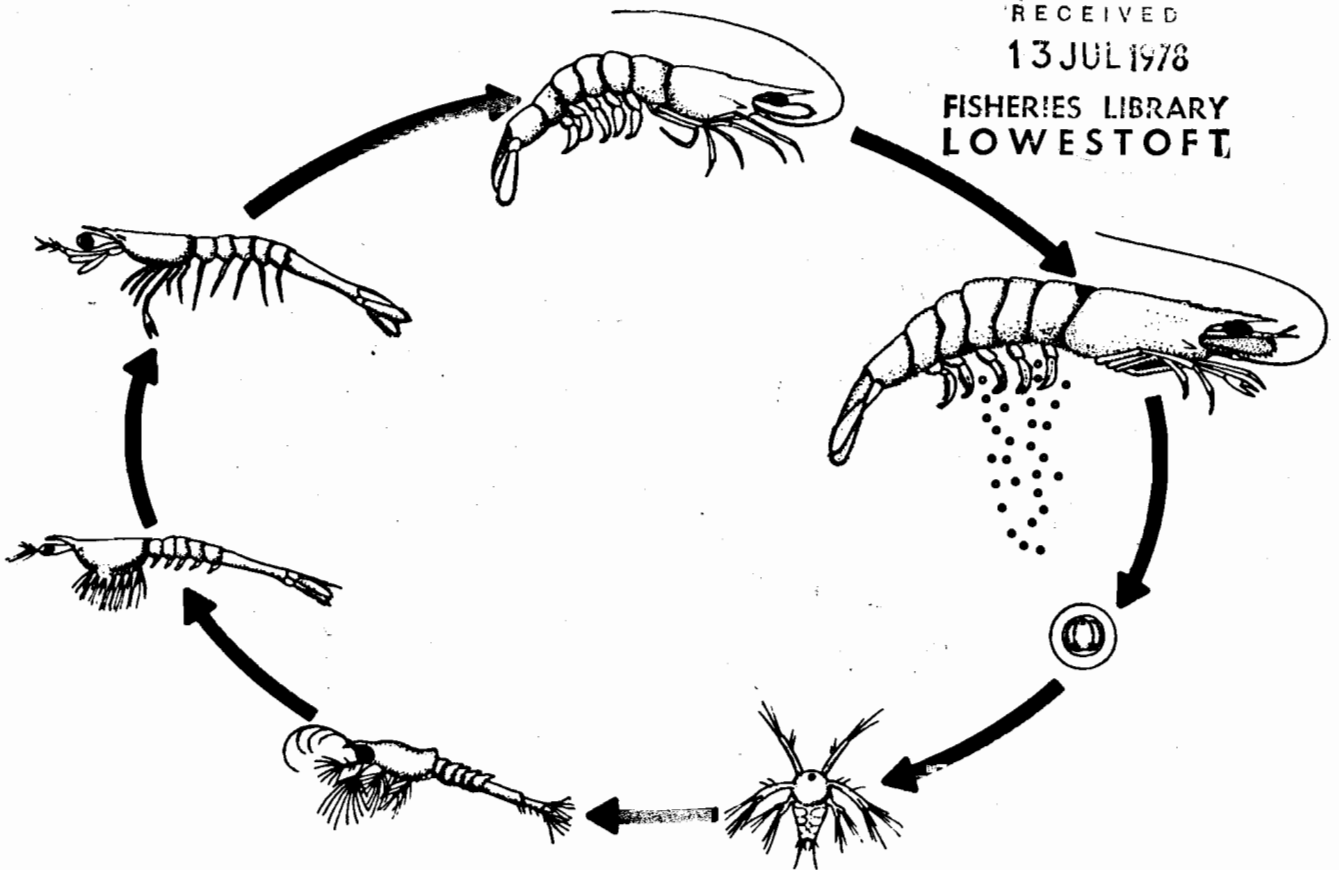


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MINISTRY OF AGRICULTURE FISHERIES AND FOOD
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MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
PRAWN CULTURE RESEARCH

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J.F. WICKINS AND T.W. BEARD

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MINISTRY OF AGRICULTURE, FISHERIES AND
FOOD PRAWN CULTURE RESEARCH

by J. F. Wickins and T. W. Beard

1. INTRODUCTION

There is a continuing high demand for shrimps and prawns on world markets. In 1975 the total world catch was over $1\frac{1}{4}$ million tonnes of which 50% was consumed by Japan and the United States of America (FAO 1976). Recently, the European Economic Community has begun to compete vigorously for supplies and in 1975 the value of whole prawns alone imported into Great Britain was £4.5 million. The high value of shrimps and prawns has led to a sustained research effort on their cultivation from both public and private sectors throughout the world. It has been estimated that during the past ten years the potential for culture of some 46 species of shrimps and prawns has been investigated in over 40 countries in addition to the traditional culture practices of India and the Far East (Wickins 1976).

At the Fisheries Experiment Station of the Ministry of Agriculture, Fisheries and Food at Conwy experiments are being made to determine the potential of prawn culture in Great Britain. Preliminary studies made during the period 1964-70 with the European common prawn Palaemon serratus, the spot prawn Pandalus platyceros from Canada and the giant freshwater prawn Macrobrachium rosenbergii from Malaysia were discussed in an earlier publication (Forster and Wickins 1972). This report discusses the results obtained since 1970 with Macrobrachium rosenbergii and ten species of penaeid prawn. References to the world literature quoted are listed at the end and a glossary of biological and technical terms including explanations for the non-specialist is appended.

2. NOTES ON PRAWN BIOLOGY

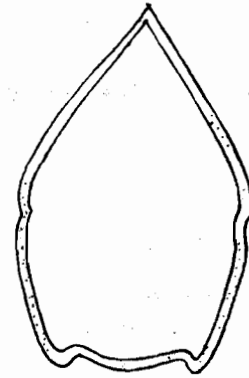
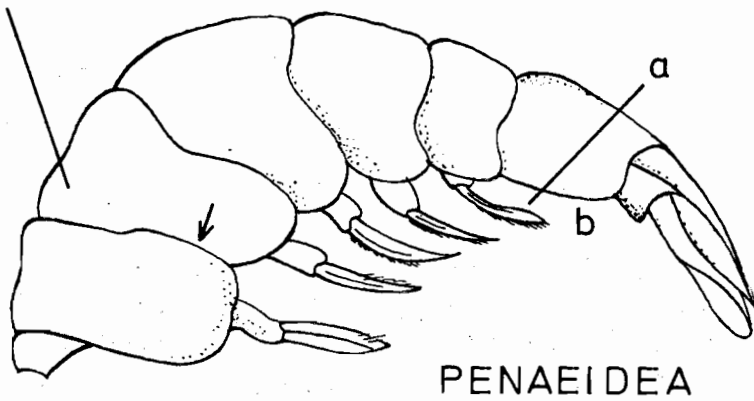
2.1. Classification

Prawns belong to a large class of animals called the Crustacea. Most members are aquatic, for example crabs, lobsters and water fleas, but there are some terrestrial representatives such as the woodlouse. It is mainly among the sub-class Malacostraca, order Decapoda that species occur which are directly important as human food. The Decapoda is divided into two sub-orders, Reptantia and Natantia. The Reptantia contains the larger, hard-shelled lobsters, crabs, crayfish, Dublin Bay prawns ('scampi') and freshwater crayfish. The sub-order Natantia contains the smaller, thinner-shelled shrimps and prawns that are considered in this review.

The Natantia are sub-divided into two groups, the Penaeidea and the Caridea which may be visually distinguished by features of their second and sixth abdominal segments (see Figure 1). These are further sub-divided into a number of genera, for example Penaeus and Metapenaeus belong to the Penaeidea, and Macrobrachium, Palaemon and Pandalus to the Caridea. Each genus contains a number of species.

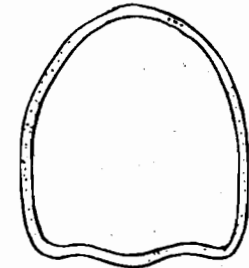
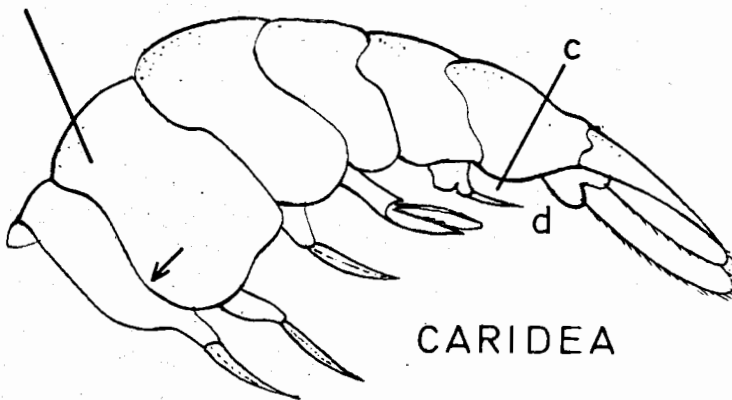
Prawn species are found in a variety of habitats that range from the ocean depths to inland streams and lakes and from the tropics to the sub-polar regions; however, in spite of their diversity of habitat, they show many similarities in their biology.

Pleuron of somite 2



Section through a-b

Pleuron of somite 2



Section through c-d

Figure 1 The main features used to distinguish penaeid and caridean prawns. In the penaeids the pleuron of somite 2 does not overlap the pleuron of somite 1 as it does in carideans, also a dorsal keel is visible in the cross-section of somite 6 in penaeids but not in carideans (after Fincham and Wickins 1976).

2.2. Life cycle

Penaeids spawn large numbers of eggs directly into the water and hatching occurs a few hours afterwards. In carideans larvae hatch only after a period of incubation during which the eggs are attached under the tail of the female. Penaeid prawns hatch at an early stage in their embryonic development, as a larva called a nauplius. The nauplius does not feed but lives on its reserves of yolk and passes rapidly through a number of moults, usually five or six, before passing into the next larval form called a protozoa. The protozoa feeds on microscopic plants and it moults, usually three times, before passing into the final larval form called a mysis or zoea. The mysis larva will take larger food such as *Artemia* and itself moults, usually three times, before metamorphosing into the juvenile (see Figure 2). Some authors call the newly metamorphosed prawn a post-larva and describe young prawns as juveniles only when they have completed several post-larval moults.

In the Caridea (Figure 3) the nauplius is passed over and becomes an embryonic stage within the egg. The larva hatches as either a protozoa or a zoea. Development is then similar to that in the penaeids, although there are frequently more than three zoeal stages in the Caridea.

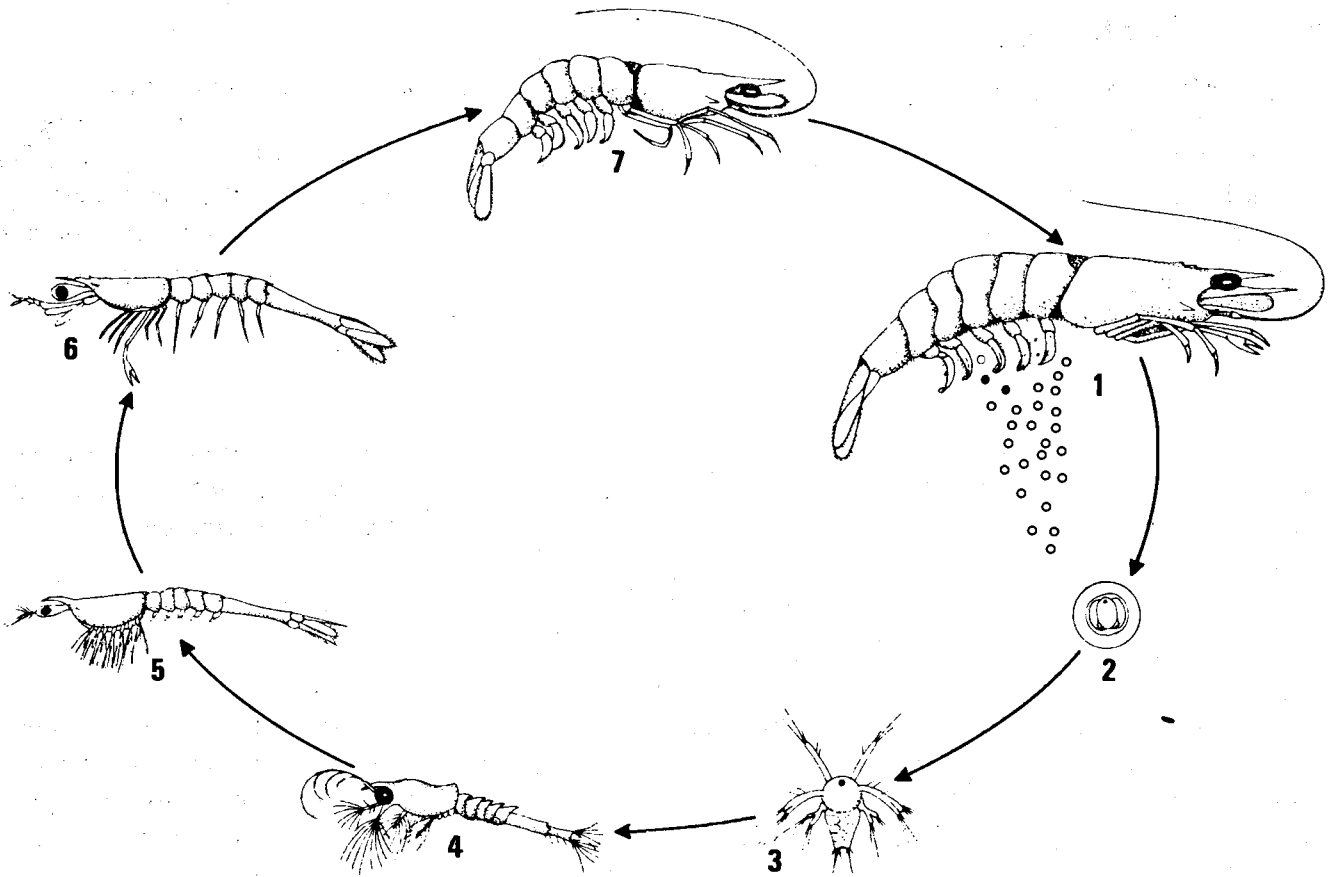


Figure 2 The life cycle of a penaeid prawn. 1. Adult spawning female; 2. egg; 3. larva (nauplius); 4. larva (protozoa); 5. larva (mysis); 6. post-larva; 7. juvenile (after Forster and Wickins 1972).

