%). Blood samples taken from these prawns indicated well developed osmoregulatory abilities in salinities of 10 to 30‰, and careful monitoring of water quality did not provide an explanation for this high mortality. In contrast, a high overall survival rate (71%) was recorded in pilot scale trial 2 despite an average pond salinity of 5.2‰ (Tables 2 and 3). Furthermore, juvenile school prawns can be collected from estuarine areas with salinities below 1‰ (Ruello 1973a). Venkataramiah et al (1974) noted similar discrepancies between natural distributions of prawns and the results of salinity experiments in aquaria. It should be noted that the other major conclusion from the salinity experiment in aquaria, ie that school prawn growth rates were positively correlated with salinity levels, has been confirmed by the results from replicated 0.01 ha ponds (Table 1) although pilot scale pond trial 2 clearly indicates that substantial growth is still possible at very low salinities (Tables 2 and 3).

Research in pens utilised sections of an individual pond as the experimental units. This allowed easy replication and partially overcame the problem of the inherent variability between ponds. Pens have several advantages over aquaria systems. They allow the prawns access to natural benthic food items and hence supplementary diets can be more usefully compared. Furthermore both high growth and survival rates can usually be obtained in pens. Because these aerated enclosures have porous mesh walls, water quality factors do not complicate the interpretation of experimental results (Maguire and Bell 1981; Maguire and Hume 1982; Maguire and Leedow 1983). Pen walls, however, present certain problems. It is not possible to investigate the effects of different forms of pond management on water quality by using pens. The pen walls support dense fouling growths which could provide additional food sources not normally available in large quantities in ponds. Fortunately this does not seem to have occurred in school prawn experiments in pens (Maguire and Bell 1981).

Free standing pools are experimental units which allow the production of natural benthic food items through fertiliser input yet also allow the effects of experimental variables on water quality to be assessed. However, pools are unlikely to experience as much wind induced water circulation as ponds. Thus experimental pools are usually aerated and this negates the effects of experimental variables, eg low water exchange rates on pool DO levels. Pools can be replicated but large differences in water quality parameters, eg plant pigments, pH and dissolved ammonia levels, did occur between replicate pools in both water exchange rate experiments. Clearly, the validity of extrapolating results from pool systems to commercial farming ponds should be enhanced as the size of each pool increases. However this raises the costs of replication and also increases the scale of the pool stocking operation. Because prawn growth rates depend on density (number of prawns per unit area), the achievement of acceptable levels of variation in average growth rates between replicates relies on relatively uniform survival rates being recorded. Thus initial mortality, eg due to excessive stress during capture or weighing and sexing procedures, must be minimised and accurately estimated for each replicate. This becomes increasingly difficult in large pool systems.

Experimental systems which utilise whole ponds as replicates should provide the type of information which is most directly applicable to commercial farming operations. Firstly, the scale of each experimental unit allows for more realistic extrapolation of production results than for smaller systems. This is particularly important if alternative pond management methods are to be assessed in terms of cost effectiveness (Maguire and Leedow 1983). Secondly, all of the factors which influence commercial results, eg natural food levels, survival rates and pond water quality and sediment condition, can vary in response to the pond management variable being tested. However, the fact that so many parameters can vary at once makes it difficult to deduce how the management variable actually influenced production results. Also, it is not always possible to minimise variation between ponds, eg in sediment characteristics or fish recruitment, that is unrelated to the management variable being tested (Maguire et al 1984). Furthermore it is logistically difficult to conduct all replicate farming trials concurrently and those carried out consecutively can be affected by temporal changes in environmental parameters, eg pond salinity (see Table 3).

Each of these experimental systems has made specific contributions to the development of methods for farming school prawns. A major problem with all of the systems is that they usually allow only relatively few aspects of a topic to be investigated at one time. Frequently the refining of a particular facet of prawn farming involves numerous considerations. Thus the substrate experiment conducted in aquaria (Table 1) assessed the physical suitability of various types of sediment for school prawns. Ruello (1973b) demonstrated that juvenile school prawns prefer to bury in fine sand but the substrate experiment showed that these behavioural preferences did not affect school prawn growth or survival rates on different substrate types. However, the suitability of a pond sediment type for a commercial prawn farm can depend on several factors including its suitability for inexpensive construction and maintenance of ponds which are not prone to water loss through porous soils. Other considerations are the tendency for the sediment to become chemically reduced, its drying rate during pond rehabilitation periods between crops, the organic content (Table 1) and soil pH levels (Simpson et al 1983). Pond sediment with a high silt content can affect product quality (pilot scale trial 3) and lead to high pond turbidity levels which can adversely affect water quality management (pilot scale trial 4) and the availability of phosphate fertilisers (Boyd 1982). Given the complexity of this single variable, it is clear that pond siting and management strategies should not just be based on studies in small scale experimental systems. Valuable contributions could be made by a variety of other inputs, eg those of experienced pond operators, soil engineers, earthmoving contractors and water chemists.

Pilot scale pond trials

Although experimentation with school prawns in small scale experimental systems has been very useful (Table 1), it was considered necessary to conduct larger scale trials (1 ha) so that production results could be used with confidence in economic analyses. Furthermore it was important to obtain experience and assess problems in the type of pond system likely to be used commercially, ie large non-tidal earthen ponds. The problems which were anticipated were those of water quality management and predator control. The Clarence River site was chosen because it was hoped that its convenience for pond stocking operations would improve survival rates in ponds. A privately owned pond was made available. Unfortunately this was in a less than ideal location in terms of the shallowness, salinity variation and silt levels in the adjoining area of Lake Wooloweyah.

The results from the pilot scale trials were usually characterised by relatively high survival rates and product quality levels but growth rates were slower than those usually recorded in pens at Port Stephens. Specific comparisons can be made with the results of school prawn trials in 19 sets of three replicate pens which were stocked with school prawns at densities ranging from 12 to 30 juveniles m^{-2}. The pens received adequate inputs of poultry or trout diets for 5 to 9 week periods during October to April.

The overall mean growth and survival results for the pens were 0.54 ± 0.04 g $week^{-1}$ (range 0.22 to 0.83) and 87.8% $\pm$ 1.8 (range 78 to 98, N=57) compared with 0.45 ± 0.03 (range 0.40 to 0.53) and 63.3% $\pm$ 4.3 (range 52.0 to 71.0) in pilot ponds indicating that more rapid growth rates are attainable at least in pen systems.

Similarly, rapid growth rates were recorded in the initial phases of trials 1 and 4 (Fig.2) and in some but not all trials in 0.1 ha ponds at Port Stephens (Maguire 1980). As already discussed, whole pond trials are influenced by numerous factors and hence it is difficult to ascribe the disappointing growth results from the pilot scale pond trials to one pond variable. It is noteworthy that poor growth results in pens (<0.5 g increase in average prawn weight $week^{-1}$, sexes pooled) usually occurred when the pond sediment had deteriorated to a chemically reduced state or when natural food levels were low. The latter condition was indicated by very slow growth rates in control pens not supplied with supplementary feed.

Survival rates for the pen experiments were considerably higher than for the pilot scale pond trials but pen results were not affected by initial mortality, water quality factors or predation. Furthermore all prawns within a pen could be harvested and although harvesting procedures were thorough in the pilot scale pond they could not be exhaustive. Although trial 4 was disappointing, the survival rates for the pilot scale pond trials were adequate for commercial operations and were generally higher than in the 0.1 ha pond trials at Port Stephens where large scale collection of juvenile school prawns is less convenient and initial mortality is probably higher (Maguire 1980). One major concern was the finding of stressed or moribund prawns along pond edges on several occasions during pilot scale trials 1 and 4. Usually less than 10 prawns were found on any one day and there were no consistent abnormalities in the appearance of these prawns nor aberrant water quality parameter readings on these days. The stressed prawns were usually inactive and could often be collected by hand.

Harvest results from the pilot scale pond have been utilised for an economic analysis carried out by Commonwealth Development Bank staff (Table 4). The analysis was based on the results of the first three pilot scale trials and the better harvest results from one private farm as well as the estimated costs of facilities at this farm. The assumption was made that any poorer results from commercial farming ponds were the result of inexperience and were less likely to occur in the future. Provided the major assumptions noted in Table 4 can be realised, the analysis predicts an annual return to capital of up to 27% depending largely on the value of the harvested prawns. Although this initial analysis is an extremely useful contribution to the development of a prawn farming industry in NSW, it should be understood that it is in part hypothetical and is presently under revision. Some but not all of its major assumptions are consistent with the pilot scale results. The weight of prawns stocked in the pilot scale pond trials was usually greater than 400 kg ha^{-1},

Table 4. Summary of an economic analysis by Commonwealth Development Bank staff on a northern New South Wales school prawn, *Metapenaeus macleayi*, farming operation.

Variable	Input
Key assumptions	
Weight of prawns stocked	400 kg ha^{-1} $crop^{-1}$
Cost of prawns stocked	\$1 000 ha^{-1} $crop^{-1}$
Weight of prawns harvested	800 kg ha^{-1} $crop^{-1}$
Unit value of prawns harvested	\$6 kg^{-1}
Value of prawns harvested	\$14 400 ha^{-1} $crop^{-1}$
Number of crops per year	3
Total pond area	20 ha
Capital costs (\$)	
Land purchase and pond construction	130 200
Buildings and plant	87 360
	217 560
Annual income from sales	288 000
Annual costs	
Pond stocking	60 480
Feed, fertiliser and pond preparation	43 560
Marketing and processing	53 820
Other	14 580
	172 440
Annual overheads	
Maintenance of ponds and plant	6 570
Wages	19 890
Other	8 040
	34 500
Other annual costs	
Plant replacement and owner's labour	21 290
Surplus	59 770
Annual return on capital	27%
Sensitivity analysis—	
Value of prawns (\$ kg^{-1})	Return on capital (% pa)
4	-11
5	8
6	27

depending on average initial prawn size. However, the stocking of ponds with Clarence River school prawns at a density of 20 juveniles m^{-2} would often involve less than 400 kg ha^{-1} and these live prawns can at times be purchased for \$2 kg^{-1}. An important factor is the extent of initial mortality. The estimated harvest of 800 kg ha^{-1} was exceeded in all four trials although some weight losses during cooking and marketing should be expected.

The prawns from three of the four trials were sold for an average price well in excess of the estimated value of \$6 kg^{-1}. This estimate is higher than the average price paid for school prawns at the Sydney Fish Market (\$4.25 kg^{-1} for 1982 to 1984, according to Commonwealth Development Bank staff). However, the quality of farmed school prawns has been high both in terms of size and appearance and those prawns can be harvested at times which coincide with favourable market conditions. The other major assumption made in the analysis was the farming of three school prawn crops each year. If each crop is harvested approximately ten weeks after stocking, it should be possible to farm three crops each year provided that juvenile prawns can be collected for restocking purposes at appropriate times. The amount of time required for pond rehabilitation between crops would also have to be minimised or farming periods would extend into cooler months with resultant reductions in water temperatures (Wolf and Collins 1979) and hence growth rates (Table 1). Other important assumptions implicit in the analysis are low water exchange rates (supported by water exchange rate experiments in pools, Table 1) and relatively low land purchase and pond construction and maintenance costs. However, no provision has been made for equipment for aerating ponds or for controlling predation by cormorants. The experience gained during the pilot scale pond trials suggests that while careful monitoring of pH and DO levels and appropriate inputs of fertiliser can minimise the need for aeration equipment, it is occasionally necessary. Aeration devices are widely used in pond systems in other countries (Boyd 1982). Similarly, predation by cormorants appears to have been far more serious in commercial school prawn ponds than in the pilot scale trials (F. Roberts[1], pers. comm.) and hence deterrant equipment would probably be necessary for at least some farming sites.

Commercial prospects in NSW

Approximately 130 ha of commercial prawn farming ponds (3 to 9 ha $pond^{-1}$) have been at least partially constructed in northern NSW and several additional applications for prawn farming licences have been received. Should continued growth in this industry occur, several limitations are likely to become apparent. The collection of juvenile school prawns from the Clarence River has not proved to be an ideal method for stocking ponds for several reasons including fluctuations in availability and price of juvenile prawns, and occasional excessive mortality of prawns during and soon after stocking. The need for a hatchery reared supply of juveniles for pond stocking purposes is likely to become more acute as the number of farms increases. In addition, the marketing advantages that high quality farmed school prawns provide, especially in terms of being harvested to suit peak market conditions, would probably decline if very large amounts of farmed prawns were sold. For a major industry, export outlets may be necessary and a small prawn such as the school prawn would generally not be suitable. Thus it is likely that an expanded industry would need to be based on the farming of a larger penaeid species using juveniles reared in privately owned hatcheries. A large tropical penaeid species with proven aquaculture potential, eg *Penaeus monodon* (New and Rabanal 1985) could be farmed in ponds in NSW although it is likely that seasonal variation in pond water temperatures (Maguire and Bell 1981) would considerably restrict the growing season for this tropical species. Alternatively a large penaeid species endemic to more temperate Australian waters, eg the eastern king prawn, *Penaeus plebejus,* (Ruello 1975), could be farmed. Except for research on induced maturation and spawning (Kelemec and Smith 1980, 1984) little is known of the aquaculture potential of this species.

The Fisheries Division, NSW Department of Agriculture, takes a cautious view of the prospects for a prawn farming industry in this state. The results of the economic analysis discussed in this paper are heartening, but the major assumptions will have to be realised consistently on a commercial scale. Furthermore, the introduction of hatcheries and the farming of penaeid species other than school prawns would entail further economic analyses. Also there are few comparable examples of profitable, large scale, marine prawn farming industries in western temperate areas (Wickins 1982). At least in the short term, commercial prawn farming in NSW is likely to be best suited to investors who can afford to take a pioneering role or who cannot find alternative uses for existing land holdings.

Future research

There is a need for research into methods for increasing the amounts of natural food items within prawn farming ponds without leading to excessive deterioration of pond sediment conditions. This will require a more detailed understanding of nutrient dynamics in ponds.

Commercial producers in NSW are likely to diversify into the farming of larger temperate penaeids, and more aquaculture research on these species, eg eastern king prawns, seems warranted. If larger species are to be grown to export sizes, diets which are more nearer nutritionally complete will have to be developed as grow-out times and biomass levels in ponds increase.

The priority given to aquacultural research on school prawns is likely to depend on its suitability for pond culture at much higher densities than those used in the pilot trials (Table 1) and on interest from farmers particularly if ponds are constructed in lower salinity areas which would probably be unsuitable for eastern king prawns (Dall 1981).

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C H A P T E R 3

Prawn pond water quality management

INTRODUCTION

In order to achieve maximum production from a prawn farm the conditions provided for the prawns must be conducive to high survival and rapid growth. One of the most important features that determines the suitability of a pond for growing prawns is water quality. In its broadest sense this term includes all the physical, chemical and biological properties of water (Boyd, 1979), however aquaculturists are mainly concerned with those features which affect survival and growth of the species being cultured. Although substantial information is available on water quality and its management in freshwater ponds, for fish farming, etc. (Boyd, 1979, 1982; Ray, 1978) there is little information available about brackish water prawn farming ponds.

The objectives of the water quality section of the pilot-scale prawn farming programme were to:

(1) identify the key water quality parameters within a prawn farming pond;

(2) describe the range of values recorded;

(3) examine some of the major relationships between the parameters, and

(4) to use this information to help develop pond management practices which will maintain water quality and prevent crisis situations from occurring.

METHODS AND MATERIALS

Pilot-scale Pond and Swimming Pool Experimental Units

The 1 ha pilot-scale pond, the swimming pool experimental units and the experimental procedures and results are described in the accompanying and complementary NPS2 paper (presented as Chapter 2 of this report).

Table 1 summarises the parameters measured, the sampling frequency, the method of analysis and the calibration procedure. The methods of analysis for the various parameters were chosen on the basis of accuracy and convenience; where possible several methods were used to enable regular calibration and cross checking. For example, two dissolved oxygen meters were used, the YSI model 57 attached to a continuous chart-recorder for constant monitoring of dissolved oxygen levels at one position within the pond, and the Yeokal model 603 which was used for daily sampling at various positions within the pond. In addition to cross checking the meters with each other, Winkler's titration (Strickland and Parson, 1968) was used to ensure that the meters were constantly in calibration.

Where possible, it was considered essential to measure the major parameters in situ so that any pond management decisions could be made immediately. Thus techniques for measuring temperature, salinity, dissolved oxygen, ammonia and nitrite at the pond site were refined and used. For the determination of ammonia an ion selective probe (HNU) coupled to a pH/mV meter (Metrohm) was used. This method has proved reliable for measurements in seawater (Merks, 1975; Gilbert and Clay, 1973) and techniques similar to those used by Rice (1982) with a similar electrode were adopted. For nitrite measurement an ion selective probe (HNU) was tested but found to be unreliable. Reagents for the colourimetric determinations of nitrite are stable and easily prepared (Major et al., 1972) and given the low levels of nitrite found a visual comparison between colour development in a series of standards and the samples was considered adequate.

For the measurement of oxidised nitrogen (nitrate) reactive phosphorous, reactive silica and the plant pigments, chlorophyll a, b, c and phaeophytin water samples were filtered and the water and filter papers were frozen and transported to the Fisheries Research Station at Port Stephens for spectrophotometric analysis (Major et al., 1972). These parameters were judged to be either less important in influencing daily pond management decisions or difficult to determine accurately at the pond site without sophisticated analytical facilities, e.g., plant pigments.

TABLE 1. Water quality monitoring procedures in pilot scale (1 ha) Clarence River pond and swimming pool trials stocked with school prawns (Metapenaeus macleayi)

Parameter [1]	Sampling frequency for pilot scale pond [2]	Measurement procedure	Comment
Temperature (T)	Continuous or early morning, noon and late afternoon.	Solid probe linked to recorder (Foster Cambridge Clearspan P120L). Hamon S/T bridge (Yeokal 602 Mk. 1 or Mk. 2).	Regularly calibrated against standard thermometer.
Dissolved oxygen (D.O.)	Continuous or early morning, noon and late afternoon.	YSI 57 (5739 probe) D.O./T meter linked to recorder. Yeokal 603 D.O./T meter.	Regularly calibrated against saturated water and Winkler titration (Strickland and Parsons, 1968).
Salinity (S)	After water exchange or rainfall.	Hamon S/T bridge. Atago refractometer. Hydrometer.	Regularly calibrated against standard seawater (35‰).
pH	Late afternoon with occasional early morning readings.	Metrohm 605 pH/mV meter with combined glass electrode (6.0203.000) or reference electrode (6.0726.100) plus glass electrode (6.0102.000). pH papers, range 6.5-10 (Merck).	Daily calibration with 6.87 and 9.18 buffers (A.P.H.A., 1971).
Total ammonia (NH_3)	Late afternoon every 1 to 3 days.	Ion selective electrode (H.N.U. type ISE-10-10-00) coupled to pH/mV meter. Unionised ammonia content estimated from detailed pH/T/S conversion charts (see Wickins, 1976).	Fresh NH_3 standards prepared for each sampling day. Method checked occasionally against spectrophotometric method (Dal Pont et al., 1973).
Nitrite (NO_2)	Late afternoon every 1 to 3 days.	Spectrophotometric method (Major et al., 1972).	Visual comparison[3] between samples and fresh standards adequate as pond and pool water nitrite levels always <0.02 mg NO_2-N ℓ^{-1}.
Nitrate (NO_3) Reactive phosphorous (PO_4) Reactive silica (Si) Plant pigments Chlorophyll a Chlorophyll b Chlorophyll c Phaeophytin	Trial 1 - Infrequently. Trial 2 - At least once per week. Trials 3 and 4 - Every 3 days.	Spectrophotometric methods (Major et al., 1972).	Samples frozen and transported to Research Station laboratory for analysis.

1 Most readings were based on pond bottom samples with occasional pond water surface samples taken to check for stratification.

2 Swimming pool trials sampling frequency: Trial 1 - T, S, DO, pH, NH_3 every 3 days
- NO_3, PO_4, Si, Chl a,b,c and phaeophytin every 8 days.

Trial 2 - T, S, DO, pH, NH_3 every 3 days
- NO_3, PO_4, Si, Chl. a,b,c and phaeophytin every 6 days.

3 Nitrite levels determined by visual comparison of colour intensity of the azo dye development in samples and standards.

To handle the very large volume of data generated from the water quality sampling programme in the pond and swimming pools an Apricot microcomputer was used. The data from all individual measurements of each water quality parameter from pond and pools was stored and analysed using the Microstat software package. Graphics were largely performed using the Open Access software package.

To present the volume of data for the purpose of this report, three approaches have been used:

(1) The range and mean for each parameter were calculated for each pond trial, for each week in each trial and for each pool in the two swimming pool experiments;

(2) Many of the water quality parameters vary together (covary) in response to changes in the weather and pond management practices. Correlation analysis was performed to measure this interdependance (Sokal and Rohlf, 1981). A correlation matrix was constructed and each parameter was correlated with all other parameters separately. Five matrices were constructed, one where data from all trials was combined and one for each of the 4 trials separately. Consistently significant correlations between the major parameters have been extracted.

(3) To demonstrate the relationships between the parameters, three events (representing periods of between 14 and 17 days) have been extracted from the data. The daily fluctuations in the parameters is discussed in relation to changes in the weather and pond management practices.