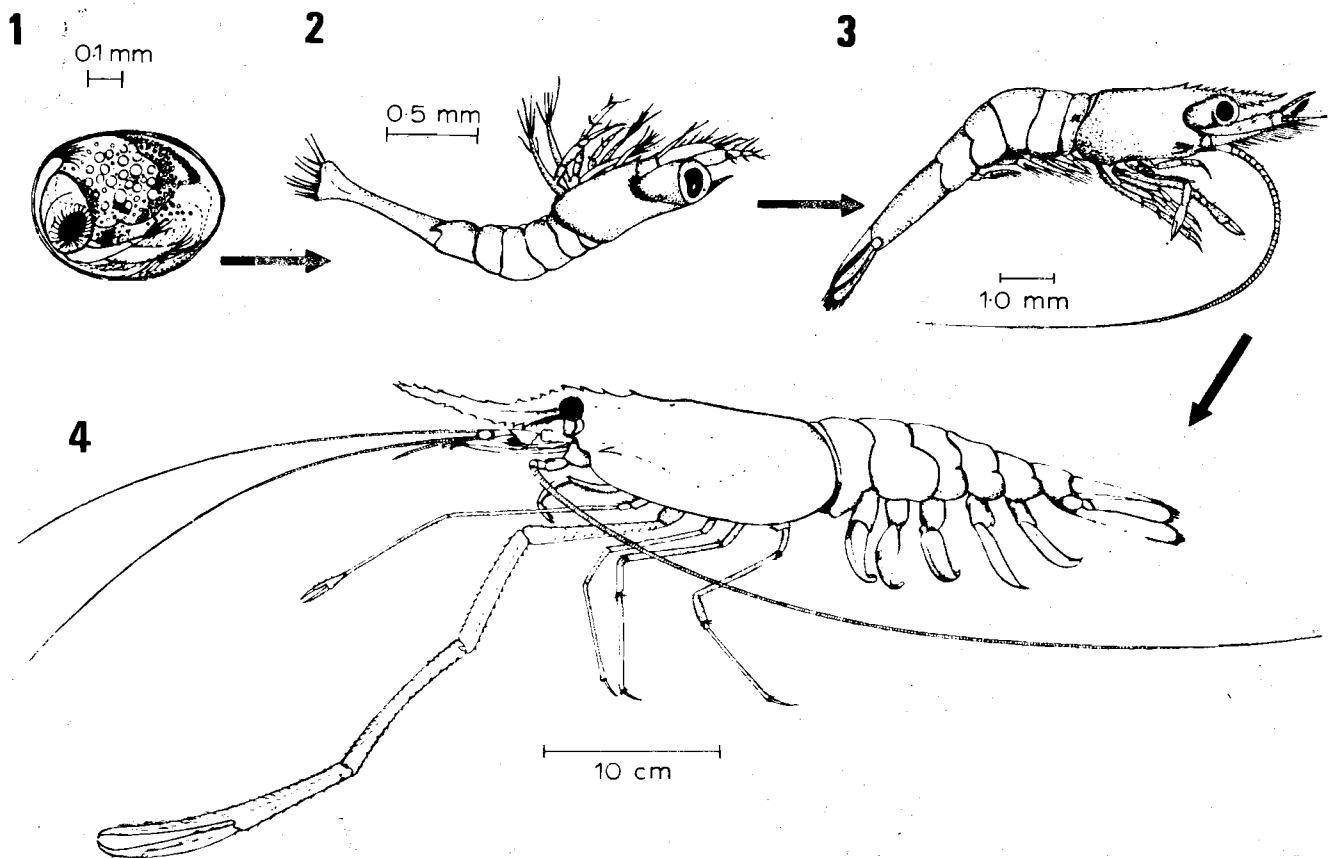


Figure 3 The life cycle of a caridean prawn. 1. Egg; 2. zoea larva; 3. post-larva; 4. adult (after Forster and Wickins 1972).

2.3. Growth and moulting

All prawns have an external skeleton or shell which serves for both muscular attachment and protection; this is capable of only limited expansion. In order to grow, therefore, they periodically have to cast off the old shell and form a new and larger replacement. This is called moulting or ecdysis. After moulting, the new shell is soft but gradually hardens with time. The time taken varies between species with age, but during this period the prawn is vulnerable and in tank conditions may be attacked, killed and eaten by its companions.

2.4. Feeding

Prawn larvae feed on microscopic plants and animals. The juveniles and adults are omnivorous scavengers feeding on a wide variety of animal and vegetable matter, although most species seem to prefer animal food such as small worms and Crustacea when available.

3. PRODUCTION OF JUVENILES

The provision of suitable quantities of juveniles for commercial cultivation in Great Britain will depend upon prawn hatcheries since the species most suitable for domestication do not occur naturally in the North Atlantic Ocean. An intensive, continuous production UK culture operation would require batches of post-larvae at weekly or monthly intervals throughout the year. It has been our experience, and that of a few commercial UK companies, that the importation of live post-larvae even for experimental purposes has been difficult to arrange, nearly impossible to time and very costly. It is unlikely to be worth-while considering regular shipments of post-larvae from hatcheries abroad for culture in Britain.

Penaeid prawns have a high fecundity and relatively few adults are needed to form a breeding stock. As a result, estimated costs of production of post-larval penaeids in Britain are not more than 5% of the total production costs of marketable prawns. There are three distinct stages in the hatchery production of juvenile prawns:

- (a) maintenance of the brood stock, spawning and hatching;
- (b) culture of the larvae to metamorphosis;
- (c) weaning the post-larvae from live foods to prepared foods and their subsequent culture to 0.1-0.2 g when they can be stocked in the grow-out facility.

In the following paragraphs the results of experiments on the culture of Palaemon serratus, Pandalus platyceros, Macrobrachium rosenbergii and Penaeus merguensis from the egg to 0.1-0.2 g live weight are summarized. Details of the methods by which juvenile penaeid prawns were produced are outlined in Sections 5 and 6 on culture techniques and costs, while methods used in the culture of caridean juveniles are described elsewhere (Wickins 1972a, b; Wickins and Beard 1974).

3.1. The brood stock, spawning and hatching

In Table 1 selected aspects of the biology of four species of prawn are compared. P. merguensis, which is typical of many penaeids, has a number of advantages for culture over the three caridean prawns. These include short generation and incubation times, high fecundity and a short larval life (see Table 2). In common with most natantians the number of larvae produced by the four species increases proportionately with the size of the parent, as indicated for M. rosenbergii and P. merguensis.

Table 1 Selected characteristics of four prawn species cultured at Conwy

	<u>Palaemon serratus</u>	<u>Pandalus platyceros</u>	<u>Macrobrachium rosenbergii</u>	<u>Penaeus merguensis</u>
Generation time (months), i.e. time from being spawned to the first spawning as an adult	8	Protandrous hermaphrodite* 24-36 [†]	7-8	6-7
Live weight of females at first maturity (g)	3.0-3.5	25-35	25-30	9-15
Interval between spawnings (months)	4 [‡]	12 [‡]	3-4	2-3
Incubation time (days)	30-40	120-150 [‡]	19-21	0.75
Number of larvae				
(a) laboratory	< 1 000	-	23 000 from 50 g ♀ 74 000 from 150 g ♀	10 000 from 10 g ♀ 35 000 from 20 g ♀
(b) wild	1 000-2 000	2 500-4 500	> 50 000	> 100 000

*See glossary

[†]Butler 1970[‡]Estimated

3.2. Culture of larvae

A number of mass cultures have been attempted with each species and the results are summarized in Table 2. Survival to the post-larval stage decreased from 75 to 25% as the culture density increased from 36 to 150 larvae/l in Palaemon serratus and from 15 to 45 larvae/l in Pandalus platyceros. Survival averaged over 50% in Penaeus merguensis, at least up to a density of 400 larvae/l. Unicellular algae were required as food by protozoa penaeid larvae (see Section 5, Culture techniques) but were not essential for caridean larvae which fed readily on newly hatched Artemia nauplii. The addition of algae, however, increased the growth rate of Macrobrachium rosenbergii larvae and decreased the time spent in the larval stage by Palaemon serratus. These beneficial effects were probably due to the removal, by the algae, of excreted ammonia (Cohen, Finkel and Sussman 1976) and, particularly in the case of the Macrobrachium rosenbergii cultures made at 28°C, to the improved food value of Artemia which had consumed some of the algae. Normally, larvae grew best when the concentration of Artemia was 5-10 nauplii/ml (Reeve 1969a). The number of nauplii consumed daily by Palaemon serratus larvae rose from 20/larva on the second day after hatching to 150/larva after 24 days when 50% of the population were post-larvae (Reeve 1969b). Newly metamorphosed post-larvae preyed actively on remaining larvae. Mortalities due to cannibalism among carideans were sometimes 10-20%/week except when the majority metamorphosed within a 7-10 day period.

3.3. Weaning

After metamorphosis the post-larvae appeared to pass through a critical phase during which heavy mortalities sometimes occurred. This was thought to be associated with a change of diet from live Artemia to prepared foods such as pieces of mussel, shrimp or small pellets. The species of prawn varied in their responses to foods at this stage. Most broods of Palaemon serratus and Palaemon elegans took prepared foods within 7 days of metamorphosis. P. serratus grew better when a mixture of two foods (e.g. mussel and shrimp) was provided than when fed with a single food (Forster 1970). Pandalus platyceros and Macrobrachium rosenbergii were weaned in about 7-9 days after metamorphosis but the latter grew most rapidly when the salinity was reduced from 10⁰/oo to 1-2⁰/oo soon after metamorphosis. Penaeus merguensis did not readily consume prepared foods until about 2 weeks after metamorphosis.

Table 2 The mass culture of prawn larvae hatched at Conwy

	<u>Palaemon</u> <u>serratus</u>	<u>Pandalus</u> <u>platyceros</u>	<u>Macrobrachium</u> <u>rosenbergii</u>	<u>Penaeus</u> <u>merguiensis</u>
Number of cultures	23	9	3	5
Initial number of larvae	2 200-24 000	40-290	15 000-18 000	6 800-40 000
Volume of culture (l)	65-200	7	380	30-150
Density of culture (larvae/l)	34-366	6-42	40-47	71-400
Number of post-larvae	1 000-4 400	40-147	3 900-5 300	2 800-26 000
Survival (%), range	5-75	23-94	22-35	42-83
mean	27	46	27	58
Length of larval life (days),				
range	18-35	15-24	34-44	10-12
mean	27	20	37	11
Temperature (°C)	20-22	18*	28	28
and				
Salinity (°/oo)	30-34	30-34	10-15	30
suitable for larval development				

*Estimated

4. CULTURE TO MARKET SIZE

4.1. Temperate water species

Cold or temperate water species may be cultured either extensively (< 20 prawns/m²) or intensively (> 20 prawns/m²) in natural or heated sea water in cages, ponds or tank systems. The choice depends upon the area of water available, the degree of control which can be exerted over it and the economic return required on the investment. There are few cold or temperate water prawns which grow to a large enough size to be suitable for culture. In addition, these are likely to be uncommon or commercially unexploited and therefore difficult to obtain alive for experimental studies. Deep-water prawns frequently have stringent environmental requirements and are less suitable for culture than species which inhabit coastal or estuarine waters. The temperate water species Palaemon serratus and Pandalus platyceros grew slowly in outdoor tanks and in one growing season attained only 1.5 and 5.0 g live weight respectively. Neither species survived well below 4°C and to overwinter them in Great Britain supplementary heating would be a necessity. Both species showed an increased susceptibility to bacterial and fungal attack (see Section 4.5, Diseases) as moult frequency declined with the onset of winter temperatures. High capital investment in unheated cultures would not seem to be justified in Great Britain, since prawn production would be restricted by seasonal reductions in temperature and also by the short-term vagaries of the British climate.

The growing season might be extended by the use of waste heat, or by the use of heated, recirculated water. The latter would require a covered or indoor situation where both methods could be used in proportions that were economically and environmentally dependent. Power stations are the best known source of large quantities of heated water and at Hinkley Point, Somerset the growth of two temperate and three tropical species of prawns, Palaemon serratus, Pandalus platyceros, Penaeus japonicus, P. merguensis and P. setiferus, in power station effluent has been studied. Temperatures were about

8°C above ambient throughout the year and ranged from 14°C to 30°C in the experimental tanks. Temperatures higher than 25°C, the minimum for good penaeid growth, were limited to not more than 5 months of the year, but during this time also the temperature sometimes fell below 25°C. The best results showed that the number of crops obtainable per year was limited to one for both Palaemon serratus (at 3-5 g mean live weight) and Pandalus platyceros (at 6-8 g) and two for the penaeids at 10-15 g due to their faster growth rates (M. Ingram, pers. comm.). If a suitable market could be found for these small prawns their culture in power station effluents might warrant further attention, particularly if they could be grown in conjunction with other valuable species such as the Pacific oyster. At present, however, none of the prawns studied at Conwy seem particularly suited to outdoor cultivation in Great Britain. Indeed there is as yet no commercially viable outdoor culture of prawns for human consumption in Europe or North America.

4.2. Tropical species

The culture of fast-growing tropical species of prawn in a controlled indoor environment is considered to be the system showing the greatest likelihood of commercial potential in Great Britain (Walne 1977).

In contrast to temperate water prawns there are a large number of tropical and sub-tropical species suitable for culture and it was judged that commercial success would depend largely on the selection of a species with the following attributes:

- (a) ability to grow rapidly and tolerate crowded conditions and handling;
- (b) acceptance of compounded foods and efficient conversion of food to flesh;
- (c) tolerance to the unusual chemical conditions that develop in recirculated sea water (most tropical prawns grow best at about 28°C and to conserve heat it would be necessary to recycle the water);
- (d) ability to survive and grow well without special environmental additions such as sand substrates or shelters that would make maintenance difficult or less amenable to automation.

A series of experiments was made in which the growth and survival of ten tropical or sub-tropical penaeids and one caridean in recirculation systems were compared. The species were chosen initially because they had been reported to grow quickly in the wild and because they could be obtained from their country of origin either as hatchery-reared or wild-caught juveniles. The prawns were cultured at two stocking densities, 25 and 162 prawns/m² of tank floor, in grey, glass-fibre tanks (86 x 72 x 20 cm depth of water) so that the effect of crowding on growth and survival of each species could be measured. The experimental conditions were the same for all the species tested but were probably not optimal for some. Thus a poor result did not necessarily mean that a species was unsuitable since better yields might have occurred under different conditions. An example is given by Penaeus japonicus which only grows well if cultured on a sand or mud substrate in which it can bury. A good result, however, clearly indicated that a species was capable of giving high yields in conditions similar to those currently envisaged for commercial culture and that further improvements in performance would be possible by paying attention to the species' specific environmental requirements. The results are shown in Figure 4.

Crowding clearly influenced growth under the conditions tested. In *Penaeus orientalis* and *P. monodon*, the two most rapidly growing species, the mean size of those grown at 25/m² was 36-49% greater than those grown at 162/m². A similar difference (44%) was observed in *Macrobrachium rosenbergii* which has strong territorial instincts. Individuals of this species were observed to maintain a clear area around themselves within the radius

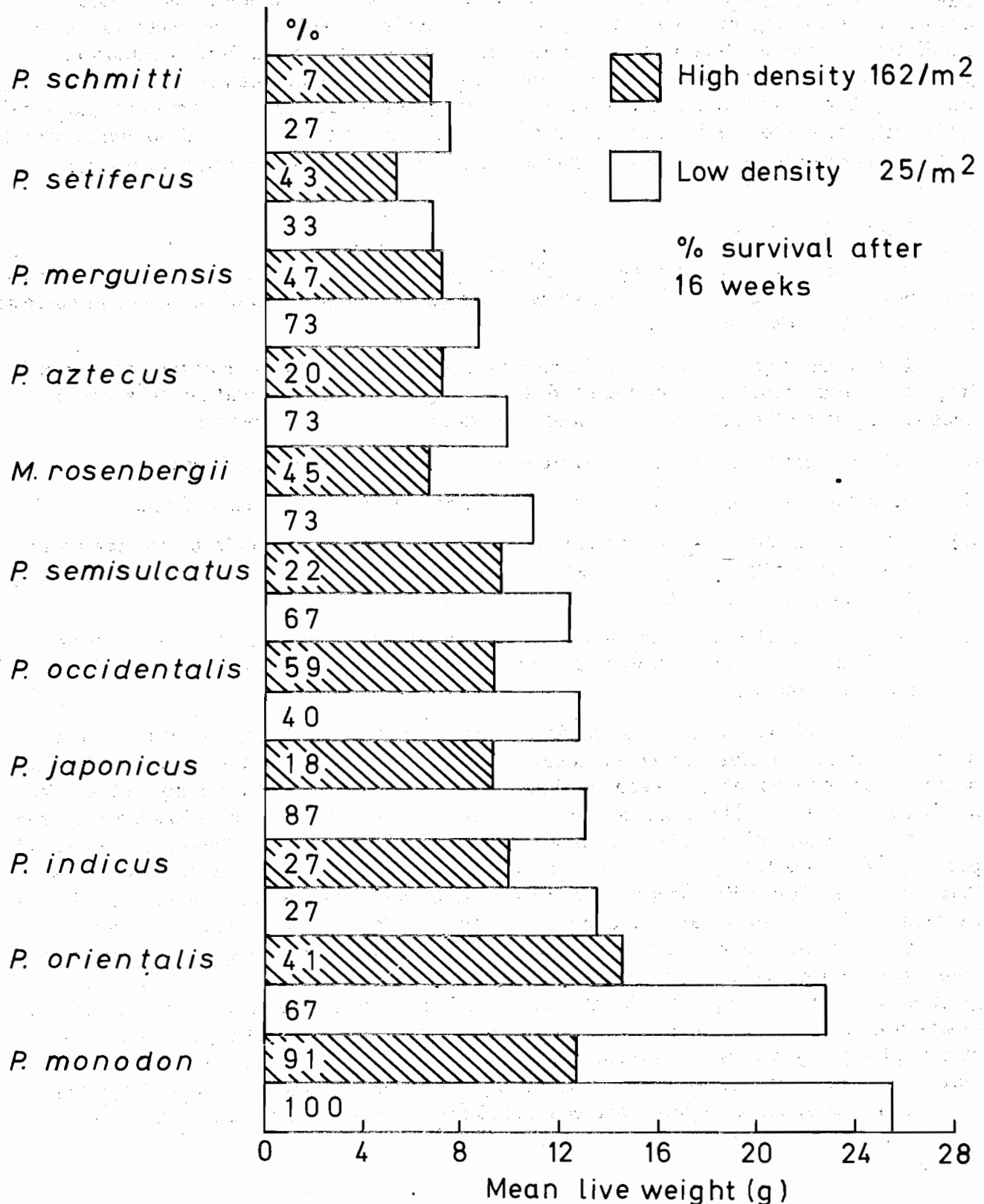


Figure 4 The growth and survival of ten species of penaeid prawn and *Macrobrachium rosenbergii* at two stocking densities. The trial with *P. schmitti* was curtailed after 8 and 12 weeks at the low and high density respectively.

of the sweep of their antennae into which no other prawns were allowed. A wide range of sizes invariably developed in populations of M. rosenbergii, regardless of density, and was probably related to their territorial behaviour. A comparison of the yields (expressed as total weight of prawns/m² of tank floor) obtained from the high density tanks and from similar trials with Palaemon serratus and Pandalus platyceros is presented in Table 3. Penaeus schmitti did not survive beyond 12 weeks and is excluded. P. monodon showed exceptionally good survival suggesting that this species is likely to be more tolerant than most to the culture environment. P. orientalis also grew and survived well up to the 12th week when yields were 1 155 g/m² (of 9.8 g prawns) compared to 1 338 g/m² (of 9.0 g prawns) for P. monodon at the same time. Between weeks 12 and 16 however 30% of the P. orientalis died and the final yield was reduced to 971 g/m².

Table 3 The yields of 12 species of prawn cultured in bare tanks for 16 weeks at an initial stocking density of 162 prawns/m²

Species	Yields (g/m ²)	Notes
<u>Penaeus monodon</u>	1 908	
<u>P. orientalis</u>	971	
<u>P. occidentalis</u>	889	
<u>P. aztecus</u>	612	
<u>P. merguensis</u>	585	
<u>Pandalus platyceros</u>	492	{ 185 prawns/m ² 23 weeks
<u>Macrobrachium rosenbergii</u>	486	
<u>Penaeus indicus</u>	432	
<u>P. setiferus</u>	366	
<u>P. semisulcatus</u>	345	
<u>Palaemon serratus</u>	315	{ 347 prawns/m ² 20 weeks
<u>Penaeus japonicus</u>	262	

4.3. Nutrition

An economical diet which combines rapid growth with good survival and which does not unduly pollute the water is essential for commercial prawn culture in a controlled environment. A diet of fresh mussel (Mytilus edulis) and frozen shrimp (Crangon crangon) consistently gave good results at Conwy but was considered to be too expensive for commercial use, except possibly as food for brood stock. These and other wet diets such as trash fish or offal-supplemented foods have a number of disadvantages:

- (a) rapid decomposition which may create areas of deoxygenation;
- (b) daily preparation from ingredients, either stored in freezers or obtained fresh each day;

- (c) vulnerability of supplies to prevailing weather conditions;
- (d) seasonal variation in quality, which affects nutritional value and influences water quality.

Because the use of these foods on a commercial scale would be impracticable and possibly uneconomic the preparation of compounded feeds was studied.

In contrast to most cultured fish, feeding prawns manipulate and break up pieces of food outside the mouth thus causing the dispersion of fragments into the water and increasing the loss, by leaching, of soluble substances. Dietary ingredients must therefore be chemically bound to minimize this wastage. Incorporation of carboxymethyl cellulose, polyvinyl alcohol, agar and guar gum to bind test diets did not seriously affect diet digestibility (Forster 1972a), but the use of some binders in commercial formulations might be limited by their high cost and the difficulty of use with conventional fish meals. Some dietary ingredients such as high gluten wheat flour, casein and starch have natural binding properties and warrant further study.

Table 4 An example of a compounded diet which gave good growth in Penaeus merguensis

Basic composition	Proportion in diet (%)
Protein	46.4
Carbohydrate	15.4
Lipid	6.9
Ash	11.9
Water	12.0
	92.6
<u>Ingredients</u>	
Freeze-dried mussel meal	70.0
Wheat starch	9.8
Mineral mix (Deshimaru and Kuroki 1974)	7.0
Cellulose	6.2
Cod liver oil	4.0
Vitamin mix (Deshimaru and Kuroki 1974)	3.0

The major components of a prawn diet are protein (40-60%), carbohydrate (20%), lipid (5-7%), minerals (5-10%) and vitamins (2-5%). Protein is expensive. A variety of sources have been investigated including fish meals, microbial protein, squid, bivalve, shrimp and soya meals. Generally those based on molluscan tissues gave the best results. The food conversion ratio of penaeid prawns fed a number of pelleted diets based on freeze-dried mussel meal (46% protein) ranged from 2.5:1 to 3.2:1 (dry weight food to live weight prawn) in comparison with 3.5:1 for a control group given fresh mussel. Growth on the dry diets was 79-90% of the controls. The composition of one of these diets is shown in Table 4. Conversion ratios obtained with these and other diets are compared in Table 5; they ranged from less than 2:1 in short-term trials with dry pellets to over 13:1 (wet weight of food:live weight of prawn) with a fresh mussel diet fed for

8 weeks. The latter on a dry food weight basis would be about 3 or 4:1. These results indicate that a conversion ratio of 2:1 with a commercial pelleted feed is a realistic target although it has yet to be demonstrated over the whole grow-out period.

Table 5 The growth and food conversion ratios of prawns fed with different diets

Species	Major dietary ingredient	Initial and final mean weights (g)	Period of trial (days)	Conversion ratio (dry food: live prawn)	Author
<u>Penaeus merguensis</u>	Commercial prawn pellet, possibly shrimp, squid and fish meals	0.2- 1.4	35	1.35	Sedgwick (In preparation)
		0.5- 2.8	35	1.96	
		0.4- 5.9	56	2.62	
"	Freeze-dried mussel meal (see Table 4)	0.2- 5.2	56	3.1	"
"	Fresh mussel (dry weight basis)	0.2- 5.2	56	3.5	"
<u>Penaeus japonicus</u>	Casein	0.8- 2.1	30	4.8	Deshimaru & Kuroki 1974
<u>Penaeus aztecus</u>	Shrimp meal	4.0-10.6	42	5.5	Sick, Andrews & White 1972
<u>Penaeus monodon</u>	Fresh mussel (wet weight basis)	0.8- 4.5	56	13-17	Beard & Forster 1973

The growth rate of juvenile P. merguensis fed with a Japanese pellet increased with an increase in feeding frequency from 1 to 4 times/day and less food was needed to stimulate maximum growth rate at the higher rate of feeding. The rate of food ingestion, however, decreased as the level of energy in the diet increased and it was thought that high energy diets could give poor growth if the reduced rate of ingestion deprived the prawns of sufficient protein (Sedgwick, In prep.).

Other factors which are shown to influence feeding behaviour include the type and texture of the pieces of food supplied (Forster 1972b), the period for which the food is available (Sick, White and Baptist 1973), and day length (Moller and Jones 1975). Further studies on these topics are needed to minimize not only the inefficient use of food but also the quantity and type of faeces and food residues left which have to be removed from intensive culture systems during water recirculation.

4.4. Water treatment

Indoor culture systems that use recirculated water have a number of demonstrable advantages over outdoor and through-flow systems. These are:

- (a) optimal conditions for growth can be permanently maintained;
- (b) stock maintenance is greatly simplified and close control can be exerted over feeding, harvesting and disease;
- (c) there is less reliance on large quantities of water from natural sources which are always vulnerable to pollution;
- (d) there are no predator or poaching problems;
- (e) these systems are particularly suitable for automation and the culture of a number of species.

A flow diagram of a generalized recirculation system for crustacean culture is shown in Figure 5. In a properly insulated building relatively little heat would be required to maintain the temperature of recycled water. In practice, a certain amount of 'replacement water' is necessary which has to be heated although the use of a heat exchanger

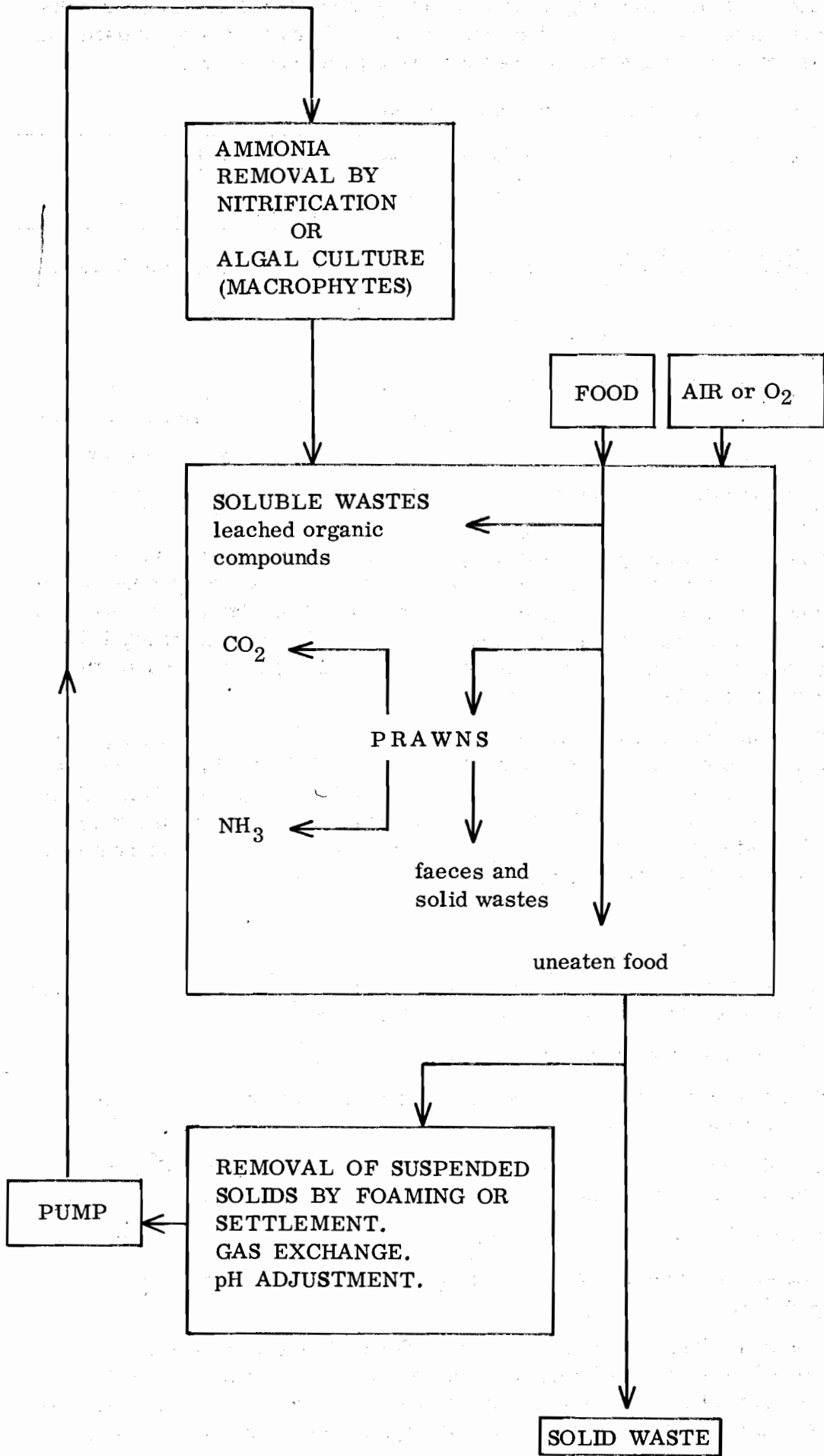


Figure 5 A flow diagram of a recirculation system for the culture of prawns.