RESULTS AND DISCUSSION

Pond Trials

The mean and range of values for each parameter measured in each pond trial is presented in Table 2. Weekly means of all parameters for each trial are presented in Table 3 (a-d). Salinity was the most variable parameter declining rapidly towards the end of Trial 1 (19.7-7.4‰) and remaining low (4.4-7.1‰) throughout Trial 2. It recovered to an average of 20.0‰ and 20.1‰ for Trials 3 and 4 respectively (Table 2). Temperature fluctuated on a diurnal and seasonal basis. The average diurnal range was 2.8°C however a range of over 5.0°C was common at times. Trial 4 experienced the highest average maximum temperature (27.6°C) whilst Trial 2 had the lowest (23.6°C) (Table 2). Despite the often high extreme maximum temperatures (range 30.8-31.6°C) no evidence of temperature stress (as evidenced by muscle necrosis) was observed.

Dissolved oxygen readings were also characterised by often large diurnal fluctuations (average 3.9 mg/l) and in periods of excessive algal (phytoplankton) activity very high maximum levels. During one algal bloom maximum dissolved oxygen reached 18.9 mg/l (Table 2, Trial 2) (diurnal range 11.2) on one day. Minimum dissolved oxygen levels occasionally fell to 3.0-3.2 mg/l but never to levels approaching those considered lethal to prawns, i.e., <1 mg/l (Maguire, 1980). Although dissolved oxygen stress has been observed in commercial prawn farming ponds with prawns swarming on the surface (F. Roberts, pers. comm.) no evidence of dissolved oxygen stress was observed in the pilot-scale trials.

With the maintenance of adequate dissolved oxygen levels the toxicity of nitrogenous compounds especially ammonia, has been considered to be the single most limiting parameter (Avault, 1978; Colt and Armonstrong, 1981) ammonia exists in solution in two forms, a highly toxic unionised form and a much less toxic ionised form. The proportion of each is dependant mainly upon pH but also to a lesser extent, upon temperature, salinity and pressure (Whitfield, 1974). Throughout all pond and swimming pool trials total ammonia was generally low (usually < 0.1 mg total NH_3-N/l) and the amount of dissolved ammonia in its toxic form was usually negligible. A reported upper acceptable level for dissolved unionised ammonia for several species of penaeid prawns of 0.1 mg unionised NH_3-N/l (Wickens, 1976) was only exceeded once and this was during a period of rapid prawn growth in Trial 1 (Table 2). Nitrite was consistently low during all trials (< 0.02 mg NO_2-N/l) (Table 2 and 3) whilst other nutrients, oxidised nitrogen (nitrate), reactive phosphorous and reactive silica were only slightly

TABLE 2. Summary of pond water quality results from four pilot-scale (1 ha) Clarence River farming trials using school prawns (*Metapenaeus macleayi*).

Parameter	Farming trial number			
	1	2	3	4
Water temperature T (°C)				
Range	20.0-31.4	16.0-30.9	17.8-31.6	21.3-30.8
Average minimum [1]	23.8	21.2	23.2	24.9
Average maximum [1]	26.8	23.6	26.4	27.6
Salinity S (‰)				
Range	7.4-19.7	4.4-7.1	16.9-23.6	14.5-27.5
Average	13.8	5.2	20.0	20.1
Dissolved oxygen D.O. (mg ℓ^{-1})				
Minimum [1]				
Range	3.2-6.8	3.7-9.4	3.2-8.8	3.0-6.7
Average	5.0	6.0	5.3	4.9
Maximum [1]				
Range	5.8-11.4	5.5-18.9	6.1-15.2	5.0-15.8
Average	8.1	9.3	9.5	9.9
pH				
Maximum [1]				
Range	7.0-8.8	7.4-9.1	7.3-9.1	7.5-9.1
Average	8.0	8.2	8.0	8.5
Ammonia NH_3 (mg NH_3-N ℓ^{-1})				
Maximum for each trial [2]				
Total	1.2	1.2	0.9	1.6
Unionized	0.17	0.07	0.09	0.05
Nitrite NO_2 mg (NO_2-N ℓ^{-1})				
Maximum for each trial	<0.02	<0.02	<0.02	<0.02
Nitrate No_3 (µg ℓ				
Range	6.0-262.0	3.0-30.0	10.0-229.0	10.0-163.0
Average	93.0	11.9	48.7	21.0
Reactive phosphorous PO_4 (µg ℓ^{-1})				
Range	7.0-9.0	1.0-156.0	4.0-363.0	<20.0
Average	8.0	31.6	24.5	<20.0
Reactive silica Si (ug ℓ^{-1})				
Range	0.2-0.3	1.0-18.0	0.2-3.8	0.1-4.6
Average	0.23	7.0	1.4	1.7
Plant pigments (µg ℓ^{-1})				
Chlorophyll a				
Range	3	3.0-123.0	14.0-188.0	24.0-290.0
Average	3	51.1	59.1	147.7
Chlorophyll b				
Range	3	3	0-6.0	0-6.0
Average	3	3	1.9	0.3
Chlorophyll c				
Range	3	3	6.0-84.0	0-173.0
Average	3	3	24.3	64.8
Phaeophytin				
Range	3	0-69.0	2.0-263.0	3.0-109.0
Average	3	15.9	27.2	28.7

1 Readings based on continuous recordings or individual readings taken daily at time when maximum or minimum readings usually occur for each parameter.

2 The minimum total ammonia readings for each trial were all <0.1 mg ℓ^{-1} and 61% of all pond total ammonia readings were <0.1 mg ℓ^{-1}. At these levels unionized ammonia concentrations are negligible.

3 Readings not taken.

Table 3
Pond Water Quality weekly means from four pilot-scale (1 ha) Clarence River farming trials.

a) TRIAL 1.

WATER QUALITY PARAMETER *

Week	Temp. max °C	Temp. min °C	D.O. max mg/l	D.O. min mg/l	pH	Sal. ‰	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments: Chlorophyll a ug/l	Chlorophyll b ug/l	Chlorophyll c ug/l	Phaeophytin ug/l	Rainfall mm
1	27.8	24.8	7.1	4.9	7.6	18.1	0.20								1.34
2	24.6	21.9	7.1	5.2	7.6	18.6	0.77								12.7
3	24.5	22.1	7.8	5.3	7.9	16.5	0.69								6.43
4	24.3	22.2	7.9	5.3	7.8	15.0	0.98	136.5	7.5	0.25					7.43
5	27.5	23.4	9.9	5.4	8.7	14.5	0.05	6.0	9.0	0.2					6.91
6	29.2	25.6	8.8	3.9	8.2	13.5	0								0.51
7	29.4	25.7	8.2	4.7	8.3	12.9	0								11.7
8	26.1	23.8	8.3	5.4	8.4	8.7	0.01								8.37
9	28.0	25.3	7.5	5.0	8.0	7.7	0								0.43

* Missing values indicates reading not taken

b) TRIAL 2.

WATER QUALITY PARAMETER *

Week	Temp. max °C	Temp. min °C	D.O. max mg/l	D.O. min mg/l	pH	Sal. %o	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments: Chlorophyll a ug/l	Chlorophyll b ug/l	Chlorophyll c ug/l	Phaeophytin ug/l	Rainfall mm
1	26.0	23.7	10.6	6.8	8.6	5.2	0.27	13.0	1.0	1.4	14.0			29.0	7.83
2	27.9	24.9	12.0	7.1	8.8	4.6	0	7.0	1.0	1.1	32.0			49.0	0
3	27.9	25.9	7.9	4.6	8.0	4.4	0	13.0	2.0	3.1	3.0			25.0	0.80
4	26.0	23.9	10.2	5.8	8.7	4.4	0.02	12.0	3.0	1.0	46.0			69.0	9.14
5	25.0	21.8	8.7	5.3	8.4	4.4	0	14.0	11.0	10.3	36.0			12.0	9.09
6	23.5	21.4	9.1	6.2	8.6	4.4	0.01	30.0	156.0	11.9	78.0			0	9.9
7	22.6	20.1	10.7	7.1	8.8	4.5	0	15.0	18.0		73.0			2.0	5.77
8	24.3	21.8	10.4	5.4	8.6	4.7	0.01	5.0	8.0	5.7	123.0			0	1.97
9	21.9	19.5	9.0	5.4	7.7	5.0	0.12	3.0	11.0	2.4	115.0			0	0.07
10	20.7	18.4	6.1	5.1	7.4	5.2	0.80	5.0	57.0	7.8	29.3			9.7	0.10
11	18.4	16.5	6.7	5.5	7.4	5.4	1.2	2.9	108.0	18.0	12.0			8.0	0.23
12	19.1	17.4	10.5	7.3	8.2	6.9	0.4	10.0	13.0	13.2	96.0			0	7.63

* Missing values indicates reading not taken

c) TRIAL 3.

WATER QUALITY PARAMETER *

Week	Temp. max °C	Temp. min °C	D.O. max mg/l	D.O. min mg/l	pH	Sal. %o	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments: Chlorophyll a ug/l	Chlorophyll b ug/l	Chlorophyll c ug/l	Phaeophytin ug/l	Rainfall mm
1	25.5	22.7	8.0	5.9	7.8	20.1	0	19.5	4.0	1.0	27.0	2.5	15.0	11.0	0.66
2	23.0	20.3	10.6	7.1	8.0	21.7	0	21.7	8.3	2.2	17.3	1.0	7.0	5.7	1.74
3	24.7	21.9	9.3	5.8	8.0	22.9	0.04	19.5	6.0	1.3	21.0	1.5	8.0	3.5	15.63
4	24.6	21.1	10.8	5.9	8.1	19.7	0	22.0	7.0	3.6	23.0	2.5	16.5	4.5	9.69
5	28.7	24.9	7.8	4.1	7.6	17.3	0.38	139.7	8.7	2.3	39.3	2.0	14.0	9.7	1.09
6	27.9	24.1	9.8	4.9	8.1	17.7	0.71	40.5	11.0	0.7	71.0	1.5	28.0	10.5	0.89
7	26.4	22.9	10.9	4.9	8.5	19.0	0	24.5	11.0	0.3	166.5	1.5	79.5	141.5	0.31
8	27.9	25.1	9.9	4.3	8.0	20.1	0.23	91.7	10.7	0.6	109.3	2.7	37.7	55.3	0.20
9	26.8	23.8	8.9	5.1	8.2	20.9	0	20.5	186.5	0.7	62.5	2.0	22.5	13.0	11.83
10	30.7	27.4	8.3	4.2	7.9	21.4	0	19.0	5.0	0.6	61.0	1.0	20.0	19.0	0

* Missing values indicates reading not taken

d) TRIAL 4.

WATER QUALITY PARAMETER *

Week	Temp. max °C	Temp. min °C	D.O. max mg/l	D.O. min mg/l	pH	Sal. ‰	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments: Chlorophyll a ug/l	Chlorophyll b ug/l	Chlorophyll c ug/l	Phaeophytin ug/l	Rainfall mm
1	28.0	25.6	7.9	4.5	7.8	24.6	0	3.0	<20	0.2	41.0	6.0	12.0	4.0	3.06
2	28.1	25.4	7.5	4.7	7.8	23.5	1.5	105.0	<20	2.2	64.0	0.5	18.0	17.5	4.2
3	29.1	26.2	11.3	5.2	8.5	24.3	0.19	11.5	<20	0.3	91.0	0	31.0	13.0	1.9
4	28.2	24.8	10.4	4.6	8.4	26.7	0	10.0	<20	0.4	130.7	0	52.0	14.7	3.86
5	26.7	24.9	10.9	5.3	8.8	25.7	0	1.5	<20	1.1	155.0	0	73.0	13.5	27.8
6	28.7	25.3	10.0	4.9	8.9	18.5	0	6.0	<20	3.2	172.5	0	79.0	7.0	1.74
7	27.2	25.3	10.1	4.1	8.7	18.1	0	35.3	<20	3.0	224.3	0	121.3	49.0	8.23
8	25.9	23.3	11.3	5.9	8.7	16.1	0	11.5	<20	1.8	208.0	0	99.5	8.0	14.36
9	27.3	24.7	9.9	5.2	8.5	16.1	0	8.0	<20	1.7	169.5	0	79.0	4.0	1.43
10	26.6	24.0	9.7	4.8	8.3	15.0	0	11.7	<20	1.9	141.3	0	45.0	103.7	3.6
11	26.2	23.6	7.7	5.3	8.2	14.5	0								10.2

* Missing values indicates reading not taken

higher than values recorded for a shallow estuary (Scribner, 1985) despite additions of either organic or inorganic fertilisers prior to and during the farming trials (Table 2 and 3).

The measurement of chlorophylls a, b and c provided a direct indication of the extent of living algal cells (phytoplankton) in the pond and ponds. Phaeophytin is a degradation product of chlorophyll and indicates the extent of dead cells. Measurement of plant pigments were not taken during Trial 1 and infrequently during Trial 2 (only chlorophyll a and phaeophytin were measured during Trial 2). Overall the concentrations of plant pigments recorded from the pond and pools were higher than those recorded from several N.S.W. estuaries (Allan, 1980) which was consistent with the practice of stimulating algal blooms through fertilisation.

Overall Trial 1 was characterised by small algal blooms (especially during the first four weeks, Table 3) resulting in lower mean dissolved oxygen levels and pH and higher ammonia levels than were recorded for the other trials (Tables 2 and 3). Conversely during Trial 4 a relatively well developed algal bloom was maintained throughout resulting in higher mean maximum dissolved oxygen levels, pH and chlorophyll a and lower ammonia (Tables 2 and 3). However, even though Trial 4 had consistently higher concentrations of chlorophyll a than Trial 3 the concentration of chlorophyll b was always higher during Trial 3 (Table 3). This indicates that the species composition of the algal blooms was different during Trials 3 and 4. As chlorophyll b only occurs in two algal divisions, the Euglenophyta and Chlorophyta (Price, 1981), the proportion of representatives from these divisions was greater during Trial 3. Concentrations of phaeophytin in Trials 3 and 4 indicate that there was a similar abundance of dead cells in the water column during these trials.

Swimming Pool Trials

The mean values for each water quality parameter for each swimming pool for both trials are listed in Table 4. There were several differences in the levels of some of the water quality parameters between different pools both within treatments and between treatments. For both pool trials phosphorous levels and plant pigments decreased as water exchange rates increased. This is related to the flushing effect of high exchange rates, however no consistent significant differences in prawn growth were recorded from different treatments. Although mass mortality was observed in one of the pools with 0% water exchange rate during the second trial (stocking density in this experiment was 50 prawns/m^2), overall prawn growth rates were slow in both the swimming pool trials and may have been influenced by progressive deterioration of the sediment.

Although dissolved oxygen levels in the pools were maintained by continuous aeration (confirmed by measurement of dissolved oxygen in bottom waters), build up and subsequent microbial decomposition of organic material may have resulted in some oxygen depletion in interstitial waters and allowed chemical reduction to occur. Redox potential and hydrogen sulphide levels were not measured, however the characteristic odour produced by accumulation of hydrogen sulphide was detected in pool sediments after drainage and harvest.

Interaction between Pond Water Quality Parameters

Table 5 presents a summary of the significant correlations between the major water quality parameters. A positive correlation is indicated where the two parameters increased or decreased together and an inverse correlation where one parameter increased as the other decreased.

Ponds were fertilised prior to and during each trial to stimulate algal (phytoplankton) activity in order to enhance natural food levels in the pond, to maintain dissolved oxygen levels, to help ensure adequate assimilation of the potentially toxic nitrogenous compounds in the pond and to reduce light penetration to prevent the colonisation of the pond bottom by macrophytes. An increase in algal activity after fertilisation was evidenced by elevated chlorophyll a concentration, an increase in the maximum levels and the diurnal range of dissolved oxygen (as a result of increased photosynthesis and respiration), increasing pH (largely as a result of carbon dioxide removal by phytoplankton [Boyd, 1982]) and a decrease in total ammonia (following assimilation by phytoplankton). Thus a significant correlation between dissolved oxygen (both maximum levels and diurnal range) and pH was established when data from all trials and from each trial separately was correlated. Similarly, a significant correlation between chlorophyll a and

Table 4
Summary of water quality data from swimming pool trials conducted at Clarence River Pilot-scale Prawn Farm site.

a) TRIAL 1.

WATER QUALITY PARAMETER (MEAN VALUES)

Water Exchange Rate/day	Pool	D.O. mg/l	Temp. °C	pH	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments ug/l Chlorophyll a	b	c	Phaeophytin
	6	8.0	18.7	8.0	0.03	5.7	73.3	5.4	56.0	14.6	8.3	15.7
0%	11	8.3	18.9	8.1	0.15	7.8	53.6	5.3	45.4	7.1	10.0	27.6
	14	8.4	18.9	8.3	0.13	10.3	36.9	4.4	85.7	34.0	19.0	41.1
	5	8.0	18.6	8.1	0.11	7.8	55.4	5.4	26.1	3.3	6.1	5.1
5%	7	8.1	18.7	8.0	0.24	7.6	38.8	8.3	32.9	6.4	7.3	7.0
	9	8.1	18.8	8.0	0.12	7.4	31.8	6.1	34.0	3.1	8.0	7.0
	3	8.2	18.6	8.0	0.32	7.4	16.4	6.3	28.1	1.0	4.9	7.3
10%	10	8.2	18.7	8.1	0.58	6.8	14.6	6.0	32.7	3.0	10.1	5.4
	15	8.2	19.0	8.0	0.10	11.6	13.8	6.6	26.6	5.1	5.6	6.7
	2	8.1	18.5	8.0	0.05	12.3	13.0	10.1	27.3	2.0	5.6	6.1
20%	4	8.2	18.6	8.1	0.04	7.6	17.0	9.7	25.0	0.6	6.9	4.4
	12	8.2	19.0	8.1	0.04	7.0	11.0	8.3	29.3	2.3	6.6	5.9
	1	8.1	18.7	8.0	0.33	9.9	21.0	11.7	17.1	0.4	3.9	3.0
40%	8	8.1	19.0	7.9	0.05	7.1	11.9	13.3	17.1	0.1	3.9	3.6
	13	8.1	19.1	8.0	0.10	6.6	12.1	12.1	16.3	0.6	3.6	3.1

b) TRIAL 2.

WATER QUALITY PARAMETER (MEAN VALUES)

Water Exchange Rate/day	Pool	D.O. mg/l	Temp. °C	pH	Sal. ‰	NH_3 Total mg/l	Oxid. N ug/l	React. P ug/l	React. Si mg/l	Plant Pigments ug/l Chlorophyll a	b	c	Phaeophytin
0%	3	6.6	23.3	8.4	23.1	0.07	7.0	161.7	1.4	107.2	25.3	32.8	36.1
	4	7.0	23.4	8.4	23.1	0.09	8.7	198.0	1.7	141.2	40.7	31.1	17.6
	7	7.0	23.6	8.4	22.8	0.18	7.7	183.4	1.3	184.4	56.1	51.6	55.2
	11	6.7	23.9	8.2	23.0	0.44	10.1	199.9	1.3	126.4	12.7	28.6	20.7
5%	1	6.8	23.1	8.3	21.0	0.06	7.8	86.7	1.1	44.9	2.1	19.8	13.9
	8	6.9	23.3	8.3	21.1	0.25	10.0	105.0	1.3	41.7	1.1	14.3	9.4
	10	7.1	23.5	8.4	21.2	0.01	10.1	51.7	1.8	98.0	3.3	28.0	15.4
	12	7.1	23.5	8.5	20.9	0.02	10.1	51.1	1.7	98.8	1.5	29.4	5.0
10%	2	7.0	23.2	8.3	20.6	0.02	7.6	37.4	1.4	50.2	9.2	11.6	13.4
	6	7.2	23.2	8.4	20.6	0.03	8.9	36.6	1.5	69.3	5.0	20.6	14.4
	9	7.1	23.3	8.4	20.6	0.03	9.7	37.4	1.8	63.9	3.6	18.9	17.0
	15	7.1	23.1	8.4	20.6	0.01	7.8	38.7	1.5	66.0	2.2	26.4	11.1
20%	5	7.2	23.2	8.4	20.3	0.03	8.9	11.2	2.1	45.9	1.9	17.9	6.6
	13	7.5	23.2	8.5	20.4	0.02	10.7	6.6	1.5	55.0	1.7	22.8	10.0
	14	7.4	23.2	8.5	20.4	0.01	7.6	7.2	1.7	41.4	3.3	13.6	9.8
	16	7.4	23.1	8.5	20.5	0.03	8.0	7.1	1.1	56.9	8.1	17.6	12.4

TABLE 5. Summary of significant correlations between major water quality parameters from Clarence River pilot scale (1 ha) pond trials [1,2]

Parameters correlated	Data source				
	All trials combined	Farming trial			
		1	2	3	4
A. Temperature					
Temp.(Max.) / Diss.oxy.(min.)	# #	# #		# #	
Temp.(Max.) / pH		* *	* *		
Temp.(Min.) / Diss.oxy.(min.)	# #	# #		# #	# #
Temp.(range) / Diss.oxy.(max.)		* *		* *	
Temp.(range) / Diss.oxy.(range)		* *		* *	
Temp.(range) / pH		* *	* *	* *	
B. Dissolved oxygen					
Diss.oxy.(max.) / pH	* *	* *	* *	* *	* *
Diss.oxy.(max.) / NH_3		# #	# #		
Diss.oxy.(range) / pH	* *	* *	* *	* *	* *
Diss.oxy.(range) / NH_3		# #	# #		
Diss.oxy.(range) / Chlorophyll a	* *	3	3	* *	* *
C. pH					
pH / NH_3	# #	# #	# #		# #
pH / Oxid. N.	# #				
pH / Chlorophyll a	* *	3	3		
pH / Chlorophyll b	# #	3	3		# #
pH / Chlorophyll c	* *	3	3	* *	
D. NH_3 / Oxid. N.	* *	3	3	* *	* *
E. Rainfall / React. Silica	* *				
F. Chlorophyll a / Chlor. b	# #				
Chlorophyll a / Chlorophyll c	* *	3	3	* *	* *

1 Data used for correlation matrices was obtained from all measurements of each parameter.

2 * * Correlation significant at p = 0.05 (positive relationship between variables).