would allow some of the waste heat to be recycled. The quantity of replacement water required determines the major part of the heating costs and depends upon the effectiveness of the methods used to remove uneaten food, faeces, suspended matter and soluble materials both excreted by the prawns (mainly ammonia and carbon dioxide) and leached out of the food. A number of devices may be suitable for the control of these substances in marine recirculation systems (Wickins and Helm, In prep.). Among those considered promising are compact sedimentation devices for the removal of uneaten food, and foam towers for the removal of some suspended solids including bacteria, algae and protozoa as well as carbon dioxide and some dissolved organic compounds. In preliminary tests with *Penaeus merguensis* at 28°C over 50% reduction in the requirement for replacement water was made possible by the use of foam towers in small recirculation systems of 150 l capacity. Further research is needed.

The most important soluble waste substance is ammonia which is removed most economically by biological filtration, a process similar in principle to that used for the treatment of sewage. Several types of biological filter are used in aquaculture including percolating and up-flow filters, activated sludge (Meske 1973), and biological sedimentation (Short 1973). The last two are likely to be more complex to operate than the first two but may be more efficient and occupy less space. Percolating filters involve higher pumping costs but they have a number of inherent fail-safe features in their operation and are therefore preferred to other types for new ventures.

A typical percolating biological filter is a bed of gravel or purpose-made plastic rings which provides an enormous surface area on which nitrifying micro-organisms grow. These organisms utilize the soluble wastes, e.g. ammonia, amino acids, amines, and bicarbonates for their own growth and metabolism. The end products include nitrates and carbon dioxide which are not harmful to the prawns until they reach levels many times higher than those in natural sea water. Table 6 shows some of the changes that occurred in sea water used in the culture of tropical prawns. During biological filtration acid is produced and in densely stocked marine culture systems care must be taken to ensure that the water remains adequately buffered against a decrease in pH (see Appendix 1, Glossary, Nitrification). Many marine algae remove ammonia and nitrate nitrogen from sea water and algal 'filters' have been used in marine recirculation systems in attempts to control levels of nitrate and phosphate (Kinne 1976). Their use in conjunction with nitrifying filters may have some potential but little is known of their effectiveness and the cost of the necessary illumination for proper functioning in tropical marine systems.

Table 6 Some differences between the laboratory supply and recirculated sea water

	Laboratory sea water	Recirculated sea water
Temperature (°C)	6-16	28
Salinity (‰)	26-30	28-32
pH	7.8-8.3	6.9-7.5
Inorganic carbon (mg/l)	16-20	5-11
Organic carbon (mg/l)	3-7	9-23
Ammonia (mg NH ₄ -N/l)	0.02-0.04	0.07-0.15
Nitrite (mg NO ₂ -N/l)	0.01-0.04	0.02-0.03
Nitrate (mg NO ₃ -N/l)	0.10-0.20	15-36
Phosphate (mg PO ₄ -P/l)	0.03-0.04	2.5-5.0
Oxygen (mg/l)	6.0	5.0
Suspended solids (mg dry wt/l)	0.9-19.4	3-100

The design of biological filters suitable for intensive crustacean culture involves consideration of three main factors:

- (a) prediction of the biological load which is likely to be placed on the system;
- (b) estimation of the tolerance of the selected species to accumulation of its own and other soluble waste products;
- (c) determination of the carrying capacity of the filter in terms of waste removal at known hydraulic and biological loadings.

4.4.1. Biological load

Little is known of the rate of nitrogen excretion in tropical prawns but rates based on approximate measurements ranged from 1 mg total ammonia nitrogen per gram of prawn per day (1 mg total $\text{NH}_4\text{-N/g/day}$) in small prawns up to 5 g live weight to 0.5 mg total $\text{NH}_4\text{-N/g/day}$ in 10-20 g animals. The type and quantity of solids and solubles leached from the food and converted to ammonia by micro-organisms in the water depends on the composition of the diet, the efficiency of the binding agent and the time the food remains in the tank.

4.4.2. Tolerance of prawns to ammonia, nitrite and nitrate

Levels of ammonia, nitrite and nitrate nitrogen (see Appendix 1, Glossary, Nitrification) which did not kill the prawns but which reduced their growth to 50% of that of prawns in normal sea water after 3 weeks were: ammonia: 0.45 mg un-ionized $\text{NH}_3\text{-N/l}$ (approximately 10 mg total $\text{NH}_4\text{-N/l}$ at pH 8.0 and 100 mg total $\text{NH}_4\text{-N/l}$ at pH 7.0) (see Appendix 1, Glossary, Ammonia); nitrite: 6-10 mg $\text{NO}_2\text{-N/l}$; nitrate: no reduction of growth was detected after 3-5 weeks exposure of Penaeus monodon to nitrate at concentrations up to 200 mg $\text{NO}_3\text{-N/l}$.

The freshwater prawn, M. rosenbergii, seemed more susceptible to nitrite and nitrate than the marine penaeids and suffered 50% mortality in 3 weeks after exposure to 15 mg $\text{NO}_2\text{-N/l}$ and 160 mg $\text{NO}_3\text{-N/l}$. The 'maximum acceptable concentrations' of un-ionized ammonia, nitrite and nitrate nitrogen chosen for our systems were 0.1, 1.0 and 50 mg N/l respectively.

4.4.3. Carrying capacity of the filter

The amount of ammonia oxidized by a nitrifying filter and hence the number and weight of animals it can support is dependent on:

- (a) input concentration of ammonia;
- (b) specific surface area of the filter medium;
- (c) filter volume;
- (d) hydraulic load;
- (e) pH, temperature, salinity and oxygen levels.

Experiments with model filters (Forster 1974) containing 1-2 cm gravel chips with a specific surface area of 150-200 m^2/m^3 showed that when the input concentration was approximately 1 mg total $\text{NH}_4\text{-N/l}$ and the hydraulic load was 20-250 $\text{m}^3/\text{m}^3/\text{day}$ then the nitrification rate was 0.25-1.0 g total $\text{NH}_4\text{-N/m}^2$ of specific surface/day. These figures provided the basis for the calculations of filter size in Section 6 on costs. In practice it is better to use filter media with larger void space than gravel (e.g. plastic rings) to minimize risks of blockage by suspended solids and bacterial film sloughed

from the filter media. Reduced pH values which are likely to occur in marine recirculation systems (see Appendix 1, Glossary, Nitrification and Buffering Capacity) caused nitrifying activity to decrease to a minimum at pH 5.5 when nitrification effectively ceased (Forster 1974).

4.5. Diseases

The possibility of disease is a constant threat in any system of animal husbandry particularly in intensive culture. A major difficulty in the study of prawn diseases has been to correlate specific recognizable signs with losses which occur in laboratory tanks. This is because many mortalities occur during moulting at night and corpses are frequently found cannibalized. Most of the infections that occurred could be attributed to inadequate animal husbandry techniques, a poor water quality or inadequate nutrition. Examples of diseases which have occurred at Conwy, including those investigated by Delves-Broughton and Poupard (1976), are:

(a) Systemic fungus disease The species affected were Palaemon serratus and Pandalus platyceros. Signs included a black area on the cuticle usually associated with a wound, surrounded by a zone of reddening and extensive ramification of fungal hyphae in the body tissues. Progressive paralysis and death usually followed.

(b) Shell disease This affected P. serratus, P. platyceros and M. rosenbergii. Signs were brown-black spots on the cuticle which, although not lethal, would reduce the market value of the prawn.

(c) White syndrome Individual prawns turned opaque white and muscular necrosis usually occurred sometime afterwards. These signs have been noticed in nearly all species particularly after they have been stressed or shocked.

(d) Vibrio infection Vibrio spp. bacteria were isolated from Penaeus merguensis, P. monodon, P. orientalis and P. setiferus. Mortality was 60-70% and associated with erosion of appendages, loss of shell colour and reddening of the gills. It was not however confirmed that mortality was due to the infection.

(e) Filamentous growth on gills Specimens of P. monodon and P. orientalis were found with slight to heavy growths of filamentous micro-organisms on the gills.

Nearly all of the diseases that we have experienced could have been attributed to inadequate animal husbandry techniques. For example, switching on room lights can cause panic among prawns which become damaged as they employ their escape 'tail-flick' reaction and crash backwards into tank walls. Poor water quality or inadequate nutrition can lead to difficulty during moulting or render prawns more susceptible to infection or infestation by micro-organisms. It is possible that under culture conditions a number of latent pathogens may become virulent in stressed prawns. Clearly many of the potential 'disease' situations will be avoided in the future as a greater understanding of the prawns' environmental and nutritional requirements is obtained and as husbandry techniques are improved. It is strongly recommended that all imported prawns are quarantined for a period to minimize the risks of introduction of diseases.

5. CULTURE TECHNIQUES AT CONWY

In this section the principle methods used at Conwy for the routine culture of batches of penaeid prawns are outlined. Paragraphs 5.1, 5.2 and 5.3 are based on the culture of Penaeus merguensis and 5.4 on P. monodon. In a few specific instances either the procedures or the description of a facility has been slightly idealized. For example, in some of our experiments it was preferable to culture prawns of known parentage by selecting

individual females from the breeding population and allowing them to spawn in isolation. Selection was based on the criteria given in Appendix 1, Glossary, Ripe Ovaries. The chosen female was placed in 30-40 l of well-aerated clean sea water that was both 2-3°C warmer and 2-4‰ higher in salinity than normal, so as to provide a stimulus for spawning. In a production as opposed to an experimental situation the females might be left to spawn *ad libitum* among the breeding population and the eggs would be collected automatically from the tank. As another example, we describe four concrete tanks (2.9 x 1.6 x 0.6 m deep) used for the regular production of batches of mature prawns. In fact, two of the tanks were only 0.36 m deep and our populations were transferred to the deeper tanks as they matured. Ideally, with tanks of equal depth each batch of animals would remain in one tank undisturbed throughout its reproductive life.

The information has been drawn together in Tables 7 to 10 and Figure 6 to produce a hypothetical scheme by which a small pilot plant yielding 250-300 kg/week might be managed. Figure 6 shows the basic flow diagram.

Table 7 A scheme for the maintenance of a breeding population of *Penaeus merguensis* in tanks

Month	Tank 1	Tank 2	Tank 3	Tank 4
1	Tank stocked with 200 weaned post-larvae			
2				
3	Selection of the most healthy 25 males and 50 females. The rest to be removed	Tank stocked with 200 weaned post-larvae		
4	} Maturation begins			
5		Selection of the most healthy 25 males and 50 females. The rest to be removed	Tank stocked with 200 weaned post-larvae	
6	} Spawning occurs repeatedly. 40 000-41 000 eggs collected and hatched each week	} Maturation begins		
7			Selection of the most healthy 25 males and 50 females. The rest to be removed	Tank stocked with 200 weaned post-larvae
8	Adults discarded, tank cleaned and cycle repeated	} Spawning occurs repeatedly	} Maturation begins	

5.1. The brood stock

Four concrete tanks (2.9 x 1.6 m ideally containing 0.6 m depth of water) were stocked sequentially with 200 weaned post-larvae (0.2 g) at two month intervals. Each batch was then cultured according to the schedule shown in Table 7 for about four months until the females matured and began to spawn. After a further four months of spawning the prawns were discarded and the tank restocked with new post-larvae. The tanks were connected to a biological filter and a foam separator through which water was circulated (10 and 2 l/min respectively) from a centrifugal pump. The physical and chemical conditions of the water were similar to those shown in Table 6 and food was provided as described in Section 6 on costs. About 40% of the water volume was renewed each week and the tanks received both natural and artificial light for 16 h/day. Spawning usually occurred in the dark and in a commercial operation this habit may be utilized for the automatic

collection of eggs by causing water to flow into a collection vessel fitted with a 200 μm mesh screen during the night. In this way broods from several parents would become mixed. Although some conditions, perhaps salinity and photoperiod, under which maturation and mating occur in nature differ among species of penaeid prawns, it is judged that the logistics of the development and maintenance of a breeding population of, for example, *P. monodon* will be essentially similar to that described here for *P. merguensis*.

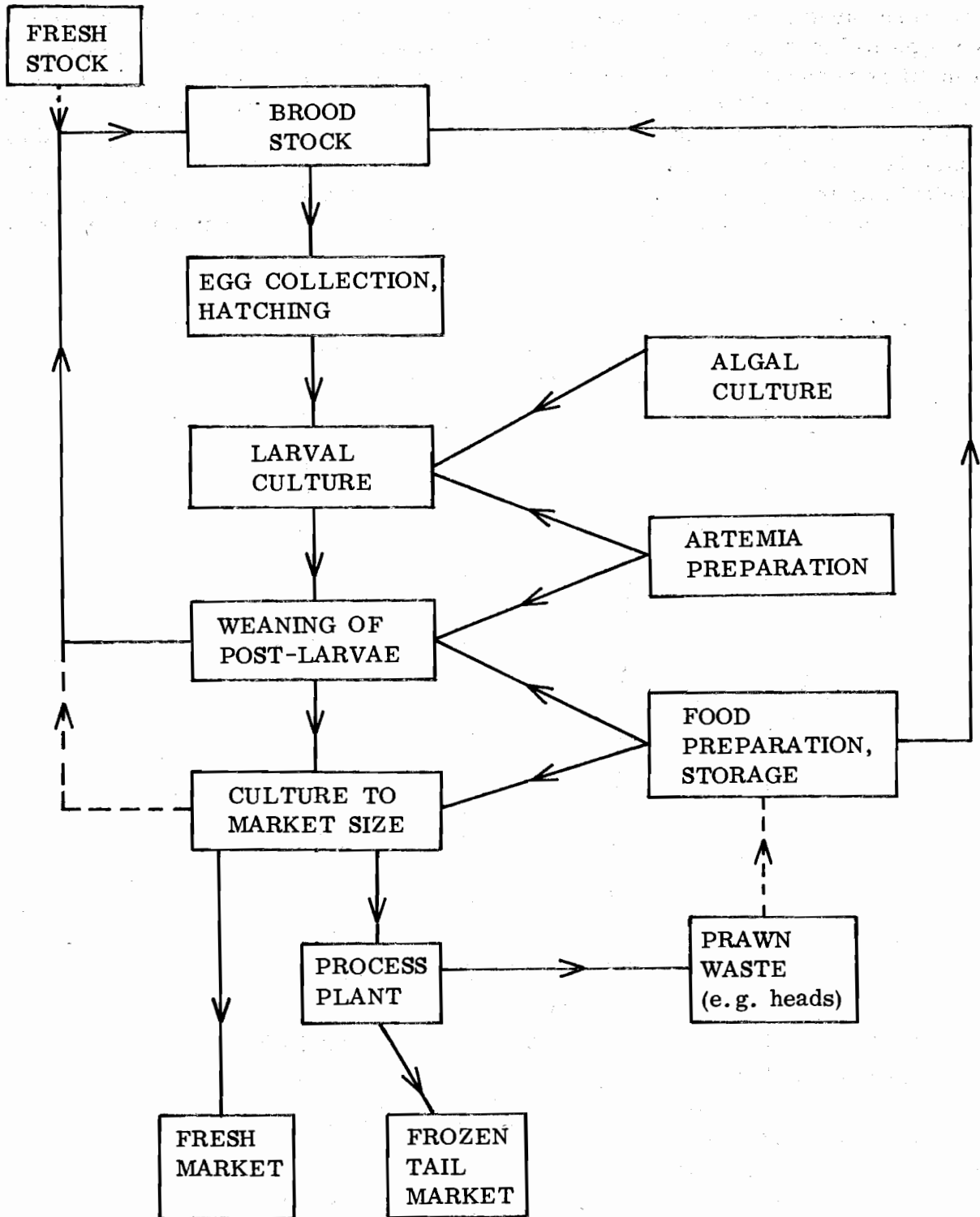


Figure 6 A suggested flow chart for a prawn production unit. Broken lines denote routes used intermittently.

5.2. The culture of larvae

In the morning the newly spawned eggs were washed by exchanging 80% of the water in the collection vessel with clean sea water. Whenever insufficient numbers of eggs were collected, broods from two nights were mixed but greater age differences between broods were avoided because of the increased frequency of cannibalism among the mysis stages. Gentle aeration was provided until hatching was completed (usually by late afternoon); eggs that had not hatched by the following day were discarded. The newly hatched nauplii were carefully washed to remove the debris released at hatching. Water was slowly siphoned through a 200 μm mesh cylinder placed inside the hatching vessel so that the nauplii were concentrated in 2-3 l of water without being forced against the screen. Clean sea water was added in sufficient quantity to reduce the concentration of nauplii to about 1/ml. Ten 50 ml sub-samples were taken while the culture was gently agitated to estimate the number of nauplii present so that each culture vessel used (Figure 7) could be stocked with the appropriate number of larvae. The larvae were cultured according to the schedule in Table 8 for 11-12 days during which time the salinity was progressively

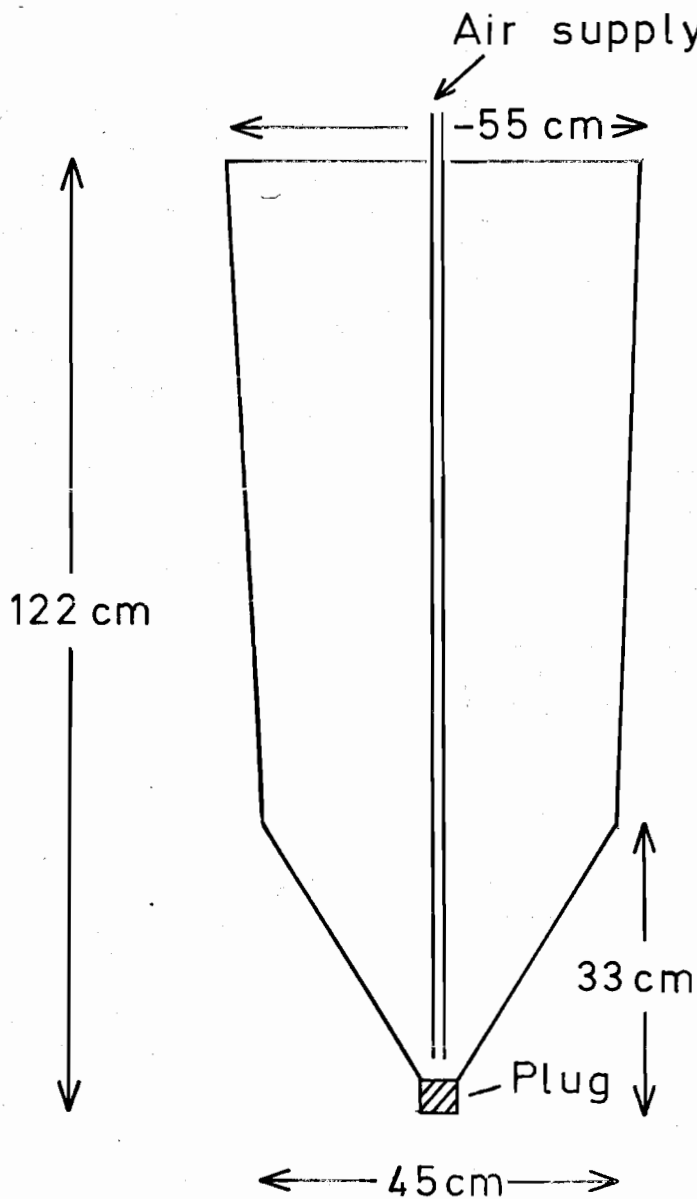


Figure 7 Cylindrical vessel suitable for the culture of penaeid larvae.

reduced to 25‰ to reduce the risk of disease. When 90-95% of the larvae had reached the post-larval stage our cultures of P. merguensis were finished and the young prawns transferred to shallow tanks to be weaned.

Table 8 A suggested scheme for the culture of penaeid larvae

Day	Job (two vessels are employed and one stocked on alternate weeks)
1	The culture vessel is stocked with 20 700 newly hatched nauplii in 166 l of clean sea water at 35‰ and 28°
2	Cells of <u>Tetraselmis</u> are prepared and added to give a density of 30-40 cells/ μ l in the culture. This provides food for the first protozoa stages
3	A further addition of freshly prepared algae is made to raise the density to 70-80 cells/ μ l. Most of the larvae will have developed to the protozoa stages
4	Approximately 80 l of water are siphoned out through a 200 μ m screen sufficiently slowly so that larvae are not forced against the mesh. The vessel is refilled with clean sea water with a salinity of 3-5‰ below that of the residual water. Algal cells are added to give a concentration of 70-80 cells/ μ l
5	The concentration of uneaten algae is determined and made up, if required, to 70-80 cells/ μ l. Two litres of sea water are added to 10-12 g <u>Artemia</u> eggs and vigorously aerated
6	As day 4. The <u>Artemia</u> nauplii are prepared and added to give a concentration of 1 <u>Artemia</u> /ml in the culture vessel. The culture contains mainly stage 3 protozoa but the <u>Artemia</u> are provided for any first stage mysis that develop during the night. A further 10 g of <u>Artemia</u> eggs are set up to hatch
7	The concentration of <u>Artemia</u> is increased to 2-5/ml with newly hatched nauplii and a further batch of eggs set to hatch. Most of the larvae are first stage mysis
8	As day 4 but no algae are added. The concentration of <u>Artemia</u> in the vessel is determined and made up, if necessary, to 2-5/ml with newly hatched nauplii
9	The concentration of <u>Artemia</u> is checked and restored, if necessary, to 2-5/ml. A batch of <u>Artemia</u> eggs are set to hatch.
10	As days 8 and 9. Some post-larvae may be noticed
11	As day 9. Ten 100 ml samples are taken from the vessel so that the proportion of post-larvae present can be determined. The culture may be continued
12	for up to 2 days (until 90% are post-larvae) if necessary.
13	The vessel is drained and cleaned in preparation for the next culture.

The culture of the alga Tetraselmis suecica as food for the protozoa stages was made in 20 l glass flasks. A full description of a unit producing 200 l/day is currently being prepared (Helm, Liang and Jones, In prep.). The cultures contained on average 1 000 cells/ μ l of algae and in order to prevent the addition of large volumes of media to the larval cultures the algal cells were allowed to settle for 1-2 h. The concentrate was then resuspended in a known volume of clean sea water, the new cell density measured by

Table 9 A scheme for the weaning of penaeid post-larvae

Days after metamorphosis	Food	Water changes	Notes (see text)
0	Newly hatched <u>Artemia</u> nauplii (5-10/ml)	50% water change every 2-3 days	Post-larvae retained in larval culture vessel, 3-5 mm netting suspended in the culture to increase settling area for post-larvae
5			
10			
15	Finely chopped mussel (1 mm ³ - consumption about 200% of the prawn biomass/day) or small pellets		Post-larvae transferred to shallow weaning tanks
20			
25	Pelleted foods	Recirculated water, 90% exchange through the tank in 3 h	
30			
35			
40			
45			
50	Post-larvae transferred to main tanks and grown to market size		

counting a sample in a haemocytometer and a sufficient volume of the resuspended concentrate added to maintain about 75 cells/ μl of algae in the larval culture. Artemia were prepared by washing 10 g of eggs in 50% 'Chlorox' for 6 minutes. They were then added to 4 l of sea water at 28°C and vigorously aerated in a transparent, funnel-bottomed vessel. The aeration was turned off after 24 h. After 20 minutes exposure to a light source most of the newly hatched nauplii had congregated in one area of the vessel and were gently siphoned out. The Artemia were then washed over a 124 μm nylon screen and resuspended in a known volume of sea water to give 30-50 Artemia/ml. Ten 1 ml sub-samples were taken with a Stempel pipette and mixed with two drops of phenol solution to kill the nauplii which were then counted in a Bogorov tray under a low-power binocular microscope. An appropriate volume was then added to the larval cultures.

5.3. Weaning of post-larvae

The newly metamorphosed post-larvae were weaned from a diet of newly hatched Artemia nauplii to prepared foods as described in Section 6 on costs and in Table 9. The glass-fibre tanks used at Conwy measured 0.9 x 0.9 x 0.15 m depth of water but were later judged to be unsuitable for weaning particularly during the time when the prawns were feeding on Artemia. This was because a considerable amount of time was necessarily spent each day in the removal of detritus from the tank floors. A preliminary test indicated that it may be less laborious to retain the post-larvae in the conical vessel for 10-14 days while they are feeding on Artemia and to provide additional surfaces (in the form of suspended sheets of 2-3 cm mesh plastic netting) to which they may cling. It has been our experience with P. merguensis that after 14 days the post-larvae rapidly begin to take prepared foods and are best kept in open shallow tanks in order to maintain correct feeding levels and a high standard of husbandry. When the majority reached 0.2 g they were counted into larger tanks (up to 3.4 m²) to grow for 16 weeks (but see Section 6 on costs).

5.4. Growth to market size

The tanks used in most of our trials were either square or rectangular glass-fibre vessels and contained 15-25 cm depth of water. In this situation there was little or no self-cleaning action by water currents in the tanks and, since fresh food was given once daily, there was always a risk of the development of anaerobic conditions in clumps of uneaten food. Husbandry was therefore particularly laborious and the utilization of food inefficient. In the hypothetical scheme the size and shape of the tanks in which seed prawns would be grown to market size are not given for the reasons discussed below. Rather, we have specified that the weaned post-larvae are stocked at 50 prawns/m² of horizontal surface area. Survival after 26 weeks is 80% at which time the prawns will have attained a mean weight of 35 g. A suggested weekly production would be 250 kg occupying 179 m² of horizontal surface. Alternatively, if the tank is 1 m deep and has three shelves in addition to the tank floor on which the prawns live, the tank floor area required would be reduced to about 45 m²/250 kg. A total of 26 tanks (or groups of tanks) would be required to produce weekly harvests throughout the year. A summary of the requirements for animals and space in the proposed scheme is given in Table 10.

Table 10 The number of animals and the space required for the culture of 250 kg prawns per week. Figures given in 6.3 in the text were used to calculate that 14 females and 7 males would be needed to produce the 40 000-41 000 eggs (21 000 nauplii) that would be required every 7 days to ensure weekly harvests of 250-300 kg of 30-35 g prawns from the grow-out facility. In practice it would be necessary to increase the number of prawns by a factor of 3 or 4 (e.g. 50 females and 25 males) in order to ensure that sufficient nauplii were available on any particular day (Table 7)

	Number of prawns	Expected survival	Number of tanks	Area covered per tank (m ²)	Total floor area occupied by tanks (m ²)
Brood stock	50 females 25 males	7% mortality/ month	4	7.5	30.0
Egg collection	40 570 eggs collected/week	51% hatch	4	0.1 (mobile conical vessels)	0.4
Larval culture	20 690 nauplii cultured/week	58%	2 (+ 1 spare)	1.0	2 (3)
Weaning of post-larvae	12 000 post-larvae weaned/week	75%	6 (+ 2 spare)	6.0	36 (48)
Growth to market size	9 000 seed stocked/week	80%	26 tanks or groups of tanks depend- ing on size and shape	Each tank or group of tanks must contain 179 m ² of horizontal sur- face area, e.g. if 3 shelves are fitted into a tank then 44.75 m ² of tank floor area will provide 44.75 x 4 = 179 m ² of horizontal surface area	4 654 or 1 170
Yield	250 kg of 35 g prawns produced/week or 1.4 kg prawns/m ² of horizontal surface area				

6. COSTS (PENAEIDS)

Production costs in prawn farming may be considered in relation to four stages of the culture operation:

1. the brood stock;
2. culture of larvae;
3. weaning;
4. culture to market size (grow-out).