Correlation significant at p = 0.05 (inverse relationship between variables).

3 Insufficient data available for correlation.

dissolved oxygen range was established using data from all trials and from Trials 3 and 4. (There was insufficient data from Trials 1 and 2 to allow correlation with chlorophylls.) A significant inverse correlation was also established between pH and total NH_3 for all trials combined and for Trials 1, 2 and 4 (Table 5).

Several processes contribute to the level of ammonia in the pond. Ammonia is the primary excretary product of prawns (Barnes, 1974) and is also released into the water following microbial decomposition of nitrogenous compounds contained in the body constituents of all dead plant and animal material (Stanier et al., 1976; Seymore, 1980). Some liberated ammonia is assimilated directly by algae (Goldman and Dennett, 1985; Maestrini et al., 1982) and microorganisms (Mills, 1981) and in aerobic conditions may be oxidised to nitrite then nitrate by nitrifying bacteria in the process of nitrification (Mills, 1981). In a study of nitrification in closed circuit marine aquaria the presence of prawns was shown to increase rates of nitrification under well oxygenated conditions (Mevel and Chamroux, 1981). The significant positive correlation between ammonia and oxidised nitrogen obtained using data from all trials and from Trials 3 and 4 (insufficient data was available from Trials 1 and 2) demonstrated the effect of nitrification in the pond (Table 5).

Whilst maximum dissolved oxygen levels were strongly determined by the extent of algal activity the minimum dissolved oxygen levels were influenced to some extent by algal respiration but also by biological oxygen demand and the oxygen carrying capacity of the water (determined mainly by temperature and salinity). As temperature increases the oxygen consumption associated with microbial decomposition of organic matter also increases and the oxygen carrying capacity of the water decreases. This relationship was reflected by the significant inverse correlation between minimum temperature and minimum dissolved oxygen for all trials and for Trials 1, 3 and 4 (Table 5).

Pond Events

Although the interdependance between temperature, dissolved oxygen, pH, ammonia and phytoplankton biomass can be established by significant correlations between these parameters, using data collected over whole pond trials, the rapid short-term fluctuations and relationships which can occur in a pond are often obscured by pooling of data. To demonstrate some of the processes which can occur at different times, three representative pond "events" have been chosen and the daily fluctuations in water quality parameters throughout these periods presented graphically, Fig. 1

FIGURE 1

Fluctuations in 4 water quality parameters during three representative pond "events"

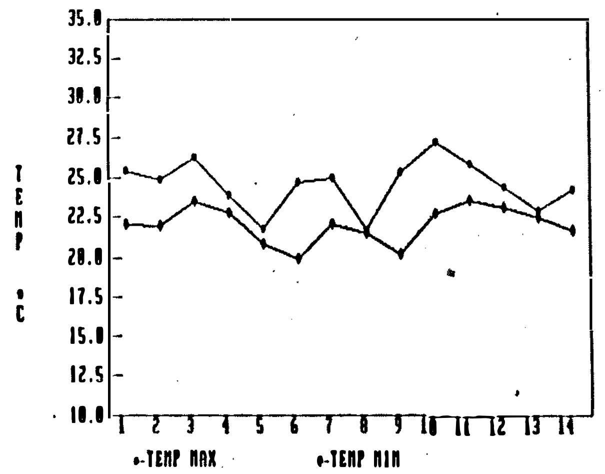
Temp = Temperature (daily maximum and minimum) °C

D.O. = Dissolved oxygen (daily maximum and minimum) mg/l

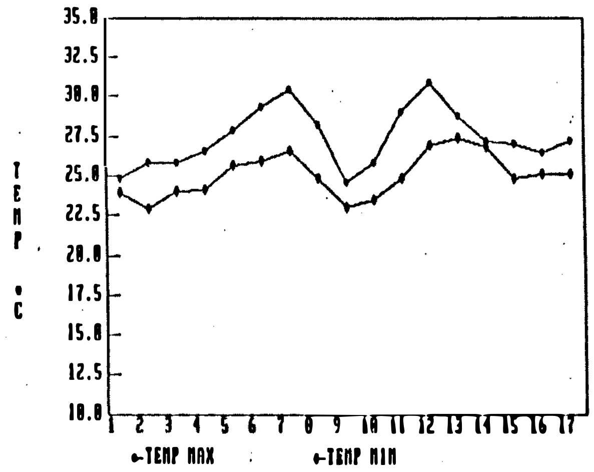
pH = pH (daily maximum)

NH_3 = Total ammonia (daily maximum) MgN-NH_3/l
(ammonia was undetectable during event 3)

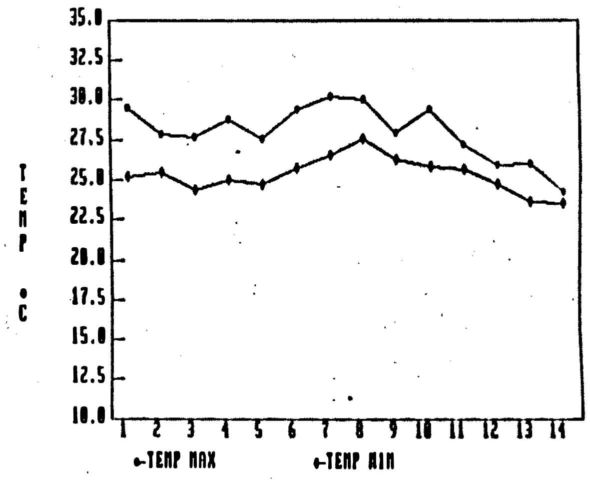
EVENT 1 TEMP



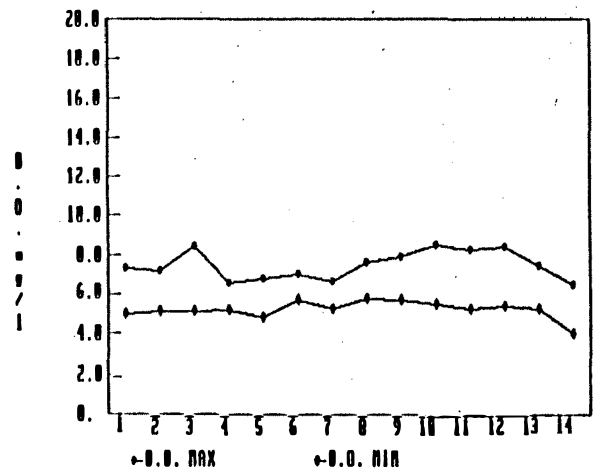
EVENT 2 TEMP



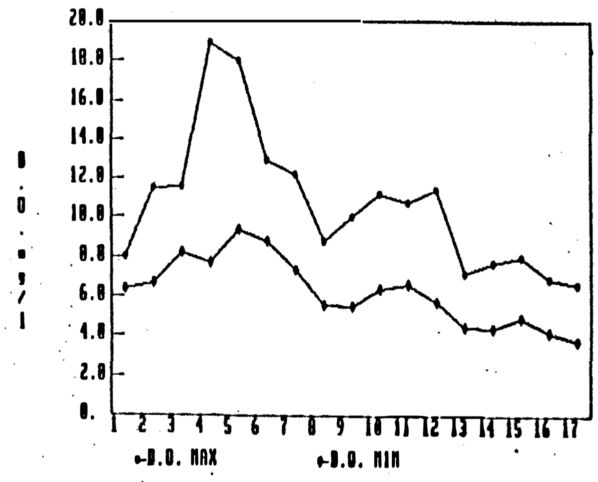
EVENT 3 TEMP



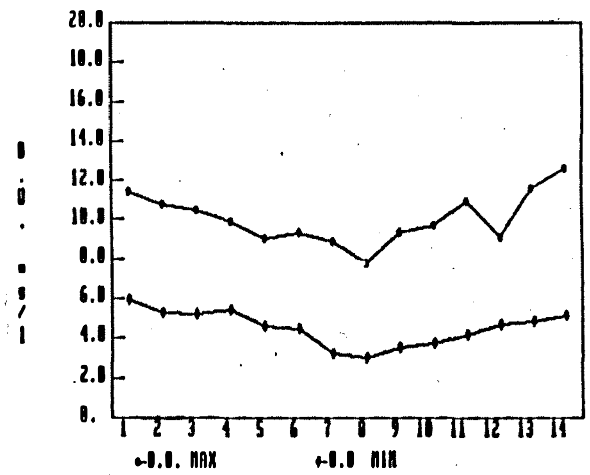
EVENT 1 D.O.



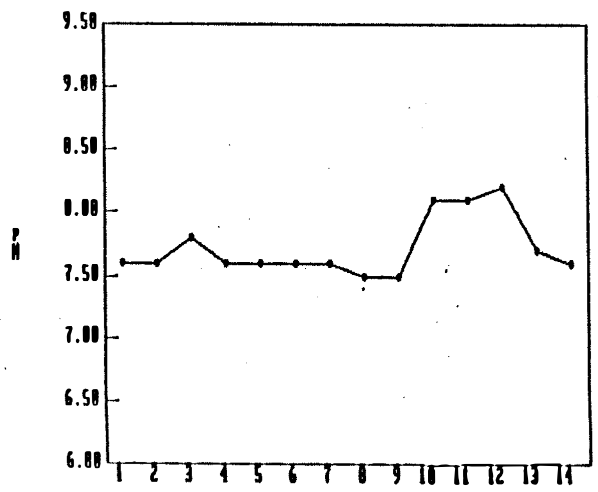
EVENT 2 D.O.



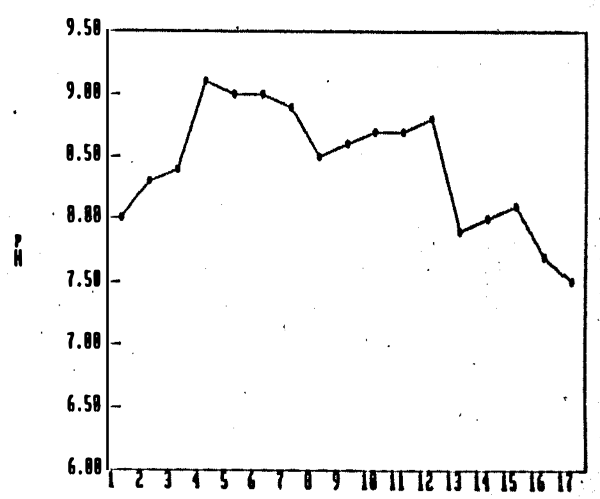
EVENT 3 D.O.



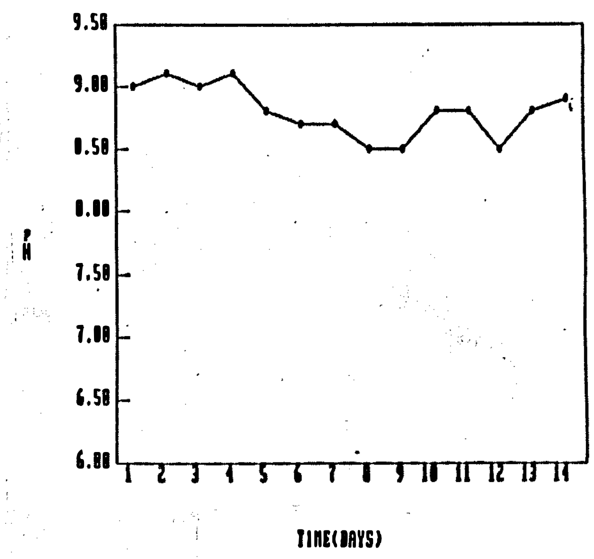
EVENT 1 pH



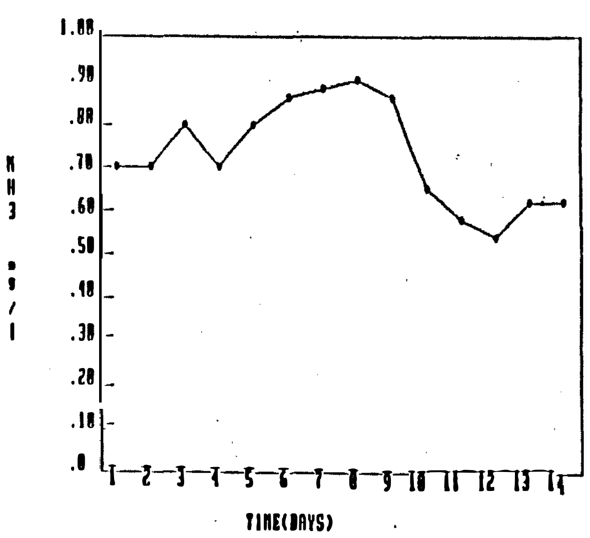
EVENT 2 pH



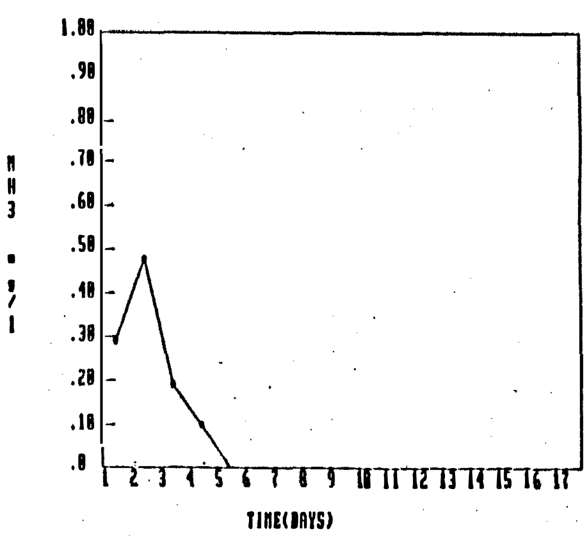
EVENT 3 pH



EVENT 1 NH3



EVENT 2 NH3



The first event, Fig. 1, depicts a period starting soon after the pond was filled and stocked for the first farming trial. The pond was relatively immature and consistently overcast weather initially and low phytoplankton production, was reflected by low dissolved oxygen levels (both maximum and diurnal range) and pH. Ammonia levels were relatively high during this period reaching a peak corresponding to minimum pH. After an improvement in the weather and an increase in algal activity, dissolved oxygen levels and pH increased and as ammonia was assimilated by the algae, total ammonia levels fell. Prior to and during this period there was little opportunity for the accumulation of organic material on the pond bottom, and the low biological oxygen demand probably accounts for the maintenance of adequate minimum dissolved oxygen levels.

The second event, Fig. 1 , was characterised by more extreme fluctuations and very high levels of dissolved oxygen and pH. This event occurred over a period starting several days after stocking of the second trial. Prior to this trial, the pond was fertilised with approximately 1500 kg of dried cow manure (the heaviest application used for any trial). A rapid response to the fertiliser resulted in the production of an extremely large algal bloom with very high dissolved oxygen levels (reaching a maximum of 18.9 mg/l) and diurnal range (maximum 11.2 mg/l). pH also increased rapidly to 9.1. The ammonia present in the pond was quickly assimilated and fell to undetectable levels. Although no prawn stress symptoms were observed following the extremely high dissolved oxygen and pH levels, such a large algal bloom was considered undesirable because of the possibility of the bloom "crashing" and depositing very large amounts of oxygen consuming organic material on the pond bottom. With the rapid uptake and removal of nutrients from the water column by such a large algal bloom, nutrients to sustain the bloom can become limiting and mass mortality of algal cells can occur very quickly. Depletion of dissolved oxygen on the pond bottom occurs following microbial decomposition of algal cells and in severe situations, anaerobic conditions can develop, the redox potential decreases and the activity of sulphur reducing bacteria can lead to the production of very toxic hydrogen sulphide (Boyd, 1982). For this reason additional water exchange was effected to reduce the extent of the bloom. This resulted in a reduction in dissolved oxygen levels and pH. Reduction of the bloom by flushing was aided by cooler, overcast weather conditions reflected by a decrease in maximum water temperature and temperature range at around day 9. With an improvement in weather conditions, days 10-12, algal activity again increased as evidenced by increasing dissolved oxygen and pH. (The massive bloom conditions of day 4 and 5 were not repeated.)

In summary the second event was characterised by the formation of an extremely large algal bloom which if allowed to develop unchecked, could have lead to serious problems with water quality, sediment condition and prawn growth.

The third event, Fig. 1 , occurred during the sixth and seventh week of Trial 4. Following experience gained during the first 3 trials, the practice of manipulating algal blooms in the pond by the addition of inorganic fertilisers was rationalised. During this trial it was found that a relatively stable bloom could be maintained by the regular additions of small quantities of fertilisers (10-15 kg superphosphate and nitram) in response to a steady decrease in dissolved oxygen levels (both maximum and diurnal range) and pH. During this event, water temperatures were relatively stable and fairly high (Fig. 1). Following a consistent decrease in dissolved oxygen levels and pH from day 1-8 (indicating a reduction in algal activity) 12 kg of superphosphate and 12 kg of nitram were added to the pond. The subsequent increase in algal activity caused an increase in dissolved oxygen and pH. The trough on day 12 corresponded with a period of cool overcast conditions and probably reflects a reduction in photosynthetic activity. During this event with relatively stable conditions (with a high level of algal activity) no ammonia was detected.

Water Quality Management

The potential for dissolved oxygen depletion in a prawn farming pond makes this parameter the most important in water quality management. When designing ponds consideration should be given to aligning the ponds (especially smaller units) to the direction of prevailing winds to maximise wind driven currents and aeration. In addition although continuous or even semi-continuous aeration is probably not necessary on a regular basis whilst a moderate algal bloom is maintained, the provision of some form of emergency aeration in all commercial prawn farming ponds is strongly recommended.

The initiation and maintenance of an algal bloom through fertilisation and water exchange is an important feature of pond management. If the pond is over-fertilised and the bloom allowed to develop unchecked, a rapid collapse can occur leading to major problems with build up of organic matter, subsequent dissolved oxygen depletion, sediment deterioration and in extreme circumstances, retardation of prawn growth and mortality. For this reason fertilisation practices should be carefully controlled and over-fertilisation avoided. Different ponds will require different applications of fertilisers (depending upon water supply and sediment characteristics). Initially ponds should be fertilised a few weeks prior to stocking to stimulate the production of natural food items. The dead and decaying algal cells form the basis of a natural food chain providing a food source for the prawns and other natural prawn food items such as bacteria and other microscopic fauna. In warm waters regular additions of small quantities of fertilisers should be sufficient to maintain a moderate algal bloom (e.g., Trial 4) which will help ensure adequate dissolved oxygen levels and prevent the build up of potentially toxic nitrogenous compounds such as ammonia or nitrite.

The results of the swimming pool trials indicate that high levels of water exchange on a regular basis are not necessary at moderate stocking densities and this augers well for the management of non-tidal ponds where pumping can be a major cost. However drainage and water exchange capacity should be sufficient to quickly flush out and reduce excessive algal blooms if and when necessary. In addition, if dissolved oxygen levels do decrease rapid drainage and water exchange will increase pond water circulation and aeration (especially if incoming water is sprayed over the pond surface) and could help prevent a crisis.

Pond drainage facilities should be designed so that bottom waters can be drained as well as allowing for overflow, e.g., after heavy rain, etc. Drainage facilities should be located at the ends of the pond where prevailing winds carry any floating vegetation. As this material sinks and decomposes it can be drained off the bottom thus reducing the risk of dissolved oxygen depletion.

To help prevent accumulation of uneaten food on the pond bottom the numbers and biomass of prawns stocked needs to be accurately determined, growth rates monitored regularly and feed rates calculated carefully. Prawns should be fed during the period of greatest activity, i.e., between dusk and dawn and food should be spread evenly over the pond surface.

Even with careful control of algal blooms and feed input the accumulation of organic material on the pond bottom can occur. It is advisable to drain ponds between crops to allow sediment to dry out and oxidise. Sufficient slope should be provided for complete pool drainage. The regular monitoring of water quality is a crucial feature of pond management. Whilst there is probably little need for a commercial farmer to have sophisticated facilities for determining all the water qualities parameters measuring during this pilot-scale programme, monitoring of temperature, salinity, dissolved oxygen and pH are recommended.

Dissolved oxygen and pH should be monitored early morning and late afternoon so maximum and minimum values (and daily range) can be recorded.
Fluctuations in these parameters will give farmers a guide to the level of algal activity in the pond and will form the basis for many of the pond management decisions.

CONCLUSIONS

* The most critical water quality parameter is dissolved oxygen. Low levels can occur especially on hot, still mornings or following algal bloom collapse.

* Continuous aeration not necessary with careful pond management, however provision of emergency aeration strongly recommended.

* Ponds should be aligned to prevailing winds to maximise wind driven circulation and aeration.