In the following paragraphs an attempt is made to indicate where the major cost areas lie within the culture operation and hence where further research or development might be most usefully directed. Although far from being a definitive costing, it is hoped that it will nevertheless provide a useful starting point for those interested in the economic assessment of indoor prawn farming. To this end it is stressed that the actual monetary values used in these calculations are included for the purpose of illustration only and are not based on any existing pilot operation. Where necessary, data given in the preceding paragraphs are repeated in this section to save the reader from continually referring back to earlier sections of this leaflet.

The calculations used in stages 1-3 were based on the production of weaned prawns of 0.15-0.20 g live weight from three generations of *Penaeus merguensis* reared between February 1975 and May 1976. In that period 176 spawnings occurred and 11 batches of larvae were cultured to the post-larval stages. For convenience, the production costs are given per 100 000 prawns at each culture stage. The estimates for stage 4 (the grow-out stage) were based on eight growth trials, each of four months duration, made with *P. monodon* at densities of 25, 47, 146 and 162 prawns/m². The results are expressed per tonne of prawns produced. It is emphasized that this exercise is based on the results from laboratory-scale experiments using 100 l cultures of larvae and 1 000-2 000 l capacity grow-out systems. There will be both economies and extra expenses involved in larger pilot- and commercial-scale operations.

The major items considered for each stage were: (1) heating; (2) pumping; (3) space; (4) food; and (5) labour. The results for the grow-out stage have been expressed in such a way that any appropriate current cost for each item can be easily substituted in the calculation (see Section 6.5, Stage 4: Culture to produce 1 tonne (1 000 kg) of marketable prawns, Example).

6.1. General points

Water heating

Heating costs were based on the cost of raising all of the water used by 15°C to allow for seasonal variations in the temperature of incoming water. Gas heating was assumed using 70% efficiency from a gas boiler and a price of 17p/therm. No allowances were made for heat loss, heat recovered from waste water, or heat that could be available from solar energy.

Pumping

Pumping costs are applied to the grow-out stage only and were based on an electric centrifugal pump moving 100 m³ of water through a 2 m head using 1 kW/h. At a price of 3p/unit of electricity the cost was £0.72/day.

Aeration costs were not considered since the amount of air or oxygen required will depend to a large extent on the control which can be exerted over the type and quantity of dissolved and suspended organic matter in the water. Shigueno (1975) deduced that of the total amount of oxygen used in a prawn pond only 9.1% was used by shrimps and prawns, 21.5% was used by fish and bottom sand, and the remaining 69.4% was utilized by organisms suspended in the water.

Space

(a) Tanks This item was calculated in terms of tank floor area. Our prawns were reared in 15-36 cm depth of water, except for larvae which were cultured in deeper cylindrical vessels. Until the best form of a prawn culture tank for the grow-out stage is known, space cannot be realistically costed. For the purpose of this exercise the figure used was £38/m², based on several commercial cost quotations (1976-77) for covered, insulated fish tanks and spread over 10 years.

(b) Water treatment plant This is expected to consist of a biological filter and plant for the removal of suspended and dissolved organic material. The area required by these units is only likely to be significant in the grow-out stage. The volume of the biological filter was calculated to be 10.5 m³/tonne of prawns and was based on the following parameters:

1. excretion rate, 1 g total NH₄-N/kg of prawns/day;
2. nitrification rate, 0.5 g total NH₄-N/m² of specific surface area/day;
3. hydraulic load, 200 m³/m³day;
4. specific surface area of media, 190 m²/m³;
5. maximum permissible concentration of ammonia in the tanks, 2 mg total NH₄-N/l at pH 8.0, temperature 28°C and salinity 28‰.

The space and energy requirements for additional water treatment (removal of suspended and dissolved organic material) have not been determined separately since quality

was maintained in our trials by the relatively large amounts of water replaced each week and by the manual removal of settled material. These are reflected in the costs given under heating and labour. No account was taken of office, workshop or food storage areas.

Food

Fresh foods (mussel and shrimp) were routinely used for the breeding stock although a few *P. merguensis* spawned viable larvae when reared on a pelleted diet. Algae and *Artemia* were used during the larval stages while both fresh and pelleted diets were tested in the grow-out stage. Until 1975 good growth of juvenile prawns was only achieved with fresh diets, but recently a pellet commercially prepared in Japan repeatedly produced growth in *P. merguensis* equal to or slightly better than mussel and shrimp during the first 8 weeks of the grow-out stage. Short-term trials (2-5 weeks) gave conversions of 1.35 and 1.96:1 (dry weight of pellet:live weight of prawn - see Table 5) and a working figure of 2:1 was used here. It is reasonable to suppose that it will soon be possible to compound a diet similar in cost to salmonid diets (currently £250/tonne) and that the food required to produce 1 tonne of prawns will cost about £500.

Labour

Initially labour costs will be high but, as with any controlled system of animal husbandry, a considerable amount of automation will be possible. In this exercise labour included food preparation, removal of uneaten food, feeding, water preparation and water changes. Measurements of water quality other than temperature, salinity and pH were not included. Labour costs are related to the scale of the operation, the frequency of feeding and the self-cleaning properties of the tanks. The present trials were made in rectangular or square tanks (0.6-3.4 m²) with little or no self-cleaning properties, feeding and cleaning being done manually once or twice each day. In the absence of a reliable estimate, particularly for the grow-out stage, a figure for the culture of trout of £0.15/kg/year was taken and multiplied by an empirically chosen factor of 2 for prawn culture. Labour in stages 1-3 was costed at £1/h. In the paragraphs that follow the costs involved in stages 1-3 are discussed briefly and summarized in Table 11 to produce a cost for juvenile prawns suitable for stocking in stage 4. For comparison the cost of juveniles from other parts of the world are given in Table 12.

6.2. Stage 1: The brood stock required to produce 100 000 nauplii

Penaeus merguensis matured after 4.5 months but an additional 1.5 months was allowed to enable a greater size (12-15 g), and therefore fecundity, to be attained. It was assumed that all the females were spawning throughout the 16 months of observation although it was possible that a proportion were spawning repeatedly. The mean rate of spawning was approximately 0.4 times/female/month; or 2.5 females would produce one brood/month. The mature prawns were stocked at densities from 5 to 15/m² and mortality was 7%/month. Losses were made good from the grow-out facility. On average a 12.5 g female produced 29 000 eggs of which 51.4% hatched. A satisfactory sex ratio was 1 male to 2 females and it was calculated that 17 females and 8 males would be needed to provide 100 000 nauplii/month.

At 10 prawns/m² a tank floor area of 2.5 m² would be adequate for the breeding stock of 17 females and 8 males and, at a depth of 0.36 m, the volume of water would be 900 l; replacement water would therefore be 1 800 l/month. Fresh mussel and shrimp provided at about 5% of the prawn biomass/day (470 g/month) would cost about 45p/kg of food. Labour was estimated at approximately 7 h/month and included food preparation, feeding and removal of uneaten food (6 min/day) and water changes (60 min/week).

Table 11 The estimated UK hatchery cost of weaned post-larvae (juvenile) P. merguensis

Objective	Stage		
	I	II	III
	100 000 nauplii	100 000 post-larvae	100 000 weaned post-larvae
ITEM	£	£	£
Initial requirement for animals	0.0*	14.4	60.1
Heating	0.3	0.7	8.8
Space	0.8	0.2	29.3
Food	0.2	7.8	71.5
Labour	7.0	22.0	84.0
TOTAL	8.3	45.1	253.7
Cost of seed prawns £2.54/1 000 or, at US \$1.7 = £1, US \$4.3/1 000			

*free; from grow-out tanks.

Table 12 The costs of 1 000 juvenile prawns abroad

Country	Species and source	Cost US \$	Notes	Author
USA	<u>Penaeus</u> sp. cultured	2.8	Production	Mock & Neal 1974
Japan	"	2.7	"	"
USA	<u>M. rosenbergii</u> cultured	2.0	Predicted	Hagood & Willis 1976
Japan	<u>P. japonicus</u> cultured	1.2	Production	Shigueno 1975
Philippines	<u>P. monodon</u> cultured	12.5	Sale price	Wear 1975
USA (Hawaii)	<u>M. rosenbergii</u> cultured	4.0-6.0	Sale price	Shang 1974
Taiwan	<u>P. monodon</u> wild	5.0-15.0	Sale price	Liao & Huang 1972

6.3. Stage 2: The culture of larvae to produce 100 000 post-larvae

The survival of larvae ranged from 42-83%, mean 57.8%, and even at the highest density used (400 nauplii/l) was 66% after the 11 days of culture. Thus 173 000 nauplii should, on average, yield 100 000 post-larvae.

A culture density of 125 larvae/l was empirically chosen for the scheme in Table 8. Thus if the survival rate was 58% the culture needed to produce 100 000 post-larvae would occupy 1 380 l of water and replacement water (50% every 2 days for 11 days) would amount to an additional 3 450 l. Two culture vessels were judged to be convenient and would occupy 2 m² of floor area.

Tetraselmis suecica was a suitable and readily cultured species of food alga and was maintained in the cultures at approximately 75 cells/ μ l for 5 days. It was estimated that about 60 l of algal culture at 1 000 cells/ μ l would be enough to feed 100 000 protozoa. A current estimate of the cost of algal production is about 5p/l. Artemia salina were fed to the mysis stages for 6 days. The consumption was about 65 Artemia/larva/day which is about 39×10^6 Artemia/100 000 mysis larvae. At 350 000 eggs/g and 50% hatch, 223 g of Artemia eggs will provide nauplii for 100 000 mysis. A price of £21.6/kg of eggs was used.

An estimate of labour needed, which included Artemia preparation but not algal culture, was 2 h/day for 11 days or 22 h/100 000 post-larvae.

6.4. Stage 3: The weaning of 100 000 post-larvae

Post-larvae grew to 0.1-2.0 g in about 6 weeks from metamorphosis. Survival rates between 50 and 90% have been achieved in cultures of 1-2 m³ in Japan (Hudinaga and Kittaka 1975). We have no precise figures for this stage at Conwy and a working figure of 75% has been used here.

Post-larvae were weaned in 16 cm depth of water at 12-13 post-larvae/l. During the first 18 days 50% of the water was changed every 3 days while Artemia were being supplied, but thereafter, when the water was being recirculated, 50% was changed each week. At a survival rate of 75% the total volume of water required per 100 000 weaned post-larvae would be 60 800 l.

At a stocking density of 2 000/m², 67 m² of tank floor would yield 100 000 weaned post-larvae, although considerable savings might be made by the use of deeper tanks and additional surfaces for the prawns (e.g. netting) within the tanks.

Artemia was fed for the first 18 days and the average consumption of a post-larva was about 250 Artemia/day. Most of the 25% mortality would probably occur during the last 4 days of feeding with Artemia, so about 3 kg of eggs/100 000 post-larvae would be required. Compounded food was provided for the following 24 days and the cost of the pellets was based on an increase in the biomass of 100 000 post-larvae of 13.5 kg as they grew from 0.015 g to 0.15 g. Thus with conversion at 2:1, 27 kg of pellets would be required.

This is likely to be a laborious stage until automatic feeding and cleaning are employed and labour was estimated at 2 h/day or 84 h for the period.

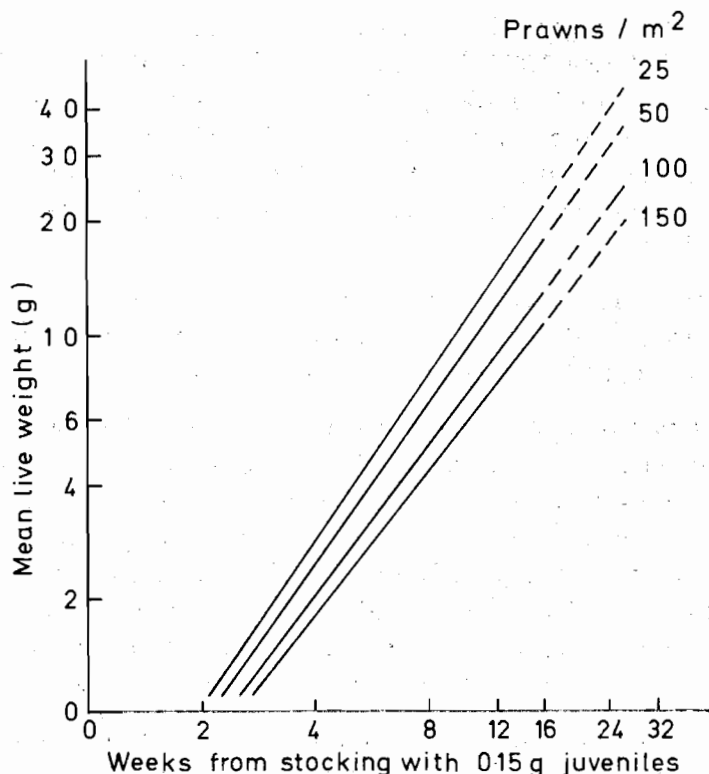


Figure 8 The growth of *Penaeus monodon* at four stocking densities. The results from eight experiments made at stocking densities of 25, 146 and 162 prawns/m² were used to calculate the growth expected at 25, 50, 100 and 150/m².

6.5. Stage 4: Culture to produce 1 tonne (1 000 kg) of marketable prawns

This stage will be the most costly part of the whole operation and, since it is generally accepted that the market value of the final product is the most influential factor on the outcome of this type of costing, consideration is given first to the size of the marketable prawn. In the report by Forster and Wickins (1972) thoughts on costs were based on growing prawns to 10 g live weight at the highest possible stocking densities (> 160/m²) and on obtaining at least three crops each year. The best results showed that yields of 1.9 kg/m² of 12-13 g prawns (*P. monodon*) could indeed be achieved in 4 months. The current high market value for larger prawns (> 30 g) has led to the reconsideration of the potential of low density cultures (25-50/m²) with perhaps only 2-2½ crops/year, since density and growth rate are related (see Figure 8). If survival was 80%, yields of 700 to 1 400 g/m² of 35 g prawns would be expected.