* Maintenance of moderate algal bloom advisable to stimulate production of natural food items to maintain adequate dissolved oxygen levels, to ensure assimilation of ammonia and nitrite and to prevent colonisation of the pond bottom by macrophytes.

* Regular additions of small quantities of fertilisers can be used to maintain a moderate algal bloom.

* Monitoring of diurnal fluctuations in dissolved oxygen and pH advisable to indicate extent of algal activity.

* High rates of water exchange on regular basis not necessary but capacity for high rates of exchange to flush out excessive algal production recommended.

* Accumulation and decomposition of large quantities of organic material can lead to chemically reduced sediments with low redox potential and production of hydrogen sulphide.

* Feed rates should be carefully calculated to prevent overfeeding.

* Capacity for rapid drainage of bottom waters following accumulation of organic material or low bottom dissolved oxygen levels recommended.

* Ponds should be drained and dried out between crops to oxidise sediments.

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APPENDIX 1

PRAWN FARMING OPEN DAY PRINTED TALKS

Agdex 486

PRAWN FARMING OPEN DAY

Wollongbar Agricultural Research Centre

4th July 1985

Department of Agriculture New South Wales

P R A W N F A R M I N G O P E N D A Y

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C O N T E N T S

PRAWN FARMING IN NEW SOUTH WALES - PILOT SCALE POND TRIALS AND THE PROSPECTS FOR THE EMERGING INDUSTRY

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Several Asian countries have long practised traditional forms of prawn farming based on the postlarval prawns entering ponds during tidal inflow and minimal subsequent pond management. Pioneering research in Japan led to the development of commercial prawn hatcheries and a sophisticated farming industry in Japan in the 1960's. This stimulated interest in prawn farming in western countries and in particular a large amount of research has been carried out in the U.S.A. However commercial prawn farming has been slow to develop in western nations although it has become a major industry in many developing tropical countries. There have been several abortive attempts at commercial prawn farming in Australia (Heasman, 1984) but surprisingly little interest in prawn farming research. In the past, the Department's Fisheries Division has been the only state fisheries authority to take the far sighted initiative of commencing a prawn farming research programme. However, at the recent Second National Prawn Seminar it became apparent that there has been an upsurge in interest in prawn farming among potential investors and research workers in Australia.

Experimental and pilot scale studies

Several years of research has been carried out at our Salamander Bay research station aimed at developing a technology for growing school prawns *Metapenaeus macleayi* in ponds. The initial purpose of this work was to see if the marketing problems caused by the very large catches of unusally small school prawns in the Clarence River could be overcome by fattening them in ponds prior to being sold. A detailed summary of this small scale experimental work is given by Maguire and Allan (1985). Briefly it has been shown that : (1) this species is adaptable to a wide range of environmental conditions; (2) it is capable of rapid growth with low mortality in pens within ponds; (3) at a stocking density of 20 juveniles per square metre moderate inputs of inexpensive chicken broiler diets are adequate in ponds which sustain sufficient natural food levels; (4)various fish are potential predators and competitors with prawns for food in ponds but should be manageable, and (5) a high quality product can be produced.

For several reasons it was decided that a pilot scale study should be conducted in a 1 ha pond in the Clarence River area: (1) we required production data from a larger scale system than small experimental units so that realistic economic analyses could be carried out; (2) it was necessary to see if the promising growth rates already obtained could be achieved in larger ponds; (3) when trials have been carried out in whole ponds at Salamander Bay, survival rates had often been disappointing. It was hoped that locating the pilot scale pond closer to a convenient source of juveniles would reduce handling stress and improve overall survival rates in ponds; (4) the Salamander Bay ponds receive abundant tidal water exchange but commercial ponds are more likely to rely on pumping for water exchange. It was considered necessary to obtain experience in managing non-tidal ponds where water exchange is usually carefully controlled to reduce costs; (5) finally, if an extension service was to be provided to farmers it is clearly necessary to have first hand experience with the range of problems which farmers are likely to experience, e.g., predator control.

A site for the pilot scale pond near Brooms Head was chosen for two major reasons. Firstly, the pond could be readily stocked with the help of the commercial trawlers operating in the adjoining Lake Wooloweyah school prawn fishery. Secondly, although the site had obvious logistic problems, the land and pond were made availale free of charge by Mr. Max Carson without whose assistance this project may not have eventuated.

The results of the pilot scale farming trials are shown in Table 1 and Figure 1. A summary of the environmental conditions which prevailed in the pond during the trials is given in Table 2. Overall the growth results were somewhat disappointing and the survival rates were encouraging. Trial 1 was characterised by initial rapid growth followed by slower growth after prawn stress symptoms were observed following an extended period without water exchange. Subsequently a water exchange rate of 6-10% of pond volume per day was used as a precaution. Although growth rates were low during Trial 2, the overall production results were impressive considering the very low pond salinity levels throughout the trial (average of 5.2‰). Trials 3 and 4 may have been affected by deterioration in the condition of the pond sediment. This probably resulted from excessive build-up of organic matter on the pond bottom. This build-up can be caused by excessive algal blooms or by over-feeding due to over-estimations of survival rates during the trials.

The major problems posed by predators related to cormorants (*Phalacrocorax* spp) fishing in the pond mostly during Trials 2 and 3 although approximately 100 eels (mostly *Anguilla reinhardtii*, the long-finned eel) were recovered from the pond during the Trial 3 harvest. Although small numbers of stressed prawns were occasionally seen in the pond, pond water quality readings were generally considered to be acceptable. Predators and at least the more readily measurable pond water quality factors, e.g., dissolved oxygen levels, were not thought to be major causes of prawn mortality. Initial post-stocking losses caused by the stress experienced during capture, transport to the pond and stocking into the pond was probably a major cause of mortality, particularly for Trial 4 when overall survival was poorest. The impact of the sediment deterioration problems is difficult to assess but certainly it was undesirable in terms of obtaining high survival rates.

The production results from the four trials are probably best considered in terms of the Commonwealth Development Bank's economic analyses (see F. Hardy's Prawn Farming Open Day Paper). Overall these results meet the major assumptions made in these economic analyses. Total production in each trial exceeded 800 kg per ha and the average price received for the prawns was in excess of $6.00 per kg. However the weight of prawns stocked was in some cases in excess of 400 kg per ha depending on the average initial size of the prawns. More importantly only two crops per year were farmed during the pilot scale trials while the economic analyses allow for three crops per year. The initial results from an ongoing farming trial being undertaken by Mr Frank Roberts at Yamba in 15 ha of ponds suggest that a third crop extending into winter months is indeed feasible. A more comprehensive summary of the pilot scale results will be made available in Maguire and Allan (1985) and Maguire *et al.* (1985).

Prospects for a New South Wales Industry

Partially as a result of the Department's pilot scale research programme and of course also through their own initiatives, two commercial prawn farmers have

Constructed ponds near Yamba. While these farmers have experienced a variety of pond management problems and have recorded rather variable prawn production results, school prawns of high quality and value have been harvested from these ponds. Both farmers seem encouraged by the prospects for a prawn farming industry in northern New South Wales although they would prefer to have a reliable supply of juveniles from a hatchery rather than depending on the collection of juveniles from estuarine fisheries. Certainly the supply and price of juveniles collected by fishermen can be unpredictable and clearly this is undesirable for commercial operators seeking predictable financial returns. Also, the logistics of stocking large areas of ponds with juveniles from the wild does not always allow as much care as can be taken with stocking a pilot scale pond and hence initial post-stocking mortality can be a problem for commercial operators.

If a hatchery reared supply of juvenile school prawns were to become available, then this species has some major advantages for commercial prawn farming. The existing experimental, pilot scale and commercial results indicate that it is definitely suitable for pond culture. Moreover while growth rates may be better at higher salinities, school prawns can be farmed successfully at very low salinities. Experimental studies at Salamander Bay indicate that when more nutritionally complete diets are used, this species has considereable potential at much higher stocking densities than 20 juveniles per m^2. The two major disadvantages of school prawns for farming are firstly, that the availability of spawners for hatchery purposes is apparently very seasonal and secondly, that they do not grow to a size suitable for lucrative export markets.

If commercial hatcheries develop as seems likely then several alternative species could be considered. Greasyback prawns (*Metapenaeus bennettae*) are unusual in that unlike most penaeid prawns they do not migrate into oceanic waters to reproduce. They readily mature in ponds but their maximum size is even smaller than that of school prawns and the results of farming trials conducted using greasyback prawns at Salamander Bay have not been promising. Eastern king prawns (*Penaeus plebejus*) are likely candidates for farming in New South Wales as they have a temperate distribution similar to that of school prawns. Species with more tropical distributions could be considered but shorter growing seasons should be expected. The tiger prawn (*Penaeus esculentus*) is one of these species but it is noteworthy that promising growth rates have been reported from New South Wales commercial ponds with this species and with eastern king prawns. Other tropical species which could be considered are the jumbo tiger prawn (*Penaeus monodon*) and the banana prawn (*Penaeus merguiensis*).

The Fisheries Division takes a cautious attitude towards prawn farming in New South Wales. While some promising results have been obtained it is still the case that prawn farming is more suited to investors seeking a pioneering role rather than those looking for exhaustively researched forms of agricultural investment with predictable financial returns. Furthermore it should be noted that there are few comparable examples of profitable, large scale, marine prawn farming industries in western temperate areas.

Regardless of these comments, future investment in prawn farming in New South Wales seems likely. Certainly it should be acknowledged that local commercial farming skills have grown quickly and that in a world wide sense prawn farming technology is developing rapidly. In particular the results from ponds in Taiwan and the Philippines have shown that the potential yields from conventional ponds are much higher than had previously been thought likely (New and Rabanal, 1985). Furthermore there is a lucrative local market which prawn farmers can exploit by producing a high quality product at times when market demand is usually high, e.g., Christmas and Easter or when relatively few prawns are being caught in established fisheries, e.g., during poor weather or in winter. If New South Wales prawn farmers produce sufficient quantities of larger penaeid species then they could supply established export markets for which there is considerable growth potential (New and Rabanal, 1985).

A very major problem faced by the existing farmers is that of preventing cormorants from preying upon prawns within ponds. In smaller farms where the owner lives on site it is possible although undesirable to control the problem by shooting birds which enter ponds. This does not seem feasible for very large farms. Ideally a harmless cormorant deterrant system could be set up but the existing systems, e.g., gas-powered scare guns and ultrasonic deterrant devices, have yet to be proved to be effective. A research programme on cormorant control, carried out by an applied scientist who has experience with bird research, would be most welcome.

Another problem concerns previous land use of proposed prawn farming sites. If large amounts of persistent agricultural chemicals have been applied to the soil, e.g., pesticides on cane farms, then it is possible that unacceptably high residue levels could develop in prawns within ponds built using this soil (see R. William's Prawn Farming Open Day paper). Also it seems unwise to expose valuable agricultural soils to overlying seawater as this may well render them unusable for future terrestrial agriculture.

The Department's role in prawn farming

This Department has several roles to play in relation to the emerging prawn farming industry in New South Wales, i.e., regulation, extension and research. Prawn farming licences are issued to enable the Department to collect statistics on commercially farmed prawn production and more importantly to respond to any disease outbreaks and to ensure that existing regulations are complied with.

If the industry expands there will be an increasingly important role for the Department to play in the area of extension work so that potential and existing farmers can be advised on aspects of site selection and pond design and management. The Fisheries Division also has extensive experience with hatchery procedures for a variety of aquatic species and could no doubt be of assistance to any future commercial prawn hatchery operators.

The Division's future prawn farming research programme is likely to undergo some major changes. The pilot scale project has been completed and if there is close cooperation between the Division and commercial prawn farmers it is unlikely that pilot scale work would have to be carried out again by the Division for some time. Instead there should be a detailed investigation of problems, identified in pilot scale and commercial trials, using carefully controlled experimental systems suitable for in depth monitoring of appropriate factors. Priority will be given to investigating the problems of pond management in terms of maintaining adequate water quality, sediment condition and natural food levels. Also it is likely that more nutritionally complete diets will have to be developed if high prawn biomass levels are to be sustained in ponds either through the use of higher stocking densities or alternatively through longer growout times with larger penaeid species. Some of the essential initial research, e.g., on the relationship between water temperature and growth, may have to be repeated using some of the alternative species to school prawns.

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TABLE 1 Summary of growth, survival, production and marketing results from four pilot scale (1 ha) Clarence River farming trials using school prawns *(Metapenaeus macleayi)*

Parameter	Farming Trial 1	2	3	4
Duration (weeks)	8	12	10	8-10*
Stocking density (no/m^2)	17.4	20.1	27.0**	20.9
Av. prawn weight (g)				
At stocking	3.2	1.8	1.5	3.0
At harvest	6.9	6.6	5.4	7.6
Total weight of prawns (kg)				
At stocking	548	370	419	617
At harvest	829	950	877	825
Survival rate (%)	69	71	61**	52
Av. market price ($/kg)	4.28	6.77	6.31	9.33

* Prawns stocked on two occasions separated by a two week period.

** The high percentage of very small prawns stocked in Trial 3 makes accurate estimations of initial stocking density and hence survival rate difficult.

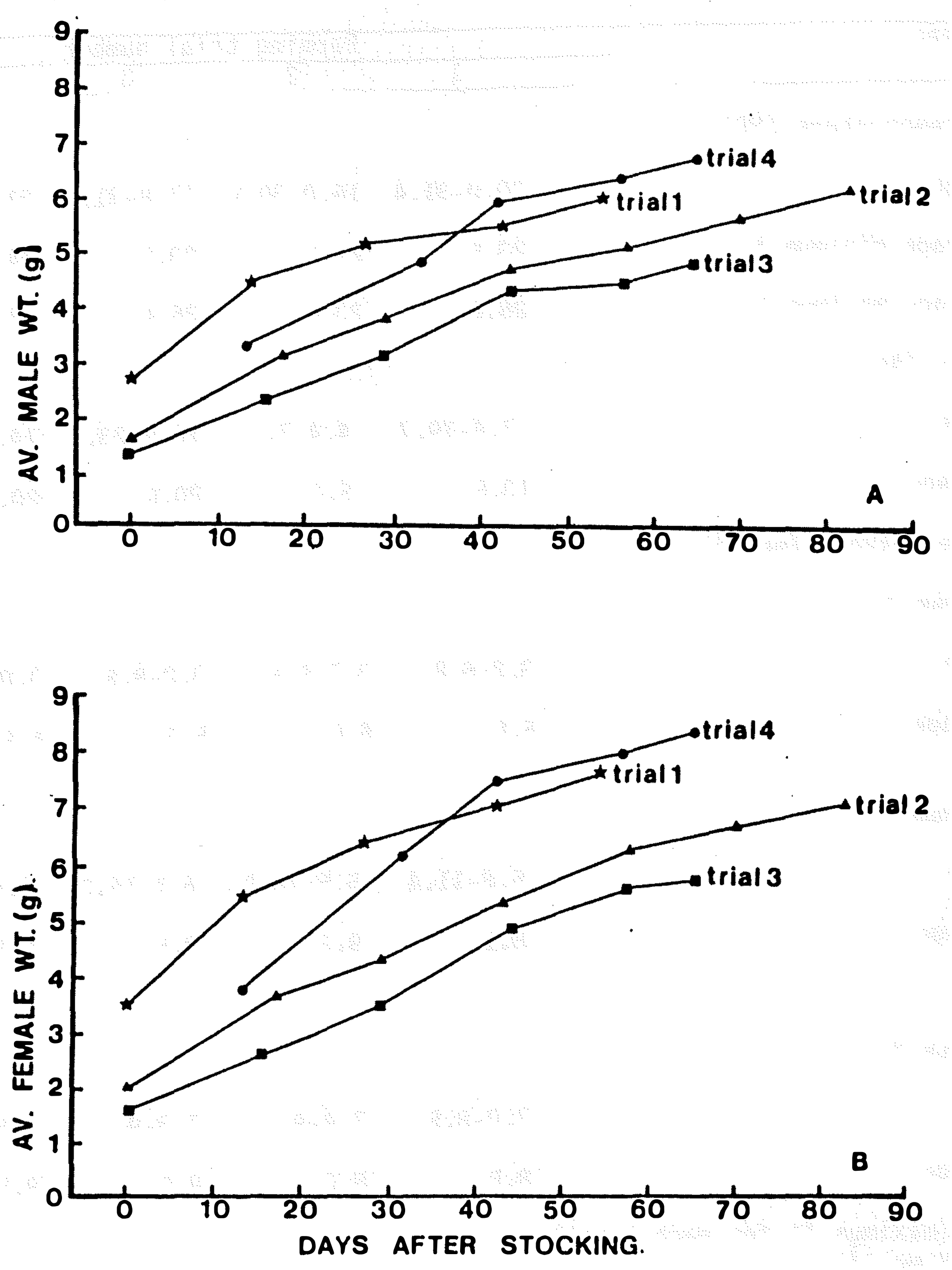

Figure 1. Growth of male A and Female B school prawns (*Metapenaeus mcaleayi*) during four pilot scale (1 ha) Clarence River Prawn farming trials.

TABLE 2. Summary of pond water quality results from four pilot scale (1 ha) Clarence River Farming trials using school prawns (*Metapenaeus maclayi)*

Parameter	Farming trial number			
	1	2	3	4
Water temperature (^{o}C)				
Range	20.0-31.4	16.0-30.9	17.8-31.6	21.3-30.8
Average minimum *	23.9	21.2	23.2	24.9
Average maximum *	26.8	23.6	26.4	27.9
Salinity (%o)				
Range	7.4-19.7	4.4-7.1	16.9-23.6	14.5-27.5
Average	13.8	5.2	20.0	20.1
Dissolved oxygen (mgl^{-1})				
Minimum *				
Range	3.2-6.8	3.7-9.4	3.2-8.8	3.0-6.7
Average	5.0	6.0	5.3	4.9
Minimum *				
Range	5.8-11.4	5.5-18.9	6.1-15.2	5.0-15.8
Average	8.1	9.3	9.5	9.9
pH				
Maximum *				
Range	7.0-8.8	7.4-9.1	7.3-9.1	7.5-9.1
Average	8.0	8.2	8.0	8.5
Ammonia (maximum ** for each trial) (NH_3-N mgl^{-1})				
Total	1.2	1.2	0.9	1.6
Unionized	0.17	0.07	0.09	0.05
Nitrite (maximum for each trial) (NO_2-N mgl^{-1})	<0.02	<0.02	<0.02	<0.02

* Readings based on continuous recordings or individual readings taken at times of day when maximum or minimum readings usually occur for each parameter.

** The minimum total ammonia readings for each trial were all <0.1 mg l-1 and 61% of all pond total ammonia readings were <0.1 mg l-1. At these levels unionized ammonia concentrations are negligible.

SITE SELECTION, DESIGN AND WATER QUALITY MANAGEMENT FOR PRAWN FARMING PONDS

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There are two quite distinct phases of prawn farming, the hatchery phase and the growout phase. The discussion of the enviromental requirements of prawns and their influence on site selection refers to the growout phase in ponds. Areas suitable for ponds and growout operations will not necessarily be suitable for hatchery operations. Hatcheries require a smaller supply of high quality water preferably of oceanic salinity and quality. In addition, temperature and sediment type will be less important and generally less land will be required.

When a prawn farmer constructs a prawn pond he is creating an artificial environment with conditions which he hopes will favour high growth and survival rates. The more information the farmer has on the environmental requirements of the target species, the better the basis for appropriate pond siting, construction and management decisions. Different species have different environmental requirements, thus some sites will be suitable for some species and not others. At this early stage in the prawn farming industry, before a hatchery supply of juveniles is available, it is advisable that wherever possible, potential farmers locate in areas suited to the culture of a range of species.

Research at the N.S.W. Department of Agriculture's, Fisheries Research Station at Port Stephens and in a 1 ha pilot-scale prawn pond adjoining the southern shore of Lake Wooloweyah in the Clarence River system, New South Wales, has provided considerable information on the environmental requirments of school prawns *(Metapenaeus macleayi)*. This information on the effect of temperature, water quality factors (e.g., salinity and turbidity) and sediment type on prawn growth is discussed in relation to site selection.

Temperature

To determine optimum temperatures for school prawn growth we ran an experiment in aquaria with prawns grown for 6 weeks at temperatures ranging from 15°C to 30°C. This indicated that maximum growth rates were obtained at 21°C to 27°C while growth was depressed at 18°C and 30°C and was very slow at 15°C. These results indicate that the further north New South Wales prawn farmers locate their farm, the longer the period when maximum growth rates can be expected (Table 1).

To demonstrate statewide differences we have combined mean monthly temperature data taken over 8 years from seaward sites in three major northern estuaries (Tweed, Richmond and Clarence) with similar data from seaward sites in three southern estuaries (Shoalhaven, Clyde and Tuross) (Fig. 1).

The number of months with mean surface water temperatures above 21 C, the minimum optimum temperature for school prawn growth, in the north was 7 and in the south only 4. The number of months above 18^{o}C was 10 and 6 respectively and for 15^{o}C, 12 and 9 respectively.

Thus the growing season is appreciably shorter in the southern areas of the state and hence, solely on the basis of temperature, production would be reduced.

Similar growth and temperature data for other local species is not available but we expect species with a predominantly northern distribution, e.g., Banana prawns *(Penaeus merguiensis)*, giant tiger prawns *(P. monodon)* and even the tiger prawn *(P. esculentus)* to have higher temperature requirements.

Water Quality

Salinity

In aquaria with an experimental range of 10-30‰ school prawn growth and survival increased as salinity increased from 10-25‰. However in the second farming trial at the 1 ha pilot-scale prawn farm on the Clarence River, growth was slow but acceptable and survival good (71.3‰) even though salinity was very low (5.2‰ average). There are tropical species which tolerate low salinities (e.g., *Penaeus monodon)* (Shigueno, 1975) however most local penaeid species have much higher requirements than school prawns. The lower lethal limit of salinity for adult king *(P. plebejus)*, tiger *(P. esculentus)* and banana *(P. merguiensis)* prawns was 7, 10 and 7‰ respectively (Dall, 1981). Juveniles of these species are more tolerant of lower salinities (Dall, 1981).

For future flexibility and in order to adapt to potential hatchery supply, prospective prawn farmers are advised to locate in areas with as high a salinity as possible. In some cases it wil be possible to reduce or even avoid water exchange for short periods when salinities are very low, e.g., as a result of increased river flow. However, this will depend on the density of prawns stocked in the pond and also to some extent on requirements for water exchange to help control pond variables such as dissolved oxygen and pH.

It is most important for prospective farmers to have detailed information on the salinity regime of their prospective water supply including recovery time after river "freshes" and floods.

Contamination

When assessing the suitability of the sea water supply attention must also be given to other features which may render it unsuitable for prawn farming.

Contamination from industrial or agricultural wastes for example should be avoided.

Turbidity (as suspended silt)

Research in aquaria indicated that school prawns are very tolerant of high turbidity levels. This is supported by the often high turbidity in their natural environment. However supplying water of high turbidity to prawn ponds can be undesirable because of the subsequent build up of silt on the pond bottom. This can pose problems with harvesting and cleaning prawns prior to marketing, with managing algal blooms and with draining and drying the pond.

These aspects will be dealt with in more detail in the next section.

Sediment type

Behavioural studies with school prawns indicate that they preferred to burrow in fine sand (Ruello, 1973). However experiments in aquaria with 4 different substrates; bare perspex, fine and coarse sand and mud, indicated that the physical characteristics of substrate had little effect upon school prawn growth. This result was supported by studies of prawns grown in small 0.01 ha ponds with concrete and sand bottoms.

However the suitability of a sediment for prawn pond construction can depend upon several other factors including the cost of constructing ponds which do not leak. For example, some heavy earthmoving equipment cannot operate in soft muds and some sandy soils will not hold water.

The pH (or acidity level) of the sediment can also be critical, with acid soils leading to problems with reduced pH levels in pond water, difficulty in pond management and in extreme cases reduced growth and even prawn mortality. In some subtropical and tropical areas overseas where prawn farms have located in coastal areas in mangrove soils problems have been experienced with acid-sulphate soils. Oxidation of pryite in these sediments yields large amounts of acid leading to reduced yields (Simpson *et al.* 1983, Webber and Webber 1978). In prawn ponds in Costa Rica prawn growth was low in acid waters and ceased when pH fell below 5 (Webber and Webber 1978).

In some areas of the north coast, the climate, vegetation and sediment may favour the formation of acid soils and it is advisable that prospective farmers test the pH of the sediment, ensuring that levels are also measured in the sediment layer to be used on the pond bottom and pond walls.

Several strategies can be employed to reduce the problems with acid soils both during the construction phase and after farming has commenced: (1) offending sediment can be removed; (2) lime can be mixed into the soil during or prior to filling the construction, and (3) lime can be added to the pond after filling, or (4) increased water exchange can be effected. These strategies will vary in effectiveness depending upon the severity of the problem.

Pond sediment with a high silt content can lead to problems with harvesting and product quality. Mud or silt adhering to the exoskeleton and pleopods (legs) of prawns can be difficult to remove and sometimes results in a discolouration of the prawns after cooking and a reduction in marketability. Furthermore sediments with a high silt content often result in excessively turbid ponds which can increase the likelihood of thermal and dissolved oxygen layering (stratification) and adversely affect water quality management. Also the availability of phosphate fertilizers can be reduced (Boyd, 1982).

It is apparent therefore that although the initial determining factors in selecting a suitable site are the environmental requirements of the prawns themselves, for example temperature and salinity tolerances, it is also important to consider the implications that features of the site, for example, sediment type and pH, have on pond construction and pond management procedures.

Pond Design

Once the location has been chosen decisions need to be made about pond design. The overall size of the farm will be determined by the scope of the planned operation, financial considerations and by the availability of suitable land. However, the size of the individual ponds will also need to be decided. This decision will be influenced by the topography of the land, the amount of material available for pond wall construction, the location of the water supply and the proposed stocking procedure and density.

The advantages of larger ponds, e.g., between 5-10 ha over a series of smaller ponds are: (1) they need less material per ha for wall construction; (2) they are less expensive and quicker to build, and (3) they generally require less duplication of pumping, aeration, water outflow and boating equipment. The disadvantages are: (1) they are more subject to wave erosion; (2) they can be difficult to harvest efficiently; (3) they are slow to fill and drain; (4) they are more difficult to manage particularly when rapid water exchange is required during crisis periods, and (5) disaster in one pond represents loss of a greater proportion of farm income.

With relatively low stocking densities of up to about 20 prawns/m^2 the economics of scale make the advantages of large ponds particularly attractive. However, if we follow the example of Taiwanese prawn farmers and move to increased stocking densities and more intensive pond management procedures then smaller ponds <5 ha will probably be desirable. In some cases it will be possible to design farms in which large ponds are initially constructed but with provision (in terms of available soil, etc.) to subdivide later to form smaller ponds (e.g., 1-2 ha) allowing each unit to be managed separately and with greater control.

Robust pond walls should be constructed that will stand up to the ravages of wind induced wave erosion. A gentle batter or slope on the walls will reduce the effect of wave erosion. In addition it is advisable to construct walls that are wide enough for heavy vehicles. This will allow access for tractors to transport fertilisers or feed, or if required, to position emergency aeration equipment along the banks. Tractor drawn harvest nets may also be designed and used in some areas.

Some pond bottom slope is desirable to enable the pond to be dried out to eradicate predator fish and if necessary to oxidise chemically reduced sediments. For some species, especially non-burrowing or shallow burrowing species, e.g., tiger prawn (*P. esculentus*), harvest by drainage may be possible. This will require adequate slope to enable rapid drainage to ensure that the prawns exit with the outflowing pond water, and do not become stranded in the drained pond.

Ponds should be deep enough to restrict: (1) wading birds feeding in the pond, (2) overheating of pond water on hot sunny days, and (3) colonization of the pond bottom by attached algae. However if ponds are too deep they: (1) are more expensive to construct as walls need to be higher, (2) require greater pumping and draining capacities, and (3) are more difficult to manage in terms of algal activity, water exchange and aeration. In most areas pond depth of about 1 m will satisfy these requirements.

The pond water outflow system must be capable of removing water added during water exchange. It is also desirable in some cases to be able to draw off bottom waters laden with excess organic materials and nutrients and to allow replacement of oxygen deficient water with well aerated water from the supply point. The need for this type of management procedure will also increase as stocking density increases.

One of the major functions of the outflow system is to allow the run off of rainwater. This is especially true for farms located in lower salinity areas and in areas with high rainfall. In the 1 ha pilot-scale prawn farm on the Clarence River we found that a 1 m wide concrete raceway was sufficient to prevent decreases in salinity as a direct result of rainfall although the sea water supply will eventually be diluted by persistent rainfall.

Pond Water Quality Mangement

After the site has been chosen and the ponds constructed and filled, the prawn farmer must aim to manage the water quality in his artificial prawn habitat to provide the prawns with an environment which is most conducive to rapid growth. Table 2 lists some of the features which comprise water quality. This list indicates the complexity of water quality dynamics especially when one realises that many of these variables interact.

In a prawn pond these variables can be influenced by the climate, characteristics of the water supply, sediment characteristics (soil pH, mineral levels, etc.), fertilizer inputs, liming, additions of artificial feed, water exchange and aeration. Some of the ways a prawn farmer can manage water quality are given in Table 3.

The initiation and manipulation of an algal bloom is one of the most important features of pond management. A well maintained algal bloom produced in the pond serves several roles: (1) dead and decaying algal cells form the basis of a natural food chain and provide a food source for prawns and for other natural prawn food items such as bacteria and other microscopic fauna, (2) dissolved oxygen levels are usually maintained by the process of photosynthesis which is carried out by the phytoplankton, (3) potentially toxic metabolic wastes such as ammonia and nitrite are assimilated by algae, and (4) the phytoplankton reduce light levels in the pond and hence restrict colonisation of the pond bottom by large attached macrophytes and filamentous algae which can present problems when harvesting or managing the pond.

An algal bloom is produced by fertilizing pond water thereby increasing nutrient levels and accelerating phytoplankton production. Either inorganic fertilizer, e.g., super phosphate, Nitram and Urea, or organic fertilizer, e.g., cow manure, may be used. In larger ponds the logistics of using organic fertilizers such as manures may render them unsuitable however they do have the advantage of providing a "ready made" fibre source which can be beneficial for increasing natural food especially in newly constructed ponds. Conversely, inorganic fertilizers can be combined to provide a more balanced nutrient source and inbalances in one nutrient can be more readily redressed, e.g., the addition of silica. Fertilizer application rates vary considerably according to sediment and water supply characteristics. In some areas with acidic soils applications of lime will help neutralise the acidity and allow the nutrients added during fertilization to be utilized by the algae. Initially fertilizer should be applied (e.g., 100 kg/ha of both super phosphate and nitram) prior to stocking to enable sufficient time for a good bloom to develop and for the production of some natural food. During the farming process regular additions of fertilizer in smaller quantities (e.g., 10-20 kg/ha of both super phosphate and nitram) should be added to ensure that adequate nutrients are available to maintain the bloom. The timing of such addition will depend primarily upon measurements of dissolved oxygen, pH, secchi depth and visual observation.

Water exchange

Depending upon location and pond design, a prawn farmer will be able to fill ponds and exchange water by tidal activity, pumping or a combination of both. Tidal exchange will usually be less expensive than pumping and enable the exchange of greater quantities of water. However suitable locations with appropriate tidal amplitude will probably be scarce, pond construction costs will probably be higher and difficulties with complete pond drainage may be experienced.

In a series of experiments conducted in swimming pools at the Clarence river pilot prawn farm water exchange rates (0-40%/day) had no effect on prawn growth or survival at a stocking density of 20 juveniles/m^2. At 50 prawns/m^2 with water exchange rates 0-20%/day growth was unaffected but mass mortality was experienced in one 0% exchange rate pool. This research indicates that there is little advantage in a management strategy of daily water exchange, however as a management tool in times of crisis water exchange may be used to: (1) reduce excessive algae blooms; (2) flush out water laden with nutrients and organic material; (3) supply well aerated water to ponds with low dissolved oxygen concentrations; (4) help break up thermal and oxygen stratification, and (5) improve pH levels in ponds with acid waters. In these situations the effectiveness of water exchange will depend upon the severity of the problem and the amount of water exchaged. The ability to rapidly exchange water during crisis periods will minimise the risk of prawn stress and mortality. As stocking densities increase the need for increased water exchange capacity will also increase. For example, more intensive farms in Taiwan can produce yields in excess of 5-10 t/ha/yr and increase water exchange rates up to 50-100% pond volume/day as they approach harvesting time.

Aeration

Probably the single most important water quality factor for prawn farming is dissolved oxygen. This is strongly influenced by the dynamics of the algal bloom and the amounts of oxygen consuming organic material on the pond bottom. The purpose of aeration is to increase the dissolved oxygen concentration in oxygen deficent pond waters. Dissolved oxygen is transferred from air to water by diffusion. The rate of diffusion will depend primarily on the amount of water surface exposed to the air, the dissolved oxygen concentration in the water and the degree of turbulence (Boyd 1982).

Aeration can be accomplished by several mechanisms including: (1) wind induced wave action and turbulence; (2) aerating water during water exchange by spraying incoming water over the pond surface, and (3) by artificial aeration, e.g., paddle wheels, turbines, air compressors.

Artificial aeration may be operated on a continuous or semi-continuous basis or during emergencies only.

In a pond with a well managed algal bloom, regularly swept by prevailing winds, dissolved oxygen will not normally be a problem and continuous or even semi-continuous aeration is probably not necessary. However during periods of prolonged overcast weather, on hot still summer mornings or following phytoplankton die-off, rapid declines in dissolved oxygen can occur. Prawns respond to low oxygen stress by swimming to the edge of the pond, swarming near the surface and jumping out of the pond. Growth will be reduced in waters with low dissolved oxygen concentration and in severe cases mass mortality can result.

In such situations, emergency aeration could save the crop. This can take the form of tractor driven paddle wheels, pumps and sprayers, emergency air compressors and even towing various devices behind boats. Research so far has indicated that tractor driven paddle wheel aerators are the most efficient (Boyd 1982, Petrille and Boyd 1984).

Pond Water Quality Monitoring

At the Clarence River 1 ha pilot scale prawn farm the following water quality factors were monitored: Temperature, salinity, dissolved oxygen, pH, ammonia, nitrite, nitrate, phosphate, silica and phytoplankton pigments. A commercial prawn farmer will not need information on many of these factors, however he will need to be able to measure the algal activity in his ponds in order to make decisions about water exchange, aeration and fertilization. The best parameters to measure to provide this information are dissolved oxygen and pH. Both these factors should be measured each day, preferably first thing in the morning and last thing in the afternoon. An increase in algal activity will result in an increase in pH values and an increase in the difference between morning and afternoon dissolved oxygen levels. Both dissolved oxygen and pH meters are available, however they are relatively expensive and very careful attention needs to be paid to calibration of the instruments.

Temperature and salinity should also be monitored on a regular basis to help make decisions on water exchange and feed rates. Temperature and salinity are easily measured using a thermometer and a hydrometer. An additional measurement which has proved useful in some ponds in secchi-depth. In ponds with low suspended silt levels, secchi-depth measurements are a good guide to phytoplankton density. This measurement has the advantage of being quick and inexpensive.

Finally the importance of visual observation when making management decisions cannot be underestimated. With experience a farmer will be able to assess algal activity visually and by observing the prawn behaviour and growth adjust his pond management accordingly.

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TABLE 1. Mean monthly surface water temperatures for northern and southern estuaries in New South Wales[a]

Month	J	F	M	A	M	J	J	A	S	O	N	D
Northern estuaries**	25.6	24.9	24.8	22.5	19.8	17.6	16.4	17.3	19.4	21.2	22.8	24.2
Southern estuaries***	22.4	22.4	21.9	19.9	16.6	14.3	13.1	13.9	15.3	17.7	19.3	21.0

Number of months with temperatures above 15°C	
Northern estuaries	12
Southern esturaries	9
Number of months with temperatures above 18°C	
Northern estuaries	10
Southern esturaries	6
Number of months with temperatures above 21°C	
Northern estuaries	7
Southern esturaries	4

* Data from Wolf and Collins (1979).

** Northern estuaries - data taken from seaward sites in the Tweed, Richmond and Clarence Rivers.

*** Southern estuaries - data taken from seaward sites in the Shoalhaven, Clyde and Tuross Rivers.

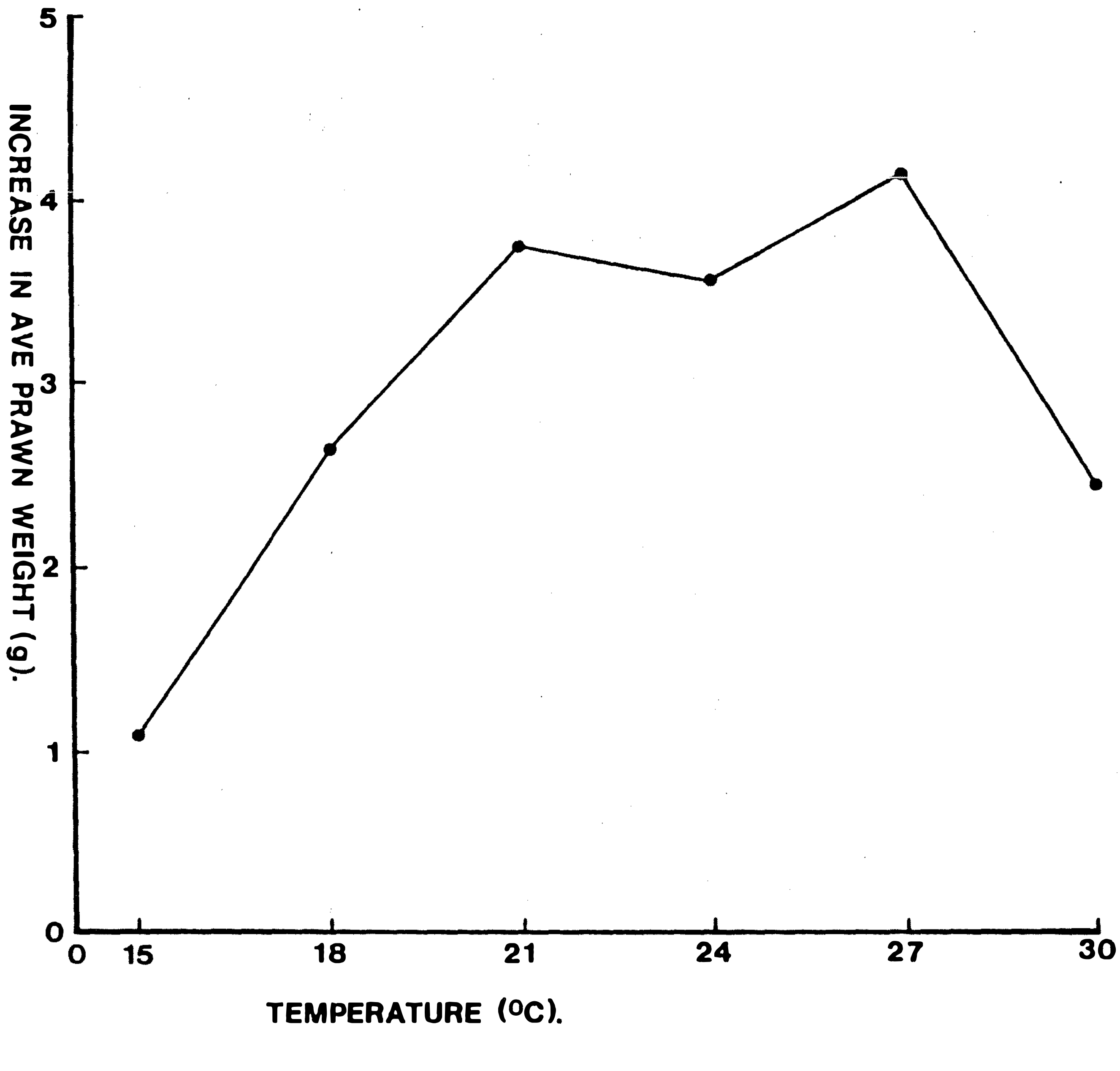

FIGURE 1 School prawn growth in aquaria at 6 different temperatures (15-30°C).

TABLE 2 Factors Affection Water Quality.

Temperature Salinity Dissolved Oxygen pH	
Nitrogen compounds - ammonia, nitrite, nitrate. Other dissolved nitrients - e.g., phosphorous, silica.	
Phytoplankton biomass Bacteria Other microscopic fauna	
Sediment condition	- Redox potential - Hydrogen sulphide
Prawn biomass	

TABLE 3. Water Quality Management

1. ALGAL BLOOM MANAGEMENT

- initiation	)	Fertilization	- inorganic
	)		- organic
- maintenance	)	Liming	- during pond construction
			- during farming process

2. WATER EXCHANGE

- tidal
- pumping

3. AERATION

- wind induced
- via pump intake, e.g., spraying
- artificial aeration, e.g., paddle wheels

4. POND DRAINAGE AND DRYING

- to oxidise chemically reduced sediments

Commonwealth Development Bank of Australia does not accept responsibility for the content of this paper or acknowledge that any of the opinions, projections or conclusions reached are necessarily in agreement with its own opinions.

THE ECONOMICS OF PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST

F.H.Hardy
Regional Rural Officer
Commonwealth Development Bank
LISMORE

Prawns are not new, but Prawn Farming (PF) in our region is.

Dr Maguire brought some prominence to PF when he set up a 1 ha Pond on the foreshores of the Lower Clarence River. This was in 1983. First product from the Pond was marketed in January 1984.

Since 1983, W. Fanning and F. Roberts have established separate Prawn Farms. Their activity has received wide publicity and it would now seem that there are numerous others who would wish to enter the industry.

It is the intention of this paper to provide an insight into the economics of PF. The paper is based on some fact and much hypothetical asssumption. It cannot be otherwise as PF is a new industry. What is being done today will be improved upon tomorrow.

The paper will present a model PF with a supporting cash flow budget. This will be supported by a capital structure. Some indication will be given of likely return on capital from different yields and prices.

It is also the paper's intention to leave you with some reference material. Note that a hypothetical loan application exercise is given together with various attachments with statistics and comparisons.

THE MODEL PRAWN FARM DESCRIBED

The product to be grown out is juvenile school prawns purchased from local trawlermen.

This base stock will be placed in 'dozer built ponds with a nett surface water area of 20 ha. It is assumed that the gross farm area is 30 ha and has frontage to a satisfactory salt waterway. The land is mainly cleared and fenced.