Cultured prawns may be sold whole or as tails. The market for fresh whole prawns is less well established than that for frozen tails in Great Britain but it commands higher prices. It was judged from Figures 8 and 9 that prawns of 30-40 g live weight would not only have a good value (£2.6-2.8/kg) if sold for tails, but also could be produced in a reasonable time (26 weeks) and at moderate densities (initially 50/m²).

In order to test the likely effect on the production costs of growing large prawns at low densities (this is discussed below), certain extrapolations from existing data were made. For this exercise the results of eight growth trials made with *P. monodon*, presented in Table 13, were used. The experiments were terminated after 16 weeks when the prawns had grown to 23 and 13 g at low and high densities respectively. Figure 8 shows the growth rates recalculated from these results for densities of 25, 50 and 150 prawns/m². The regression lines have been extrapolated where necessary (shown by the dotted lines) to either 28 weeks for the high density cultures, or to 35 g for the low density cultures. No experimental data have been obtained in Great Britain to confirm the

extrapolation but even faster growth rates have been reported for pond cultured P. monodon in Taiwan (Liao and Huang 1972), Indonesia (Alikunhi, Budiono, Adisukresno and Busman 1975), and the Philippines (Shigueno 1975). It may be noted that P. monodon does not normally mature below 50 g and that, since they grew rapidly to sizes in excess of 80-100 g in our tanks, they would remain in the logarithmic phase of growth throughout the extra 5-12 weeks of culture. These projections were used in the requirements and costings discussed below.

The experiments in Table 13 lasted 16 weeks. The mean survival was 76.5% but a working value of 80% was used here since the present costings are concerned with the lower densities (25 and 50/m²) where the mean was 88%.

There is considerable uncertainty about the volume of water it will be necessary to replace, and therefore heat, in this stage. The proportion replaced (50%/week) in our trials was empirically chosen in an attempt to maintain the buffering capacity of the water during nitrification. Evidence from recent experiments suggests that chemical control of buffering capacity in sea water is possible and could substantially reduce the volume of water replaced. In the most favourable trials 1.83 kg of prawns were produced in 16 weeks from a system containing 970 l of water, of which 400 l were replaced each week. The heating of the initial charge of water was also costed in.

Pumping costs were based on the volume of water delivered per unit of time to the greatest biomass of prawns produced in the laboratory trials. This was 2 l/min to a tank containing 124 l of sea water which produced 1.2 kg of 13 g P. monodon or 100 m³/h/tonne of prawns.

Table 13 The increase in mean weight of Penaeus monodon in populations grown at different densities

Weeks	Density/m ²							
	25	25	47	146	146	146	162	162
	Experiment							
	1	2	1	1	2	3	1	2
0	0.15	0.20	0.13	0.29	0.29	0.29	0.15	0.30
2	1.27	1.00	1.04	0.95	0.85	0.87	0.86	0.70
4	3.43	2.10	2.93	1.73	1.61	1.57	1.87	1.30
8	10.00	6.70	8.16	4.57	4.41	4.36	4.73	3.30
12	18.47	15.50	14.43	6.84	6.89	7.06	9.00	7.90
16	25.43	20.90	21.50	10.66	11.46	11.99	12.93	10.30
Survival (%)	100	73	90	73*	57*	60*	91	68
Mean (%)	76.5							

*Survival values adjusted because of sudden mortality during the last 4 weeks of culture.

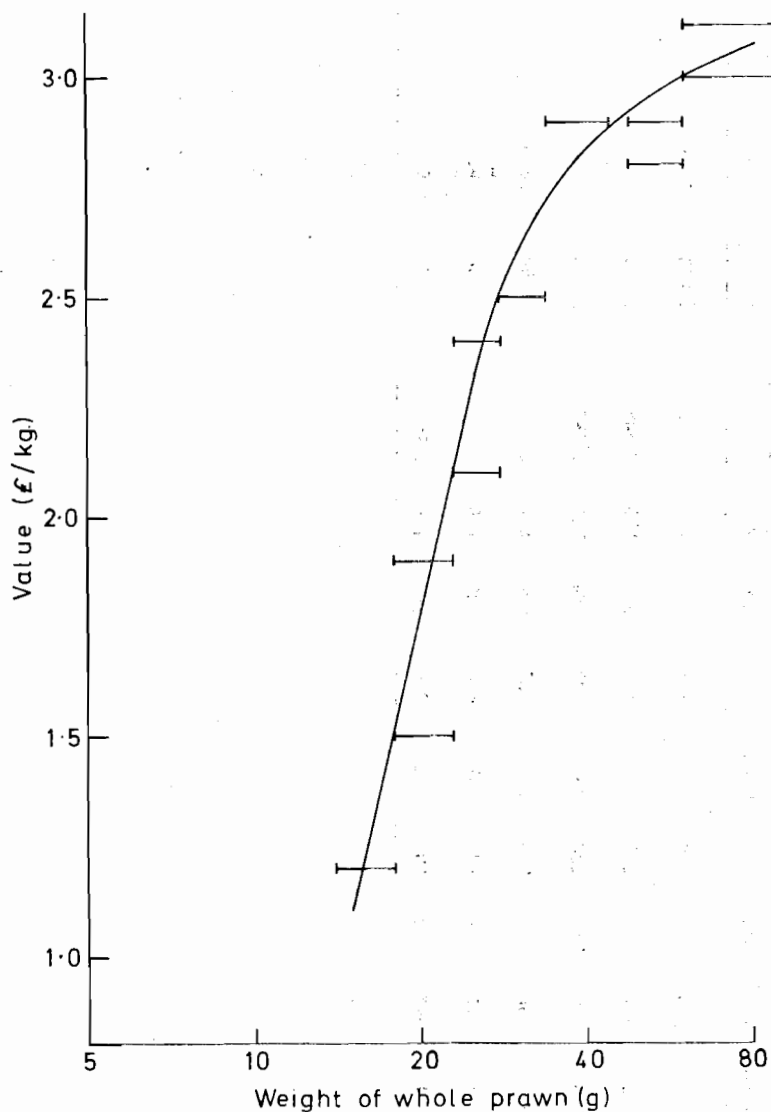


Figure 9 The approximate value of prawns (as tails) in April 1977.

The cost of space is given in terms of the biomass of prawns produced/m² of tank floor and the number of crops produced each year. The use of shelves is discussed below.

The costs of food and labour, derived in Section 6.1 above, are:

Food	£500/tonne of prawns produced;
Labour	£0.3/kg of prawns/year.

Six costings are presented in Table 14 based on the production of 15, 25 and 35 g prawns stocked initially at densities of 25, 50, 100 or 150/m². The extrapolated growth rates were taken from Figure 8. The effect of providing one or three shelves within the tank (or stacked shallow tanks) to effectively double or quadruple the yield is demonstrated, although the cost/m² was taken as constant in the absence of better data. The total costs were then compared with an average price for given sizes of prawn (from Figure 9, based on the frozen tail market) and the difference expressed as a percentage of the cost. The five most favourable results, that are also considered biologically feasible, and one high density result, when compared in this way, emphasize the potential of low density cultures (25-50/m²) and of shelves for the production of large prawns (35 g). The range of

Table 14 An illustration of the effect of culture density, product size and the use of 'shelves' on costs of production of 1 tonne of prawns

Row	Mean weight (g)	Initial density (prawns/m ²)	Duration (weeks)	Number of shelves	Weaned juveniles		Heating		Pumping		Space		Labour		Total cost (including £500 food) £	Value (from Fig. 9) £	Difference (%) $\frac{\text{Value} - \text{Cost}}{\text{Cost}} \times 100$
					Units	£	Therms	£	Days	£	Units	£	Units	£			
1	15	150	21	0	83.3	212	4 500	765	147	106	226	859	404	121	2 563	1 100	-57.1
2	25	100	26	1	50.0	127	5 571	947	182	131	127	483	500	150	2 338	2 300	- 1.6
3	35	25	21	1	35.7	91	4 500	765	147	106	290	1 102	404	121	2 685	2 750	+ 2.4
4	35	25	21	3	35.7	91	4 500	765	147	106	146	555	404	121	2 138	2 750	+28.6
5	35	50	26	1	35.7	91	5 571	947	182	131	181	688	500	150	2 507	2 750	+ 9.7
6	35	50	26	3	35.7	91	5 571	947	182	131	92	350	500	150	2 169	2 750	+26.8

Table 15 The proportionate costs for selected items in the culture of penaeid prawns from 0.2 g to 35 g in 21-26 weeks

Item	% of total costs (range)	Basis of estimate
Weaned juveniles (0.2 g)	3.4- 4.2	Production of <u>P. merguensis</u> at Conwy
Heating	28.5-43.7	Quantity of water used from best results with <u>P. monodon</u> . Gas heating only, and no allowance for heat loss or recovery
Pumping	3.9- 6.0	Recirculation of water, best results with <u>P. monodon</u>
Space	16.1-41.0	Speculative - cost of an insulated fish culture tank fitted with 1-3 shelves to increase surface area
Food	18.6-23.4	Pelleted food (e.g. trout pellet @ £250/ton), conversion 2:1
Labour	4.5- 6.9	Intensive trout production x 2

the proportionate costs are summarized in Table 15. An example of the way in which Table 14 was constructed (referring to row 6 of Table 14) is given below.

Example

Production of 1 tonne of 35 g prawns in 26 weeks in tanks 1 m deep fitted with three shelves spaced at 25 cm intervals and initially stocked with 50 weaned post-larvae/m² of horizontal surface (i.e. 200 prawns/m² of tank floor):

Cost of weaned juveniles: 1 tonne of 35 g prawns contains 28 571 prawns; survival from juveniles is 80%; thus $\frac{28\ 571}{0.8 \times 1\ 000} = 35.71 \times 10^3$ juveniles are needed at a cost of £2.54/1 000 (Table 11) = £91.

Water heating: the quantity of water used is the initial charge plus the volume renewed each week = $\frac{970}{16 \times 1.83} + \frac{400}{1.83} = 252$ l/kg/week; the duration of culture is 26 weeks; thus 6 552 m³ of water/tonne of prawns must be heated through 15°C requiring 6 552 x 15 x 1 000 = 98.28 x 10⁶ kilocalories = $\frac{98.28 \times 10^6 \times 3.96832}{10^5} = 3\ 900$ therms; which, at 70% efficiency, means using 5 571 therms; 5 571 x 17 pence = £947.

Water pumping: the quantity of water pumped is $100 \text{ m}^3/\text{h}/\text{tonne}$ of prawns produced and costs £0.72/day; the culture period is 26 weeks (182 days); so $182 \times 0.72 = \text{£}131$.

Space: after 26 weeks $40 \text{ prawns}/\text{m}^2$ remain on each horizontal surface and weigh 35 g each. The tank cost (see Section 6.1) is spread over 10 years and the biological filter (height 2 m) occupies 5 m^2 ; so area required $= 5 + \frac{1\ 000}{40 \times 0.035 \times 4} \times 0.5 = 91.8 \text{ m}^2$;
cost $= 91.8 \times \frac{38}{10} = \text{£}349$.

Food: £500.

Labour: costs estimated at £0.3/kg/year; two harvests each of 1 000 kg obtained each year thus $\frac{1\ 000 \times 0.3}{2} = \text{£}150$.

Total: £2 169/tonne = £2.2/kg
= £1/lb whole prawns.

6.6. Discussion of costs

The first three stages need little comment since they are together not likely to account for more than 5% of the crop value unless prawns below 20 g weight are harvested. Even so, estimated costs of juvenile production were 2-3 times higher than figures from the USA, Taiwan and Japan that were based on large-scale cultures.

In the high cost stage 4 space and heating stand out as the major expense items and in these areas further developmental work will be most valuable. The cost of the diet is unlikely to be reduced substantially below £250/tonne but research into prawn feeding behaviour could improve conversion efficiency.

Clearly the use of shelves is an important area for research, particularly if it can be shown that the additional horizontal surfaces give rise to higher yields/tank, without causing the reduction in growth rates normally associated with increased stocking densities and without significantly increasing tank costs. The use of shelves poses problems of animal husbandry; feeding and cleaning are made difficult and excited or fleeing prawns frequently damage themselves on such structures. Nevertheless, it may be possible to design a satisfactory multi-surface tank with self-cleaning properties by consideration of the behavioural responses of the species to be grown.

Reduction of the heating costs might be achieved firstly by research into factors affecting the amount of new water used and secondly by the development of designs for culture facilities that will capitalize on the proper use of insulation (including the 'greenhouse effect') and solar heating to reduce conventional heating costs.

We appreciate that the figures shown for both the amount of water used and for pumping could perhaps be reduced if they were calculated relative to the biomass of prawns in the tanks at any particular time instead of relative to the final weight of prawns produced. Since this has not been tested in practice we had chosen not to extrapolate in this direction.

7. CONCLUSIONS

In this report we have reviewed the work at Conwy on the culture of prawns. Particular emphasis was placed on laboratory-scale mass cultures in order to obtain information that would be applicable to studies of larger pilot-scale operations. We have now reached the point at which the basic economics of prawn farming may be considered on the basis of results achieved in the laboratory. Clearly the intensive farming of prawns in a controlled indoor environment will initially require a high capital outlay and the use of a sophisticated technology.

It is also evident that there is considerable potential for the improvement of yields and probably for the reduction of heating costs. Specific areas where further research is necessary are in the design of a suitable self-cleaning tank for the final growth stages to improve growth and survival; reduction of replacement water, and hence heat, and the use of insulation and heat recovery systems.

A British company wishing to avoid the heating costs might consider starting their operations in warmer countries. While it is indeed true that at the present level of development heating costs are high, our results indicate that these can be substantially reduced by adapting existing methods of water quality control to reduce the requirement for replacement water. In addition there are a number of sacrifices that are likely to be necessary abroad. According to the country chosen, these might include:

- (a) political instability;
- (b) transport costs to worth-while markets;
- (c) little opportunity to sell significant quantities of live or fresh prawns which will fetch much higher prices than frozen or prepared animals;
- (d) cost and time involved in importing plant, equipment and spares for such items;
- (e) availability of suitable feedstuffs and feedstuff manufacturing equipment. This only applies to controlled intensive culture where 'trash' foods are not appropriate;
- (f) climatic and biological hazards such as typhoons and invertebrate pests;
- (g) warm-water prawns are more likely to pick up disease organisms from naturally warm waters than from cold waters heated artificially.