Why select a 20 ha Pond area? Preliminary assessments suggested that a family type operation is desirable, say father and son plus casual labour at critical times. Comparison of a 20 ha v 10 ha Pond area will confirm the desirability of the larger area. (Attachment No. 8).

Having outlined what the model prawn farm will be let me now look at its development.

(1) Land

Land purchase is required. Initial cost of land at \$3,100/ha is based on a recent sale of a suitable piece of land. Total cost of land including legals is \$95,500. What you pay for land will vary depending on numerous factors, including the size of the block and its location. Unfortunately for prospective

Prawn farmers, land resource is a limited commodity in a near sea location, hence land price is likely to be high.

(2) **Physical Development**

To the land must be added ponds, drains, roads buildings and services. The 20 ha of ponds is made up of 3 rectangular ponds each about 800 m x 85 m. Pond walls have a flat top for access. They also allow for filling pipe, water exchange activity and emptying. More detail is shown in Attachment 3. Total cost of development is $75,800 which includes Ponds, drains and roads @ $2,300/ha.

(3) **Plant Purchase**

Finally, a suitable plant unit is necessary. (Attachment 2). Note the need for some specialised plant that will be necessary to monitor water quality. Estimated cost of plant is $71,330.

(4) **Capital Requirement**

Total capital for land development and plant for the 20 ha model is $242,530. The breakdown is shown in a Farm valuation (Attachment 1) and a Plant List (Attachment 2).

THE CASH FLOW BUDGET

The cash flow budget gives a projection of the yearly income and costs for the 20 ha pond system providing three turn offs per year. (Attachment 4).

The budget portrays the position after the Prawn Farmer has gained some experience, maybe say about 2-3 years after starting up. Let us assume it to be a Year In Year Out position (YIYO).

Some explanation is required about some items of the budget.

(1) **Income Considerations**

Yield of prawns/ha used is assumed to be the final product amount submitted to market.

There is little evidence of local yields. Dr Maguire's project would probably show an average yield of 850-870 kg/ha per batch. Other growers might be able to show 300-600 kg/ha for batches grown under experimental conditions.

Dr Maguire's yield attainment would seem to suggest that prospects exist for school prawn yields of 800 kg plus to be achieved after some expertise is gained.

Prawn yield per ha for the model is set at 800 kg per batch. This yield is based on prawns being grown in the Pond for ten weeks and coming out at a weight of 6.5 gm.

Apart from yield, the price paid for cooked school prawns is another income consideration. There is little background to prices paid to prawn farmers for their product but evidence available for the few batches turned off would show a price range of about $3.50 to $10/kg on the floor of the Sydney Fish Markets. Possibly one group could have averaged $6.67/kg.

With such a brief history of price achievement, one needs to exercise caution in selecting a budget price. Could I outline the steps I have used in selecting my budget price of $6 a kg.

(a) What has been achieved by Prawn farmers to date.

(b) What has been the average price paid for all the prawn supply on the Market floor.

Average prices for cooked school prawns at the Sydney Fish Markets are shown on Attachment 5 Table 1. Reference will show 3 Year average to September 1984 at $3.85/kg. Obviously there is a major variation between PF achievement and the market average.

(c) Consider the timing of the product on the Market.

Prawn farmers currently would operate under some restraint, (River i.e. source of juvenile prawn supply is closed at times). Clarence River growers could supply three batches per year - possibly December-January, March-April and June-July. One would need to examine average prices during these periods. Reference to Attachment 5, Table 2 shows the average prices for various months and indexed prices.

(d) Will Prawn farmers be able to grow a quality product?

It has been suggested that management practices such as feeding, fertilizing, water quality and ability to vary harvest time will be rewarded with a quality product that should fetch a premium.

Analysis of some prices paid to date has indicated to me that some of a PF catch gave a 54% higher price than the market average. Using this information and the index of prices paid I could see a grower's average price for turn off months as follows -

December	-	$6.56
January	-	6.10
March	-	5.93
April	-	6.00
June	-	6.98
July	-	6.98
Average		$6.42/kg

(e) The future outlook.

read with interest the article "Prawns" by Perry Smith which suggests -

> Prices on Australian Markets are expected to fall. Supplies of farmed prawns from Asian Pacific area are expected to increase sharply in the short and medium terms.

These comments were made following a review of the world wide situation.

I would take some notice of these comments and for that reason selected $6 kg as my budget price.

(2) Some Cost Considerations

Costs are placed in three sections.

The listed direct costs are those of a variable nature. Stocking the Pond is based on 460 kg/ha @ $2.50/kg. Weight in is allowed at 2.3 gm. Stock number is 20 prawns/m^2. Cost to stock a pond is about one-third of direct cost total.

Feeding is based on a 25% protein ration landed at $341/T. Feed consumption is calculated on a Food Conversion (FC) of 1:3 but I understand a FC of 1:2 is possible. Simple calculation of food amount is -

	Weight Out	6.5 gm
	Weight In	2.3
Therefore	Weight Gain	4.2 gm x FC (3) = 12.6 gm feed/prawn

Allowance has been made for prawn losses in calculating feed usage.

The costs listed as other, are mainly of a fixed nature. Each item cost is set on some base. For example, each piece of farm improvement is valued new and a cost apportioned for repairs on accepted budget practice, such as Building (New Value (NV) $28,800 @ 2%). Pond (NV @ $46,000 is costed at 5%).

Special costs are possible non-cash costs, but they must be included to give a meaningful assessment of the project. Plant replacement is based on 10% of NV, while the owner's labour allowance is set at a figure that would be close to a wage paid to a rural worker.

(3) Discussion on the Budget Result

The cash flow budget for a 20 ha Pond turning off 3 batches of prawns at 800 kg per batch and a price of $6/kg shows an income of $288,000. After all costs (except tax, principal and interest) there is a surplus income of $47,160. Is this a good result?

The measure performance, return on capital will be used.

The capital of the model PF is given as -

Land	$171,200
Plant	71,330
	$242,530

Items such as stock of prawns and materials are not included.

The result of this budget shows a 19% return on capital. (Attachment 6). This is a very favourable return, which I think is a little too generous. At the same price and a yield of 700 kg, return is 8%. Maybe a potential investor may not go into PF with this situation. If a return of 10-19% could be obtained PF would be an attractive proposal.

(4) Prawn Farming Sensitivity

I have looked at the sensitivity of PF at various prices and yield levels (Attachment 6) and I have also made a comparison with a 10 ha PF (Attachment7).

If price of $6.50 kg is achieved on a yield of 800 kg, return jumps to 28% which I would consider too good to last. (The higher the return the higher the risk). At a price of $6.50 kg yield would have to approach 650 kg to provide a reasonable return.

One analyst has suggested future price falls for Prawns. If price received was $5.50 kg, a grower would need to achieve at least 800 kg/batch to make a reasonable return.

A $5 kg and yield of 800 kg return would be only about 2%.

Some prospective prawn farmers may contemplate a smaller size farm, e.g. 10 ha. The economics of the smaller area compared to a 20 ha farm show significant differences. For example, at a price of $6 kg and a yield of 800 kg return declines from 19% for 20 ha to 8% for the smaller farm.

With 10 ha PF, a grower would have to achieve at least a price of $6 kg and a yield of 800 kg to give a moderate return.

A LOOK AT A HYPOTHETICAL LOAN PROPOSAL

An exercise has been completed to show a prospective prawn farm investor borrowing funds to set up a 20ha project. The exercise covers most aspects required in a loan application.

The starting point of the exercise is to complete an up to date balance sheet. (Attachment 9). Among other things the Balance Sheet will reveal the applicant's current net worth (equity). In the presented case, equity is 96%, which is a very strong position.

Next comes the costing of the development (Attachment 3).

A cash flow budget should be prepared. In a new proposal it is most important to examine the early periods closely as income from the venture at that time could be low and costs high. An example of a cash flow budget to cover the early development period is shown (Attachment 10).

Note that the cash flow is complete: it covers all costs except interest and principal (you can include them if you wish). All income is included.

This cash flow is on a peak debt basis where the first budget period is taken up to the point just before the first prawn income. This approach enables you to calculate carry on needs.

Prawn income in the budget is based on lower yields in the early years. YIYO position is in the third year.

Before the investor approaches his banker for funds, he will need to have an idea of how much loan funds he should be seeking. A simple needs and source exercise will highlight the position. (Attachment 9).

In summary it is shown that this investor needs about $322,000 and that his own supply is $222,000, so he needs to borrow $100,000.

In looking at the application, a banker would note the equity his client would have in the activity. Note that equity before the project started was 96% but later it has declined to 67%.

The Banker would also look at his client's ability to repay; Bankers use cash flow budgets for this purpose.

My budget (Attachment 10) does not include Interest and Principal as these payments are shown on a Budget Summary (Attachment 11). This summary traces the debt movement year by year and the actual funds needed.

Result of this loan application is that the investor can handle an initial farm debt need of $110,860 with ease, as would be expected with a project showing a YIYO return on capital of 19% and a moderate debt load.

SUMMARY

It is considered that a reasonable sized prawn farm for a family type activity is 20 ha of ponds. Estimated capital required in land and plant to set up is about $242,000 plus carry on until income is derived.

A cash flow budget based on 20 ha producing 800 kg of prawns for 3 batches per year and at a price of $6/kg shows a 19% return on capital. At the same yield, but at a price of $6.50/kg, return would be 28% which I would consider too generous.

If price paid was $6.50 kg, a yield of 650 kg per batch is necessary to achieve a reasonable result. At a price of $5.50 at least 800 kg per batch has to be obtained to give a reasonable 10.8% return.

A price of $5/kg would produce poor returns unless yield was well in excess of 800 kg per batch.

A smaller sized farm, say 10 ha, produces less than half the return on capital of the 20 ha ponds. A price level of $6/kg and yield of 800 kg per batch is essential to produce a moderate 8.4% return from capital.

It is important to realise that management is a key factor in achieving reasonable returns on capital. Reference to Attachment 8 will highlight this feature.

Potential prawn farmers requiring loan funds will need to demonstrate that they have a reasonable interest (equity) in their venture. They will also need to work out their precise requirements to see that they can not only launch a project but be able to get through until production and income increases to acceptable levels.

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST

FARM VALUATION

ATTACHMENT 1

1. Land Valuation

30 ha land suitable prawn farming at $3,180/ha fenced		$95,400
Add Buildings	$26,500	
Silo	2,300	
20 ha Prawn Ponds including Roading and drains @ $2,300 per ha	46,000	
Structure for aeration facility	1,000	75,800
ESTIMATED MARKET VALUE		**$171,200**

2. Plant

Farm Plant Present Value	$12,950	
Pumping	22,520	
Transport	6,900	
Boating	7,300	
Harvesting	3,730	
Refrigeration	2,200	
Testing	2,570	
Workshop	1,530	
Office	230	
Pond Stocking	3,600	
Aeration	5,400	
Predator Control	2,400	
		71,330

3. Stock on Hand

i.e. Prawns in ponds, if any

4. Materials on Hand

Fertilizer, feed etc if any

5. Value of a Licence?

WALK IN WALK OUT VALUE (WIWO)	**$242,530**

****

PRAWN FARMING THE NEW SOUTH NORTH COAST
PLANT NECESSARY FOR A 20 HA PROJECT
ATTACHMENT 2

	Present Value	Replacement
Farm Plant (For preparation of Pond Floor)		
Tractor	$ 9,000	$18,000
Rotary Hoe	2,800	6,700
Harrows	300	500
Grader Blade	350	700
Farm Trailer	500	800
Pumping (To fill Ponds, Exchange Water.)		
Pump & Motors - to shift $1000m^3$/hr 55 Kw - 4	$21,700	$21,700
Pump & Motor - small mobile - 3.5 HP - 2	820	820
Transport		
Vehicle	$ 6,000	$11,000
Bike	900	1,000
Boating		
Punt - 40 HP Outboard	$ 4,000	$ 4,500
Punt - 5 HP Outboard (3)	3,300	3,500
Harvesting		
Nets - 3	$ 1,100	$ 1,200
Scales	450	500
Cookers (2)	900	900
Crates	790	870
Baskets	80	80
Cooling tanks	410	450
Refrigeration		
Cool Room	$ 2,200	$ 2,200
Testing		
pH meter	$ 300	$ 300
Salinity meter	450	500
Oxygen meter	1,620	1,800
Scales	200	200
Repair - workshop		
Various workshop items, drills, grinders, welding	$ 1,530	$ 2,000
Office		
Minor furniture items	$ 230	$ 500
Stocking Ponds		
Boxes fitted with trays for transferring prawns, 8 boxes of 10 frames	$ 3,600	$ 4,000
Aeration - 3 sets	$ 5,400	$ 7,500
Predator Control - Electronic	$ 2,400	$ 2,400
	$71,330	**$94,620**

DEVELOPMENT PLAN EXPENDITURE: PRAWN FARM VENTURE

ATTACHMENT 3

Date: 3/7/85

DEVELOPMENT PLAN - DESCRIPTION OF ITEM (If applicable show unit costs. Indicate contract work).	to Hectares	20/12/85 Cost ($)
1. Land Purchase - 30 ha @ $3,100/ha		93,000
Legals		700
Stamp Duty		1,800
2. Buildings - by contract		
Plant Shed - 56m^2 - cgi		4,000
Workshop - 56m^2		5,000
Processing including office, refrigeration, annex, cgi conc floor		16,000
Pump Shed		1,500
Grain Silo elevated 900 Bus.		2,300
3. Development of Ponds, Drains and Roading		
Pond area 20ha net water area		
Roading 1600m		
Major Drain/Canal to river 1100m		
Minor Drains 1900m		
Drain Crossings - 3 needed		
Ponds Base 11m, Height 2m, Top 2m		
Batters 1:2		
Overall cost $2,300/ha x 20 ha by contract		46,000
Sundry items for aeration facility		1,000
4. Plant Purchase		
(a) Farm Plant - Tractor, R. Hoe, Harrows, Grader Blade, Trailer - 2nd Hand say		12,950
(b) Pumping - 4 pumps and motors - about 50-60 Kw		21,700
2 smaller mobile pumps		820
(c) Transport - Vehicle Bike, 2nd hand		6,900
(d) Boating - 40 HP Punt say 5 HP Punts (3)		7,300
(e) Harvesting. Nets, scales, cookers, crates, baskets, cooling		3,730
(f) Refrigeration - cool room		2,200
(g) Testing pH, salinity, O_2 Meters Scales		2,570
(h) Repairs - workshop - allow		1,530
(i) Stocking plant - boxes		4,000
(j) Aeration of Ponds - allow 3 sets		4,500
(k) Predator Control - electronic device		2,400
(l) Office plant - allow		230
5. Contingencies say		10,000
Total Development Expenditure		$252,130

PRAWN FARMING ON THE NSW NORTH COAST

CASH FLOW BUDGET. ATTACHMENT 4

Income

	800kg per ha x $6/kg x 3 batches pa = $14,400/ha x 20 ha		$288,000
Costs	**(A) Direct**	**Per Ha Per Batch**	
1.	Condition Pond	$ 102	
2.	Stocking pond including fuel	1,159	
3.	Feeding including fuel	640	
4.	Fertilizing and fuel included	31	
5.	Water Exchange - fuel	156	
6.	Aeration - fuel	5	
7.	Predator Control	4	
8.	Harvesting - fuels only	43	
9.	Processing	39	
10.	Marketing	795	
11.	Sundry	50	
		$3,024	
	$3,024 x 3 batches p a x 20 ha		$181,440
	(B) Other		
12.	Repairs to Plant	$6,000	
13.	Repairs to Improvements	3,000	
14.	Rates	1,800	
15.	Electricity	600	
16.	General Freight	300	
17.	Fuel oil	1,100	
18.	Reg Insurance	600	
19.	Insurance	2,400	
20.	Phone	600	
21.	Accounting	700	
22.	Wages	18,600	
23.	Sundries	700	
			$ 36,400
	(C) Special		
24.	Plant Replacement	$ 9,400	
25.	Owner's Labour	13,600	23,000
			$240,840
		SURPLUS	$ 47.160

PRAWN FARMING ON THE NEW SOUTH NORTH COAST

ATTACHMENT 5

Table 1. Average Prices Cooked School Prawns per Kg. (Source NSW FMA)

Year ending September	1982	-	$3.41/kg
	1983	-	4.23
	1984	-	3.92
	3 yr ave		$3.85

Table 2. Prices Paid for Cooked School Prawns. (Source NSW FMA)

3 year average 1982-1984

	Price in Kg.		Price Indexed Base $3.92 = 100
Jan	$4.10		104
Feb	3.97		101
March	3.93		100
April	4.00		102
May	3.92		100
June	4.98		127
July	4.98		127
Aug	5.91		150
Sept	6.86		175
Oct	4.77		121
Nov	4.53		115
Dec	4.56	(2 yrs prices only 82/83)	116

Table 3. From a Price Viewpoint what are the Prime Price Months. In Order.

1.	Sept	Index	175
2.	Aug		150
3.	July)		127
3.	June)		127
4.	Oct		121
5.	Dec		116

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST

RETURN ON CAPITAL AT VARYING PRICES AND YIELDS

ATTACHMENT 6

Cooked School Prawns

For 20 Ha Ponds

Price per Kg	Yield in Kg/ha/Batch (3 Batches pa)	Return on Capital
$6.50	800	28
6.50	700	16
6.50	600	3.9
$6.00	800	19.4
6.00	700	8.4
6.00	600	-2.6
$5.50	800	10.8
5.50	700	0.7
5.50	600	Negative
$5.00	800	2.2

For 10 ha Ponds

Price per Kg	Yield in Kg/ha/Batch (3 Batches pa)	Return on Capital
$6.50	800	15.1
6.50	700	5.6
6.50	600	-4.9
$6.00	800	8.4
6.00	700	-2.5
$5.50	800	1.8

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST

A SUMMARY OF A 10 HA PRAWN FARM

ATTACHMENT 7

1. Cash Flow Budget

Income - 800 kg/ha x $6/kg x 3 batches p.a. = $14,400/ha x 10 ha		$144,000
Costs		
(A) Direct - $3,024/batch $3,024 x 3 batches p a x 10 ha	$90,720	
(B) Other	19,260	
(C) Special	20,810	130,790
SURPLUS		$ 13,210

2. Farm Valuation

(a)	Land Valuation 15 ha x $4,100/ha fenced		$61,500	
	Add Buildings, Silo	$18,300		
	10 ha Ponds	23,000		
	Aeration facility	700	42,000	
	ESTIMATED MARKET VALUE			$103,500
(b)	Plant			52,850
(c)	Stock on Hand			-
(d)	Materials on Hand			-
(e)	Value of Licence			-
	WIWO VALUATION			$156,350

3. Return on Capital at Varying Yields and Prices

Price/Kg	Yield in Kg/ha per Batch	Return on Capital
$6.50	800	15.1
	700	5.6
	600	- 4.9
$6.00	800	8.4
	700	- 2.5
$5.50	800	1.8
	700	Negative

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST
A COMPARISON BETWEEN PRAWNING ENTERPRISES
PRAWN TRAWLING AND PRAWN FARMING

ATTACHMENT 8

	BAE Results Adjusted	A Good Trawl Operator	Prawn farms on 800 kg x 3/ha x $6	
			20 ha	10 ha
Bases	Ave 1982/83 Results	1982/83 Results	1985 Budget	1985
Vessel	13 years	11 years		
Length	14.2m	14.2m		
Underdeck Volume	130.2m^3	132m^3		
Engine HP	131.6Kw (176 HP)	108Kw (145 HP)		
Ave Fuel Use	24 L P Hr	23 L P Hr		
Crew or Labour	1.9	2	2.3	1.5
Capital -				
Vessel/gear	$97,680	$103,000		
Part Vehicle	4,000	4,000		
Total Capital	$101,680	$107,000	$242,530	$156,350
INCOME	$ 71,880 (1)	$ 77,000 (1)	$288,000	$144,000
COSTS				
(A) Direct	$ 30,100	$ 25,000	$181,440	$ 90,720
(B) Other	22,780	20,000	36,400	19,260
(C) Special	20,640	18,000	23,000	20,810
Total Costs	$ 73,520	$ 63,000	$240,840	$130,790
SURPLUS	-$ 1,640	$ 14,000	$ 47,160	$ 13,210
Return on Capital	-1.6	13%	19.4%	8.4%
Prawns in Kg	NA	13,950	48,000	24,000
Prawns Yield per ha p.a.	NA	-	2,400	2,400
Labour cost/kg prawn	NA	$ 1.70 (1)	$ 0.67	$ 0.86
Labour as % of gross income (includes owners if used)	42%	31%	11%	14%
Fuel costs as % gross income	20%	17%	6%	7%

ATTACHMENT NO 8 CONT...

	BAE Results Adjusted	A Good Trawl Operator	Prawn farms on 800 kg x 3/ha x $6	
Fuel cost per kg product	NA	$ 0.93	$ 0.38	$ 0.40
Ave Gross Income/kg Product	NA	$ 5.52	$ 6.00	$ 6.00
Costs/kg				
Direct	NA	$ 1.79	$ 3.78	$ 3.78
Other	NA	1.43	0.75	0.80
Special	NA	1.29	0.47	0.86
TOTAL		$ 4.51	$ 5.00	$ 5.44
Net/kg Product		$ 1.01	$ 1.00	$ 0.56

NOTES (1) Includes Fish Income

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST
SOME BASIC INFORMATION FOR A LOAN APPLICATION
A BUDGET EXAMPLE

ATTACHMENT 9

1. Balance Sheet of at 4/7/85.

Before the Project Started

Assets	
House	$ 90,000
Interest Bearing Deposits	200,000
Plant - car, mower etc.	15,000
Credit Funds	3,000
Company Shares	10,000
Life Policies	NE
Funds due	4,000
	$322,000
Liabilities	
Home Loan (1)	$ 10,000
Monthly Accounts	1,000
	$ 11,000
SURPLUS (96% Equity)	$311,000

NOTES (1) Bank has 1st Mortgage, I. 13.0% Monthly Pays of $200 P and I.

After the Project Launched (January 1986)

Assets	
House	$ 90,000
Plant	NE
LP's	15,000
Prawn Development say	242,530
	$347,530
Liabilities	
Home Loan	$ 9,450
Monthly accounts	2,000
Own Bank - od	10,000
FDL	40,000
Development Bank	52,000
	$113,450
SURPLUS (67% Equity)	$234,080

2. Funding the Development

1. Funds Needed to Set up -	
(a) Purchase Land, Development and Plant (See Itemised List)	$252,130
(b) Carry on funds until project launched, say	70,000
	$322,130
2. Source of Funds	
(a) Own Supply	$222,000
(b) Proposed Loans - own Bank overdraft facility	10,000
(c) Fully Drawn Loan	40,000
(d) Development Bank - Term Loan	52,000
	$324,000
SURPLUS FUNDS	$ 1,870

ESTIMATED RECEIPTS AND PAYMENTS: PRAWN DEVELOPMENT
(excluding commitments on borrowings)

ATTACHMENT 10

Chosen Income Month and Source: Prawns - monthly Date 4/7/85

RECEIPTS ($)	TO 4/1/86	1986/87	1987/88	Y.I.Y.O. 19 /
I.B.D. "Cashed"	200,000			
Credit Funds	3,000			
Sale of Shares	10,000			
Funds due	4,000			
Interest	5,000			
Prawns	-	228,000	252,000	288,000
Total Receipts	222,000	228,00	252,000	288,000
PAYMENTS				
Prawn Costs - Direct (1)	44,000	164,500	172,600	181,440
Other Costs (2)	11,000	30,300	33,000	36,400
General Operating Expenses	55,000	194,800	205,600	217,840
Living and Personal (3)	5,000	11,000	11,000	11,000
Life Assurance	500	500	500	500
Total H/P Expenses	-			
Plant Replacement	-	2,000	4,000	9,400
Development Expenses	252,130			
Cattle purchases				
Sheep pruchases				
Costs associated with own house, car	1,500	3,000	3,000	3,000
Loan fees - in contingencies	-	-		
Tax (2 P/ship)				15,000
Total Payments	314,130	211,300	224,100	256,740
SURPLUS		16,700	27,900	31,260
DEFICIT	92.130			

NOTES:

(1) Includes items 1-9 inclusive and 11 of Direct costs Attachment No for the first batch.

(2) Costs Nos 12-23 shown on Attachment No 4 adjusted for short period, new plant, etc.

(3) Food, Clothing, medical.

BUDGET SUMMARY: PRAWN DEVELOPMENT
ATTACHMENT 11

DATE: 4/7/1985

Periods			TO 4/1/86	1986/87	1987/88
			$	$	$
Income in Chosen Income Month				65,000	84,000
RECEIPT & PAYMENTS - Surplus				16,700	27,900
(brought forward) - Deficit			92,130		
PEAK DEBT CALCULATION			11,000		
Total closing debts, first period			103,130		
Interest @ Broken period say 7.5%			7,730		
Opening hard-core debt				45,860	20,770
Interest @ 15.25				6,990	3,170
Fluctuating debt				48,300	56,100
Interest @ 7.5				3,620	4,210
Farm Debt Requirement			110,860	104,770	84,250
SOURCE OF FUNDS					
Creditors	1,000		2,000	2,000	2,000
Pastoral House					
Trading Bank					
Home Loan	10,000	P & I $200 pm	9,450	8,280	6,960
Fluctuating od		Interest only	10,000	10,000	5,000
FDL		Repay over 5 years	40,000	32,000	24,000
		Sub-total	61,450	52,280	37,960
PROGRESSIVE ADDITIONAL FUNDS REQUIRED			49,410	52,490	46,290
PROGRESSIVE C.D.B. LOAN CONSIDERED		10 yr term I 15.25% 1st due 1/86 P & I = $10,710	52,000	52,000	49,220
Residual Surplus/Deficit (Progressive)			- 2,590	+ 490	- 2,930

TOTAL CLOSING DEBTS FIRST PERIOD -

FURTHER COMMENT/EXPLANATIONS
- Show taxation calculation
- Calculation of interest for broken period if broad estimate not considered appropriate
- Any other items

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST
CASH BUDGET EXPRESSED IN HA

ATTACHMENT 12

		PER Ha
INCOME		$
800kg per ha x $6/kg x 3 batches pa		$ 14,400
COSTS		
(A) DIRECT	$	
1. Condition Pond	306	
2. Stocking pond including fuel	3,477	
3. Feeding including fuel	1,920	
4. Fertilizing and fuel included	93	
5. Water Exchange - fuel	468	
6. Aeration - fuel	15	
7. Predator Control	12	
8. Harvesting - fuels only	129	
9. Processing	117	
10. Marketing	2,385	
11. Sundry	150	9,072
(B) OTHER		
12. Repairs to Plant	300	
13. Repairs to Improvements	150	
14. Rates	90	
15. Electricity	30	
16. General Freight	15	
17. Fuel oil	55	
18. Reg Insurance	30	
19. Insurance	120	
20. Phone	30	
21. Accounting	35	
22. Wages	930	
23. Sundries	35	1,820
(C) SPECIAL		
24. Plant Replacement	470	
25. Owner's Labour	680	1,150
		$12,042
	SURPLUS	$ 2,358

PRAWN FARMING ON THE NEW SOUTH WALES NORTH COAST
CASH BUDGET EXPRESSED IN KG

ATTACHMENT 13

INCOME		**PER kg**
800kg per ha x $6/kg x 3 batches pa		$ 6.00
COSTS	$	
(A) DIRECT		
1. Condition Pond	0.13	
2. Stocking pond including fuel	1.45	
3. Feeding including fuel	0.80	
4. Fertilizing and fuel included	0.04	
5. Water Exchange - fuel	0.20	
6. Aeration - fuel	0.01	
7. Predator Control	0.01	
8. Harvesting - fuels only	0.05	
9. Processing	0.04	
10. Marketing	0.99	
11. Sundry	0.06	3.78
(B) OTHER		
12. Repairs to Plant	0.13	
13. Repairs to Improvements	0.06	
14. Rates	0.03	
15. Electricity	0.01	
16. General Freight	0.01	
17. Fuel oil	0.02	
18. Reg Insurance	0.01	
19. Insurance	0.05	
20. Phone	0.01	
21. Accounting	0.01	
22. Wages	0.40	
23. Sundries	0.01	0.75
(C) SPECIAL		
24. Plant Replacement	0.19	
25. Owner's Labour	0.28	0.47
		$5.00
	SURPLUS	$1.00

SOME CONSIDERATIONS IN ESTABLISHING A COMMERCIAL PENAEID PRAWN HATCHERY IN NORTHERN NEW SOUTH WALES

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Abstract

The stage appears to be set for the development of a number of large scale penaeid prawn farms in northern New South Wales. Critical to this development will be the establishment of effective hatchery operations to supply postlarvae for pond stocking. There are numerous aspects which should be considered when planning a hatchery. This paper provides a basis for the discussion of some of the important functional considerations based on past research and recent commercial experiences.

Introduction

Obtaining a reliable supply of suitable postlarvae is a major constraint on the development of large scale culture of penaeid prawns both overseas and in Australia. The situation in northern New South Wales is no different. The simplest method of postlarval access, the collection of wild postlarvae (Fig. 1) has been employed for about ten years to stock tanks and ponds for growth trials. Since October 1984 similar techniques have been used by two growers on the Clarence River to produce commercial crops of school prawns, *Metapenaeus macleayi*.

Although these techiniques have been streamlined to enable school prawn postlarvae to be obtained and stocked at competitive prices, there are several reasons why they will not support a large scale industry. The supply of school prawn postlarvae is severely affected by a closed season and also by variability in prawn size, survival and catchability. In addition, postlarvae of larger, more valuable species such as the Eastern king prawn, *Penaeus plebejus,* are simply not caught en masse in the way that school prawns are. The overriding consideration however is that accelerated removal of postlarvae of any species may adversely affect the commercial fishery. Therefore, it is clear that the best means of obtaining postlarvae for stocking culture ponds is to rear them in a hatchery.

Broodstocks

Fig. 1 shows the various methods by which broodstocks may be obtained and induced to spawn so that resultant larvae can be reared under controlled hatchery conditions. The methods are divisible into two categories according to the history of the spawners.

The first category involves the induction of gonadal maturation in captivity. This is usually not a problem in the case of males which tend to mature precociously, but is more difficult in the case of females. Sub-adults for maturation may be obtained either from grow-out ponds or by capture in the wild.

Pond stocks must first be grown to the stage where they exhibit fully developed primary sexual characteristics before they will be suitable for induced maturation. However stocks from the wild will usually be obtained with fully developed sexual structures and transferred directly to maturation units.

Maturation procedures for several tropical penaeids have been refined overseas to the point where they contribute commercially significant quantities of larvae to hatcheries. However, work on several sub-tropical species commonly occurring in New South Wales is incomplete, and it is not presently feasible to obtain large numbers of larvae by means of controlled maturation.

Preliminary studies on the inshore greasyback prawn *(Metapenaeus bennettae)* have shown that this species will readily mature and spawn without ablation in tanks and ponds but only in synchrony with the natural spring and summer breeding season. The school prawn, which reproduces naturally in shallow oceanic waters, has similarly been observed to mature and spawn in ponds in late summer and autumn, however this appears to be a less common occurrence. In addition, consistent ovarian maturation of school prawns out of season has been induced in a controlled recirculating seawater system following eyestalk ablation but this did not lead to spawnings producing viable offspring.

In the case of the Eastern king prawn it was found that ovarian maturation of ocean-caught stocks could be induced under controlled conditions without eyestalk ablation, but that in accordance with other studies unilateral ablation enchanced the process. Viable spawnings of laboratory-matured king prawns occurred until females had moulted and therefore lost sperm implanted in the wild. Subsequent spawnings were not viable, the most likely cause being the failure of the prawns to mate in captivity.

The second category of methods for obtaining larvae for hatchery rearing involves more simply the capture of gonadally mature (gravid) females from natural breeding grounds (Fig. 1). These are transferred to the hatchery where spawning may occur spontaneously or may be induced. This procedure is widely used overseas, and has been shown to produce good results for the three common penaeids of New South Wales (Table 1). These results indicate that spawning, fertility and hatching rates of wild greasyback prawns (and possibly school prawns) would be sufficient to support large scale hatchery production. The number of eggs produced per spawner is relatively low because of the inherently small size of these species. However this could be overcome simply by the use of more spawners. The major difficulty is that wild spawners of both *Metapenaeus* species are only available during the summer months. Hatchery reared postlarvae could therefore only be stocked towards the second half of the preferred growing season.

By contrast, the Eastern king prawn is a larger species (produces more eggs per spawner) and gravid females are available throughout the year (Table 1). These factors in particular provide much greater potential to support a large scale hatchery. In addition spawning, fertility and hatching rates are high, and techniques have been defined for the storage of spawners. Storage enables continuity of production in the event that access to spawner grounds is prevented by poor weather, and also allows a hatchery remote from fishing grounds to collect spawners more economically in larger batches.

Larval Biology

Fig. 2 shows representative larval stages of a penaeid prawn. The naupliar, protozoeal and mysid stages of most species develop among the plankton of the open ocean. The benthic habit begins to appear in the late mysis stage and the postlarvae migrate back into the estuarine areas. The oceanic development phase in nature points to a need for water of stable oceanic character during hatchery rearing. A temperature/salinity combination of 25°C and 35‰ is considered to produce best survival and growth of larval school prawns, king prawns and greasyback prawns. However, other more subtle parameters such as pH, dissolved oxygen and ammonia, nitrite and nitrate levels are also extremely important.

The naupliar stage utilises stored yolk deposits and requires no feeding. The onset of feeding at the time of transition to protozoea represents a critical period, and highest mortality usually occurs at this stage. Protozoeae are filter feeders with their staple diet being phytoplankton cells. During the development of the mysid stage the diet preference gradually changes to zooplankton. The most commonly used zooplankton diet is the brine shrimp, *Artemia*. Postlarvae should not be removed to ponds until they have been converted to a solid pelletised diet.

Hatchery System Options

Hatchery rearing methods can be divided into two broad categories, the semi-flow through system and the recirculation system. The basic aim of both systems is to provide and maintain a seawater environment of suitable quality for the rapid growth and good survival of the larvae. Various foods are added to the culture water as required for the nutrition of the larvae during the rearing cycle.

The semi-flow through system is almost universally used for the rearing of penaeid larvae. This system is made up of free-standing tanks filled with culture medium. A proportion of the water in the tanks is replaced periodically with new filtered water in order to remove toxic nitrogenous wastes excreted by larvae and produced by the degeneration of uneaten food. Semi-flow through is particularly suited to sites where seawater of consistently suitable character is readily available and ambient temperatures are high so that there is no need to heat large volumes of new water.

The recirculation systen is used successfully to mass rear marine fish larvae and freshwater prawn larvae, however it must be considered unproven with respect to large scale rearing of penaeid larvae. This type of system consists of rearing tanks which connect with a reservoir, particle filters and biological filters. The seawater is reconditioned within the filtration units and then recycled back to the rearing tanks, with only small quantities being replaced. The costs to establish such a system are greater, however some operating costs may be lower (e.g. heating) and the system could be operated on a site remote from the ocean. Replacement water could be shipped to the site or made up using artificial salts.

Hatchery Siting

Clearly a site with open-ocean access is preferable because this will allow the use of the simpler, proven, semi-flow through system with minimal water treatment throughout the year. Oceanic sites may in turn be classified as rocky shore or sandy beach. A rocky shore site is more likely to have the advantage of a shorter pipeline access provided that the elevation (pumping head) is not excessive. On the other hand a sandy beach site is more likely to require a long pipeline and be subject to problems associated with sand movement. The possibility of drawing water from a borehole adjacent to the beach should not be overlooked.

Estuarine (up-river) sites in northern New South Wales are generally subject to high rates of run-off and flushing during the rainy season. This will cause hatcheries employing a flow through system to be inoperable for a substantial part of the year. Salinity and rainfall records for the lower Clarence region suggest that closure would be necessary for 4 to 5 months from March each year unless an alternative water system (recirculation or artificial salts) were to prove effective.

Hatchery/Grower Relationships

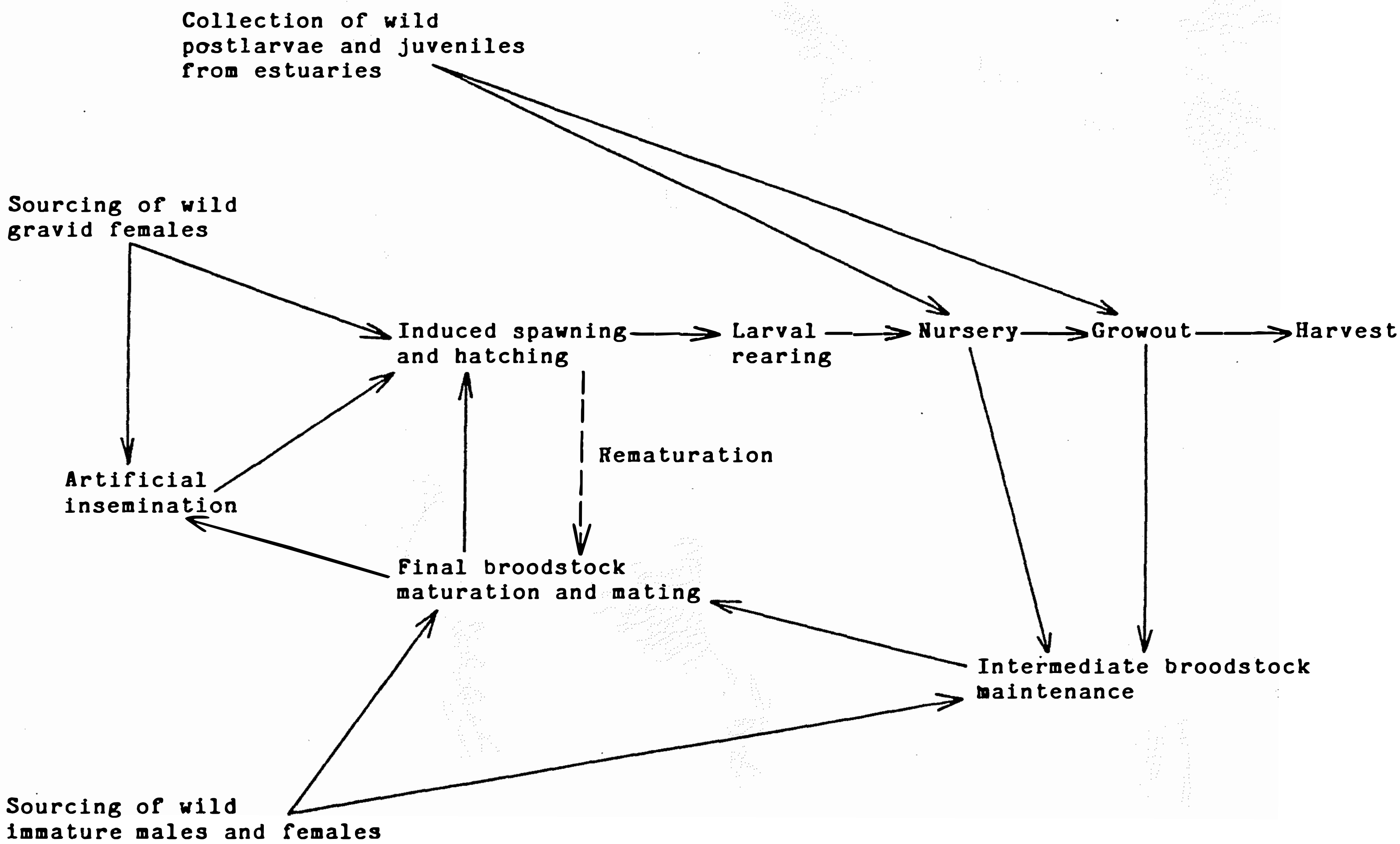
There appear to be three likely organisational options for the hatchery operation. Firstly, a hatchery may be owned and operated by a private grower. In this case the hatchery will be designed to have a production capacity matched to the owner's pond stocking requirements. Incidental surplus production may be supplied to other growers, although the amount of this surplus is likely to be small with no guarantee that it will be consistently available. Secondly, a large private hatchery with no or few co-owned ponds may be established specifically to supply growers on an order book basis. This type of hatchery will need to be large, well situated and efficient to remain competitive. The third likelihood is a cooperative hatchery in which a number of growers will participate as shareholders to ensure that their own ponds are stocked as a priority and at a lower price. There may be a small surplus which would be sold to others on spec.

It is probably desirable to allow all three types of hatchery to co-exist because each fills a slightly different need and functional diversity will give the industry greater stability. Except in the case of the supply of surplus production, there is an obvious need for strong ties and good communication between hatchery operators and growers, because of the high degree of economic inter-dependence. In general, it will be necessary for hatcheries to provide follow-up service to ensure that postlarvae are correctly handled and survive well during stocking activities. Assistance to growers with water analysis and biological aspects would also be desirable. Likewise, growers should provide feed-back to hatchery operators so that the reasons for any particularly poor or excellent survival or growth of postlarvae might be understood.

Conclusion

Sufficient is known of the major functional aspects to enable the establishment of commercial prawn hatcheries in Northern New South Wales for the production of postlarvae of several locally occurring species from wild broodstocks. The effectiveness of these hatcheries will largely depend on the nature of the sites selected and the proper matching of seawater treatment systems to each site. It is most desirable that some sites with open-ocean access be made available by Government for hatchery developments.

FIGURE 1. Relationships of penaeid postlarval production within the farming operation.