There is at present no established British market for large fresh prawns (35 g whole weight) and competition of farmed penaeids with caridean prawns fished from British waters (Pandalus, Crangon and Palaemon) which weigh less than 15 g seems unlikely. The considerable quantities of large prawns sold frozen or processed in Great Britain are imported, and it is expected that the consistency of quality and supply of farmed prawns would ensure them a place, not only at home but also on the higher priced European markets.

The outlook for breeding Penaeus monodon seems promising since this species has been induced (see Appendix 1, Glossary, Unilateral Eyestalk Ablation) to mature and spawn unfertilized eggs in Great Britain (Arnstein and Beard 1975) and viable eggs in Tahiti (A. Q. U. A. C. O. P. 1976) and in the Philippines (Santiago 1976) while intact animals have matured and spawned viable eggs in captivity in Taiwan (I. C. Liao, pers. comm.) and Tahiti (A. Michel, pers. comm.).

The future development of a prawn farming industry now seems likely to depend upon our ability to breed P. monodon in captivity, demonstrate that juveniles can be obtained as required and to offer initial batches of juveniles to commercial operators for test purposes.

ACKNOWLEDGEMENTS

This report summarizes to date the research done at Conwy. We are particularly grateful to all our colleagues who contributed.

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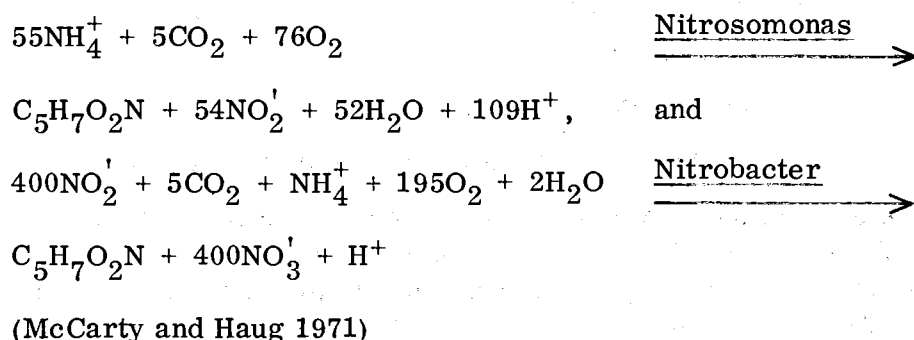
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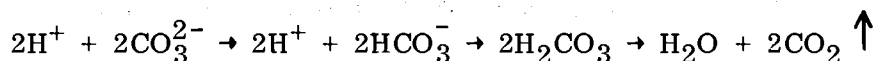
GROW-OUT - an American term covering the period of growth from small juveniles to marketable size. The last growth phase of a cultured species before harvesting.

HYDRAULIC LOAD - see **BIOLOGICAL FILTER**

NITRIFICATION - the oxidation of ammonia (the main soluble nitrogenous product secreted by prawns) by autotrophic bacteria in a biological filter. The overall reactions involved in nitrification and assimilation by the bacteria are



In intensive culture systems the H^+ ions produced often lower the pH and unbalance the equilibrium between carbon dioxide, bicarbonate and carbonate molecules in the water:



This results in a net loss of inorganic carbon to the air (as carbon dioxide) and hence destroys the buffering capacity of the sea water (see **BUFFERING CAPACITY**).

NITROGEN - see **AMMONIA**

PRAWN and **SHRIMP** - these terms are used throughout the literature as vernacular names. There is no internationally accepted relationship between these terms and the taxonomic affinities of the animals under consideration and their use varies from country to country. In Great Britain the term 'shrimp' is applied to the pink shrimp Pandalus montagui and the brown sand-dwelling shrimp Crangon crangon, while the term 'prawn' is applied to the somewhat larger species such as Palaemon serratus and Pandalus borealis; in some parts Nephrops norvegicus is called 'Dublin Bay prawn'. The term 'prawn' is used for all species considered for culture in this review.

PROTANDROUS HERMAPHRODITE - an animal that changes sex, functioning first as a male and then as a female, for example the spot prawn Pandalus platyceros.

QUARANTINE - procedure to minimize the risks of introducing disease or alien organisms to healthy stock or to the local environment. Imported adult prawns were maintained in isolation throughout their stay at the laboratory. Small post-larvae and larvae obtained from imported breeding stock were washed in several changes of clean sea water within about a day of their arrival. All contaminated water and equipment were exposed to an initial concentration of 50-100 mg/l free chlorine (from bleaching powder) for 24 h before being discharged or re-used.

RIPE OVARIES - the ovaries of a prawn that is about to spawn. The outline of the ovaries in Penaeus merguensis is readily visible through the exoskeleton although it is necessary to view darker species like P. monodon against a strong light. A penaeid prawn that is likely to spawn usually exhibits the following characteristics (see also Appendix Figure 1):

- (1) the tips of the frontal lobes of the ovary are full and clearly visible through the carapace at points just behind the eyes;
- (2) the ovaries appear granular and dark green (in P. merguensis particularly) when viewed through the membrane between the carapace and first abdominal segment;
- (3) an expanded portion of the posterior lobe of the ovary is visible in the region of the first abdominal segment. In female Caridea (e.g. Macrobrachium) the ripe ovary is bright orange and mainly confined to the area beneath the carapace.

SHELVES - a stack of PVC sheets to increase the available floor area within a tank.

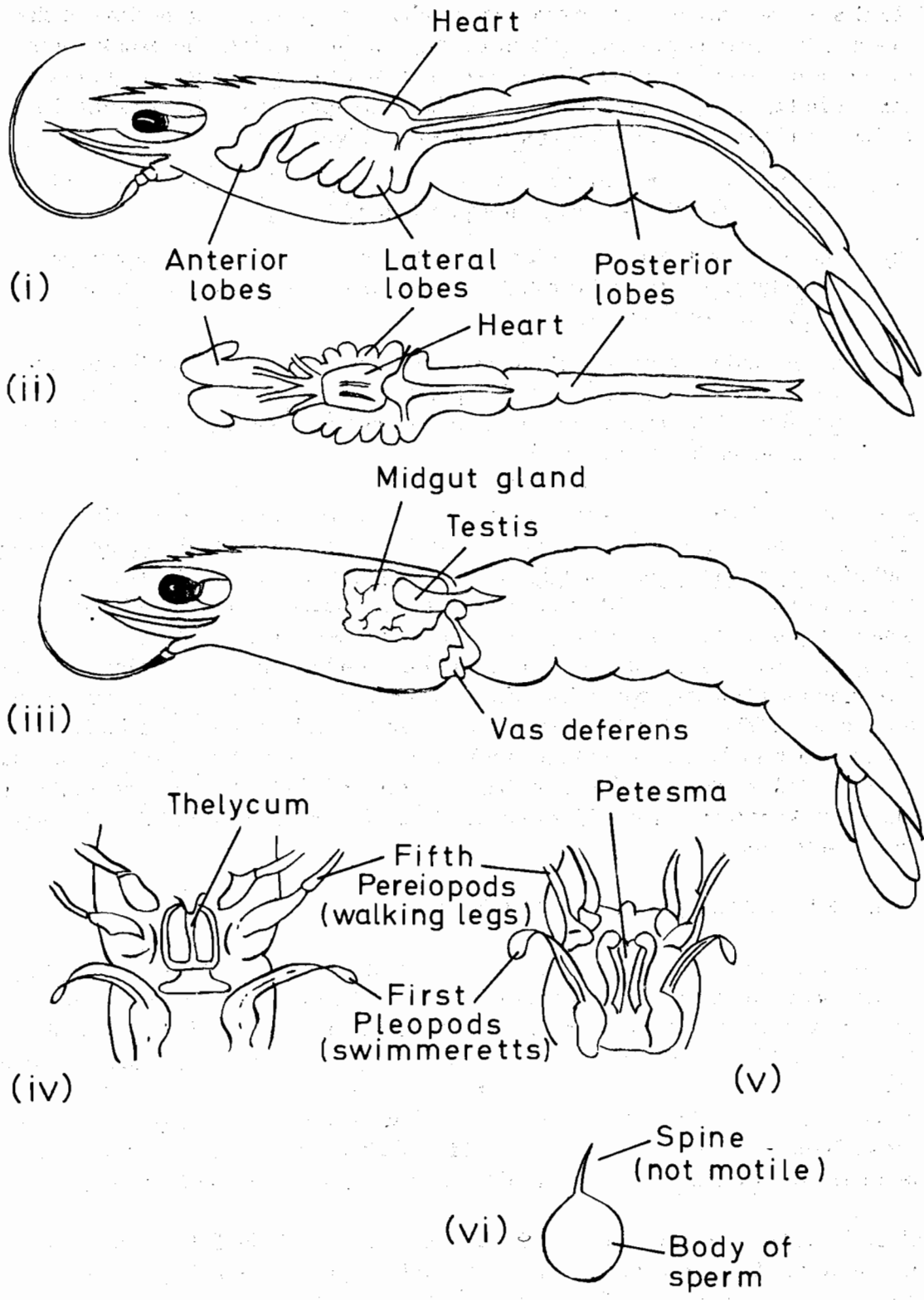
The greatest single cause of mortality in intensively cultured Palaemon serratus and Macrobrachium rosenbergii was cannibalism. These species are known to be territorial and mortality was effectively reduced by the provision of shelves. The young prawns (1 g) readily clung to upper and lower surfaces. Larger M. rosenbergii (8 g), however, became damaged by repeated violent contact with the shelves when they were disturbed either by their fellows or by sudden noises and changes of illumination. In a well-designed tank, under good husbandry conditions, it may be expected that yields of the more docile penaeid species such as P. monodon will be increased by the provision of shelves. An untested design is shown in Appendix Figure 2 as one example of how shelves might be incorporated into a self-cleaning tank.

SPECIFIC SURFACE AREA - see BIOLOGICAL FILTER

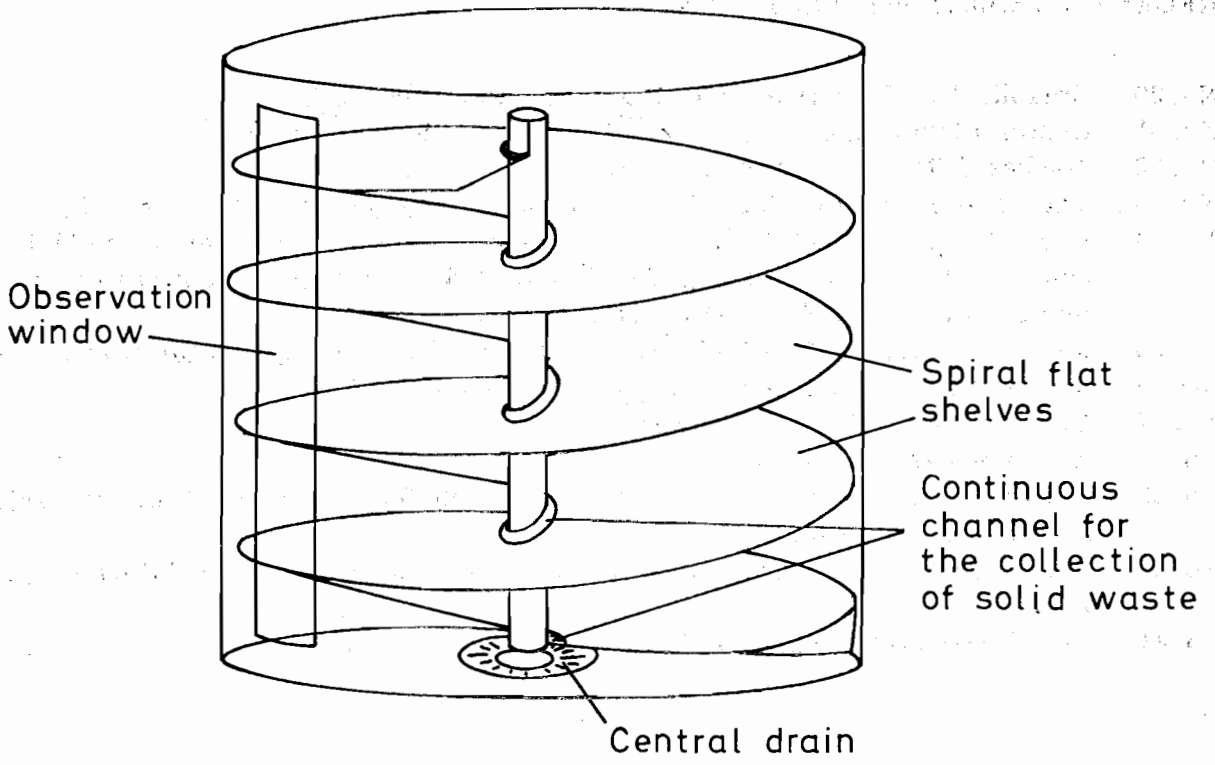
TAIL - the name frequently used for the edible part of the prawn. The tail weight (edible meat and shell) expressed as a percentage of the total weight is less in Caridea than it is in Penaeidea: average values are about 40 and 60% respectively. This is important because the yield of tails from a penaeid rearing operation would be greater than from a caridean culture system for the same total weight of prawns produced. It should be noted, however, that certain luxury markets for whole (unshelled or 'heads-on') prawns would probably not distinguish between penaeids and carideans except on grounds of quality, i. e. flavour and texture.

UNICELLULAR ALGAE - microscopic plants; examples include Tetraselmis suecica (suitable for the protozoa larva of penaeids), Isochrysis galbana and Chlamydomonas coccoides (good food for Artemia nauplii).

UNILATERAL EYESTALK ABLATION - removal of one eyestalk and its associated glands allowing maturation to proceed perhaps by reducing hormone concentration. The eyes of prawns are on stalks which contain numerous glands capable of secreting hormones (or chemicals) that control a number of bodily functions, e.g. colour change, moulting, maturation. One hormone which prevents the maturation of the ovaries seems to be continually secreted by some penaeid species when they are held in captivity.



Appendix Figure 1 Reproductive structures in a penaeid prawn. (i) The ovary in situ, lateral view; (ii) dorsal view showing the ovarian lobes and position of the heart; (iii) the testis in situ, lateral view; (iv) external genitalia of the female, ventral view; (v) external genitalia of the male, ventral view; (vi) one spermatozoa.



Appendix Figure 2 A hypothetical (untested) example of how 'shelves' might be incorporated into a self-cleaning tank to allow prawns to distribute themselves throughout the water column. Circular water currents would tend to move detritus towards the central channel and thence to the drain.