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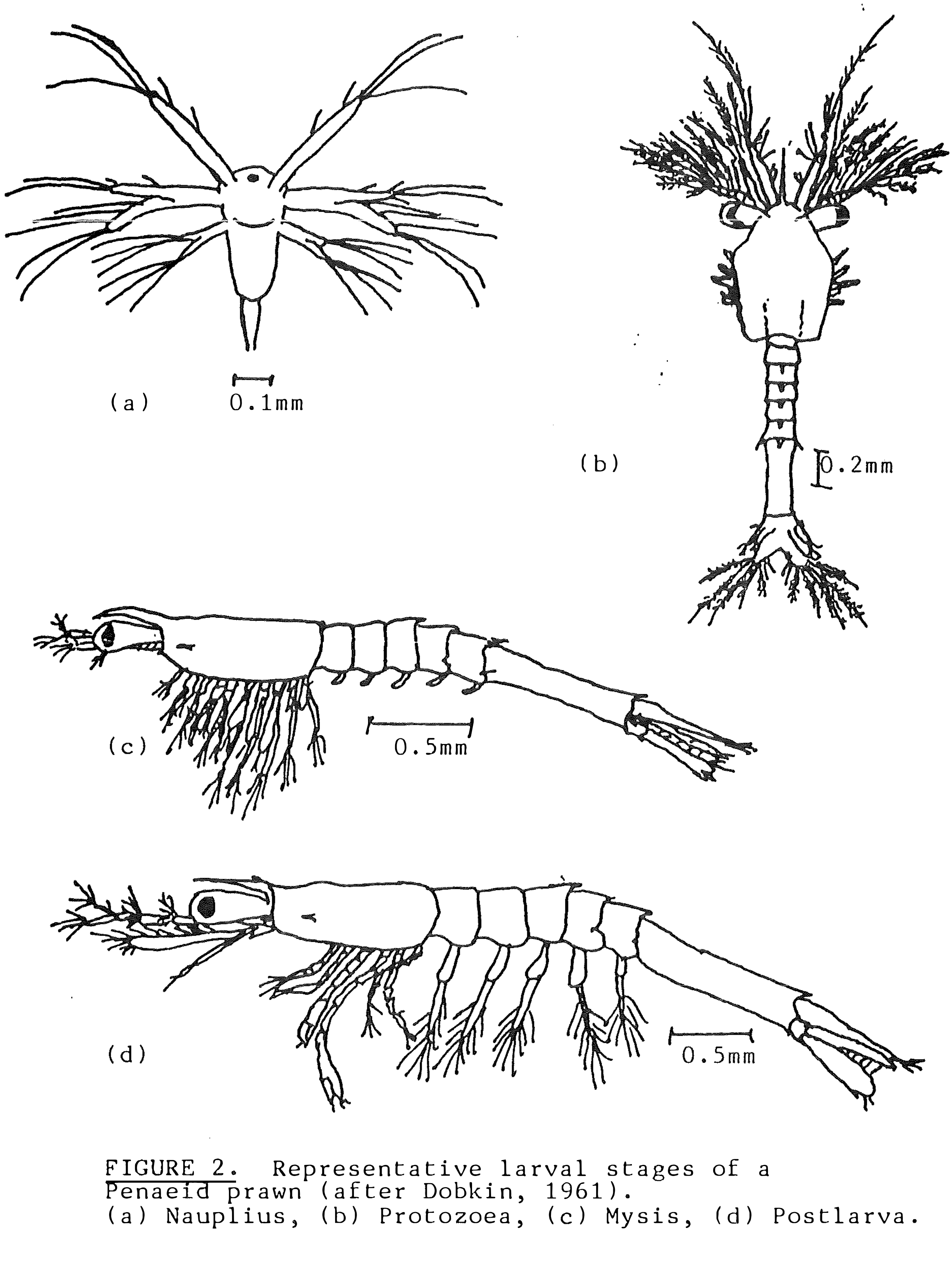

FIGURE 2. Representative larval stages of a Penaeid prawn (after Dobkin, 1961).
(a) Nauplius, (b) Protozoea, (c) Mysis, (d) Postlarva.

TABLE 1. Biological attributes affecting the design of induced breeding formats for three New South Wales penaeid prawns.

Species (thelycum type)	Availability of wild spawners	Inducibility of spawning	Spawner size	Spawning success (%)	No.eggs per spawn (x 10^3)	Hatch rate (%)	Long term maintenance in captivity	Ovarian maturation	Mating in captivity
Penaeus plebejus (closed)	Abundant all year in oceanic waters north of Coffs Harbour	Readily induced (23-26°C)	40-120g	94 (all fertile)	197	69	Difficult, requires sophisticated water treatment	Will occur under controlled environmental conditions, enhanced by eyestalk enucleation	Not observed
Metapenaeus macleayi (semi-closed)	Irregularly between Oct. - April, inshore waters adjacent large rivers (esp. Clarence and Hunter)	Limited data suggest readily induced (23-26°C)	27-31 mm C.L.	100 (all fertile)	30	41	Fairly easy using simple aquarium systems	Achieved only after eyestalk ablation	Not observed
Metapenaeus bennettae (semi-closed)	Abundant Oct. - April, semi-enclosed waters central N.S.W. (esp. Lake Macquarie)	Readily induced (21-28°C)	3-14 g	83 (66% fertile)	32	69	Very easy with simple aquarium systems	Achieved without ablation under loosely controlled conditions	Not observed

Spawning data for M. bennettae, I.R. Smith, personal communication.

PLANNING AND ENVIRONMENTAL ASPECTS

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A prospective prawn farmer must make two major decisions: the first is whether or not to thoroughly investigate the many and varied planning, environmental, biological and marketing controls on prawn farming. A farmer who does not rigorously examine these controls may find himself in difficulty later on. The second major decision is of course whether or not to invest.

The purpose of this paper is to highlight some of the planning and environmental aspects which require the potential farmer's close consideration in the very early stages.

Planning Aspects - Legislation

Acts of Parliament which relate to prawn farming include:

1. Environmental Planning and Assessment Act (Department of Environment and Planning).
2. Fisheries and Oyster Farms Act (Department of Agriculture, Division of Fisheries).
3. Crown Lands Consolidation Act (Crown Lands Office).
4. Clean Waters Act, (State Pollution Control Commission).
5. Local Government Act, 1979 (Department of Local Government).
6. River Foreshores Improvements Act (Public Works Department).

All specific requirements of those acts must be met before the Department of Agriculture will issue a license to farm prawns.

It is not my intention to present a boring summary of the relevant sections and subsections of those acts, rather a process of consultation with the other affected departments and instrumentalities has facilitated the Fisheries Division's identification of the salient bits of legislation and allowed the prawn farm application form to be structured around them. The application form and, indeed, the whole application process, is still under review and some changes can be expected. One potential problem, recognised right from the start, is the undesirability of the licensing process taking an inordinately long time.

One issue arising from the various pieces of legislation is the fundamental question of whether or not prawn farming is agriculture. The Department of Environment and Planning firmly holds the view that "prawn farming is not agriculture for the purposes of the Local Government Act, 1919 or the Environmental Planning and Assessment Act, 1979, but constitutes the establishment of a fishery". This view means that development consent is required from a council before ponds may be constructed. Various Councils may have alternative views on this statement and/or planning methods for dealing with this potential problem. While the question appears academic, its resolution is needed in order to minimise delay in the processing of prawn farm applications.

Under Part 6 of the Environmental Planning and Assessment Act, the Department of Agriculture cannot issue a prawn farming licence if a proposed farm is likely to have a "significant" environmental impact, unless an Environmental Impact Statement is prepared. It is not the Department of Agriculture's intention to call for such an investigation in the case of every prawn farm; it is conceivable however that in some instances it will be necessary.

Planning Aspects - Estuarine Habitat Conservation

The Department of Agriculture must weigh up a great variety of items in any one prawn farming application before a licence is issued. Under the terms of the Fisheries and Oyster Farms Act, the Minister is charged with the protection, development and regulation of the state's fisheries resources. It is not in anyone's interest to see the destruction of one fishery to create another. Rather, a balance must be sought through the weighing up of the pros and cons of a prawn farm application. It is intended that the applicant will supply details on the *biological* environment surrounding the proposed farm. For example, are saltmarsh plants, mangroves, or seagrasses present? The value of these wetland areas in fisheries productivity terms is well known, and efforts must be made to conserve them. Wholesale destruction will not be permitted and the siting of ponds must conform with the sensitive nature of these wetland areas.

It is also worth recalling that many wetlands are home to birds and/or other fauna which are protected by special legislation and treaties.

As well as consideration of the biological environment, a through canvassing of the *physical* and *chemical* environment is necessary. In some cases physical constraints such as tide and flood heights will eliminate possible farming sites. In other cases, the civil works proposed to create ponds will not be acceptable due to possible adverse hydraulic consequences. The Department will be strongly guided by the expert opinion of the Public Works Department in this regard.

In other cases there will be chemical constraints on a prawn farming proposal. Pesticides have been used in cane farming areas and are persistent in soils. The effect on prawns is still uncertain and further consideration will have to be given as to how this matter is dealt with. For example, if high soil pesticide levels are anticipated, how, by whom and at whose cost are analyses to be done (pesticide analyses are expensive)? How many and over what area?

Another chemical consideration is the nature of effluent from the ponds of prawn farms. Normal effluent is expected to be somewhat elevated in its nutrient levels and the effect on the adjacent estuarine receiving waters may be undesirable. On occasion effluent may contain additional chemicals such as those used to control a disease outbreak. This matter is to be further examined by the Department of Agriculture and the State Pollution Control Commission.

Suffice it to say that merely deciding to investigate the potential for prawn farming should not be taken lightly. There are many issues which require close consideration before the prospective farmer is in a position to decide whether or not to invest his capital.

PITFALLS FOR A PRAWN FARMING INDUSTRY

Paul Bolster

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If you are considering going to Prawn Farming you must consider a number of matters some of which are as follows:

1. The site of the farm
2. Soil Structure
3. Pond Construction
4. Source of larvae
5. Method of Harvesting
6. Marketing.

I am only going to deal with three of these items as I consider they are essential for the long term viability of a Prawn Farming Industry. They are pond construction, method of harvesting and marketing. You are probably wondering how these are related and what they have got to do with a grower organisation which is part of the topic I am covering. Let me assure you they are all very closely related. Pond construction and the method of harvesting will determine the ability of the farmer to turn off regular crops of Prawns which in turn will enable the farmer to get the greatest return for his product from the market place.

I'll deal first with marketing proposals in an attempt to show how these can be related to pond construction and harvesting techniques. The present marketing of prawns in New South Wales is governed by the Fisheries and Oyster Farmer's Act which provides for products such as prawns to be sold to either a local co-operative or the Sydney Fish Market.

This system which has worked reasonably well for trawlermen would be in my opinion a complete disaster for a well organised prawn farming operation.

For those of you already in the industry you will say, "Well what's wrong with the present system because we can regulate when we're going to turn our prawns off, well'll turn them off in the week before Christmas or the week before Easter dump them on the Sydney Fish Market and get top dollar for them".

Consider this, consider a hundred prawn farmers in New South Wales and southern Queensland dumping their entire production on the Sydney Fish Market in the week prior to Easter or Christmas and that price of $9.00 a kilo that you've enjoyed for school prawns to date will be about $1.50. Well then you'll say, "What is the solution that you are prepared to provide us with?" The answer to that is the free market.

Let's look first of all at what has happened to other primary industries. We're all aware of the vagaries of agricultural markets and the resultant pressures that fluctuation and market prices place on the farmer. The Government has attempted on one hand to provide the answer by regulating by statute rule industries, but has met with little success. You look at the grain and egg producers of this State you will see the results. It does not paint a very pretty picture. On the other hand producers have attempted regulation and if we look at the cane industry we could also consider that to be an object failure.

We cannot escape the fact that the free market will always dictate the price of a product and unless producers are sensitive to the forces of the free market they're living in a fool's paradise.

Having already said that government regulation hasn't worked in industries you'll probably say, "Well what will?" If we look at those industries we will see quickly why the form of regulation has not worked and it can all be directly attributed to the fact that the price paid to the producer has not quickly responded to the market situation. It, takes in a lot of cases, five to ten years for the market surpluses which strike all primary industries to get back to the producer in terms of dollars and cents. What I am proposing is this, that we establish a producer organisation. That producer organisation will be multi-faceted.

Firstly, a company should be established, for convenience sake and as an example only, we will call it "Prawn Distributors Limited". It would be multi-functional and would serve the following purposes:-

1. It would negotiate with exporters a forward contract for the sale of export prawns.

2. It would be a producer lobby group.

3. It would promote the product domestically.

4. It would be a means of pooling industry information for the increased benefit of farmers and to assist people wishing to establish as farmers.

The basic structure of the company would, it would have five directors, four would be elected Producer Representatives and one would be a Department of Agriculture Officer appointed to the Board by the Minister for Agriculture.

I have drafted a set of Memorandum and Articles of Association for such a company, however there was not sufficient time for me to have them printed for this paper. They do run into some thirty pages.

Now after saying that this company is going to be the producers' way of organising themselves to cover any of the contingencies that may arise in the industry I will now deal with how I would see that the markets that are available would be dealt with.

First of all I consider it is false economy in the long term to restrict licences to prawn farms to comply with the size of the domestic market. We are all aware and Markwell Fisheries in Tweed Heads is a shining example, that the product can be reaily exported at a reasonable price and a large market does exist. There should be no quota system; apart from the fact that it is false economy to have a quota system it would be impossible to police satisfactorily.

The only method of a quota system would be to limit pond areas. For those of you who are familiar with rice farming quotas you will realise what a failure this was when they are able to control the crop. In a prawn farming situation this system would fail miserably because it depends pricipally on the efficiency of the Farmer as to the production per hectare and there can be very large variants. You must take into account that you simply cannot count the prawns that are being grown in a pond so the short answer is, forget about a quota system.

Secondly, let's deal with the two types of market for the industry. First there's the domestic market and secondly the export market. My recommendation is this, that any person who qualifies for a licence for a prawn farm from the Department should receive an exemption under the Fisheries and Oyster Farms Act to enable them to sell on the domestic market their product. In other words, if you have a licence to be a prawn farmer and you're producing prawns you should be entitled to go to your local restaurant proprietor and say to him, "I can guarantee you each week, each month, every six months a certain quantity of prawns" and he can say to you, "I'm prepared to pay to you a certain price per kilo for those prawns."

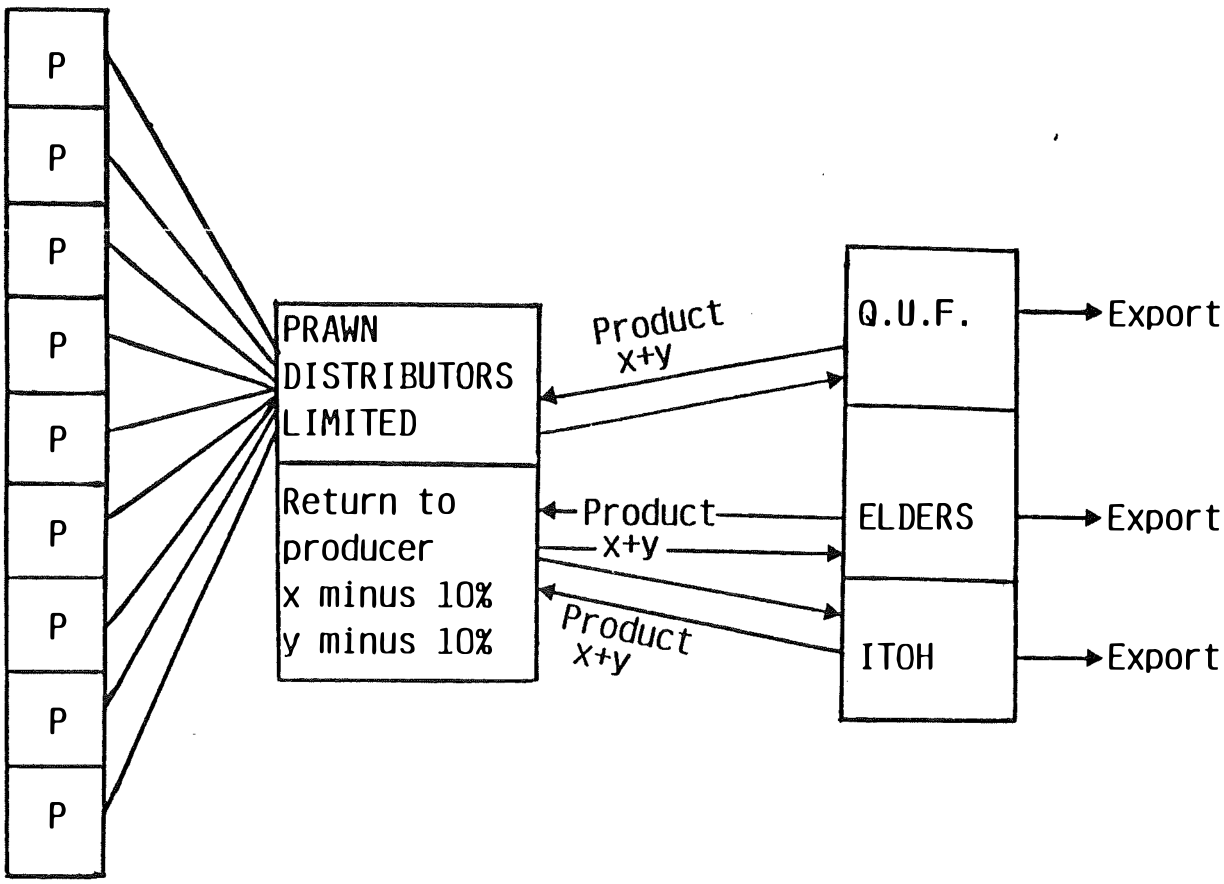
The market itself will regulate the product. Let it be the judge of the quality, price and freshness of the product. I don't propose to say anything more about the marketing domestically of prawns. I will now deal with how I would see the marketing of prawns for export could operate.

The adjacent flow chart provides the example:

The "P" represents the producers who would supply their product to the company I have already mentioned, Prawn Distributors Limited who on their behalf would negotiate a back to back agreement with one or all of the export companies mentioned. The agreement would consist of this. In return for Prawn Distributors supplying the exporters with a set quantity of prawns of a predetermined size (which for the purposes of the exercise we shall call x) over a period of twelve months the exporter would guarantee a minimum price for the productand that price would be payable when the product was landed at their New South Wales processing plants.

The quality of prawns to be supplied (referred to as x) would be supplied by the producers as a predetermined amount from each one, depending upon their capacity to meet the demand. Should a producer deliver more than the minimum quantity negotiated by Prawn Distributors Limited, then it would be sold to the exporters, but at the prevailing market price. This will have the effect of keeping the producers aware of the vagaries of the market place but at the same time it will guarantee the producers a return for the year which will enable them to budget with reasonable certainty.

You may well ask, what prevents an individual from making precisely the same arrangement as Prawn Distributors Limited with the exporters? The answer is nothing, but because they will not be able to supply the same quantity of prawns



Guaranteed price of (x) for 12 months

Balance of product sold on market at market price (y) this will not enable them to secure as high a return for themselves as Prawn Distributors could secure for the producers. The Second Factor is that Prawn Distributors Limited hold a small percentage of payments due to the producers until the next harvest in order to ensure delivery of the minimum quantity of prawns required and guaranteed to the exporter.

Some of you may say, "Well why bother going to the exporter at all? Why not export direct to Japan? No one should be naive enough to consider that they could manage an export product to Asia or anywhere else for that matter. Let me tell you about a person who set up an export business for sea urchins to Japan. He went to Japan, arranged a contract for the purchase of all goods he could produce to a company in Japan and established a price for first quality sea urchin meat at say $35.oo per kilo. He then started harvesting and shipping to Japan by air freight. However, what happened to him was that once the product reached Japan, he was told by his purchaser that the product was not first quality but third quality and was only worth $10.00 per kilo, take it or leave it. The product was already in Tokyo. The marketing of products is a high risk business and a matter for professionals. It should not be tackled by an individual producer or by a group.

Now, you will say, "What relationship is there between the marketing proposals you have just spoken about and pond construction and methods of harvesting". The relationship basically is this. The domestic market and the export market do not respond well to large quantities of prawns being dumped on them at one particular time. For example, the Japanese have a number of festivals a year when they consume a large number of prawns. The people of Australia would prefer to eat prawns on a more regular basis provided the price did not fluctuate the way it presently does. In other words, the farmer should be in a position to guanantee continuity of supply.

When I say continuity of supply I don't mean once every six months, I mean on a regular basis being weekly, fortnightly or monthly. Any of you who have been to the large seafood restaurants up and down our east coast would be aware that every weekend there are large numbers of prawns consumed in these restaurants and at greatly varying prices. The only way to guarantee continuity of supply is to construct a specific style of pond. What I am about to say is not meant as a criticism of any person currently in the industry. The people that are presently producing prawns are currently adopting an approach for constructing large ponds and harvesting by net. Any person in the industry who wishes to produce a product which can guarantee to the market continuity of supply, should look at the paper produced by Holcomb and Parker on the efficiencies of drain and net harvesting techniques.

Basically, the difference between the two systems is this; if you want to drainage harvest, you construct a small pond, say half a hectare in size, you put a slope on the bottom of it which will enable the prawns to be effectively drained from the pond. In a large area of land you could construct say fifty to one hundred ponds. On the example supplied by Holcomb and Parker you will need one eighth of the labour content as would be required to net harvest the same number and size of ponds and you would get an increased return in production of approximately 18%.

The advantage of the small pond is that you could turn off a pond every week or fortnight and guarantee continuity of supply to the market as opposed to a large pond which requires a number of men to net the pond out and means that you would be dumping a large number of prawns onto the market, but only doing it periodically.

In summary let me return to the marketing proposals which I started this paper with. We can have one producer-run controlling body which will negotiate forward contracts for the export market, be an effective lobby group, could promote the product domestically and be a source of information on a continual basis for farmers and people wishing to become involved in the prawn farming industry.

What I have said is not intended to be a hard and fast system for the topics that I have covered, however, I recommend to any person who is already in the industry or thinking of joining the industry that the only effective and efficient way to protect your interest is to establish the company that I have spoken about and to ensure that it is run along the guidelines that I have mentioned.