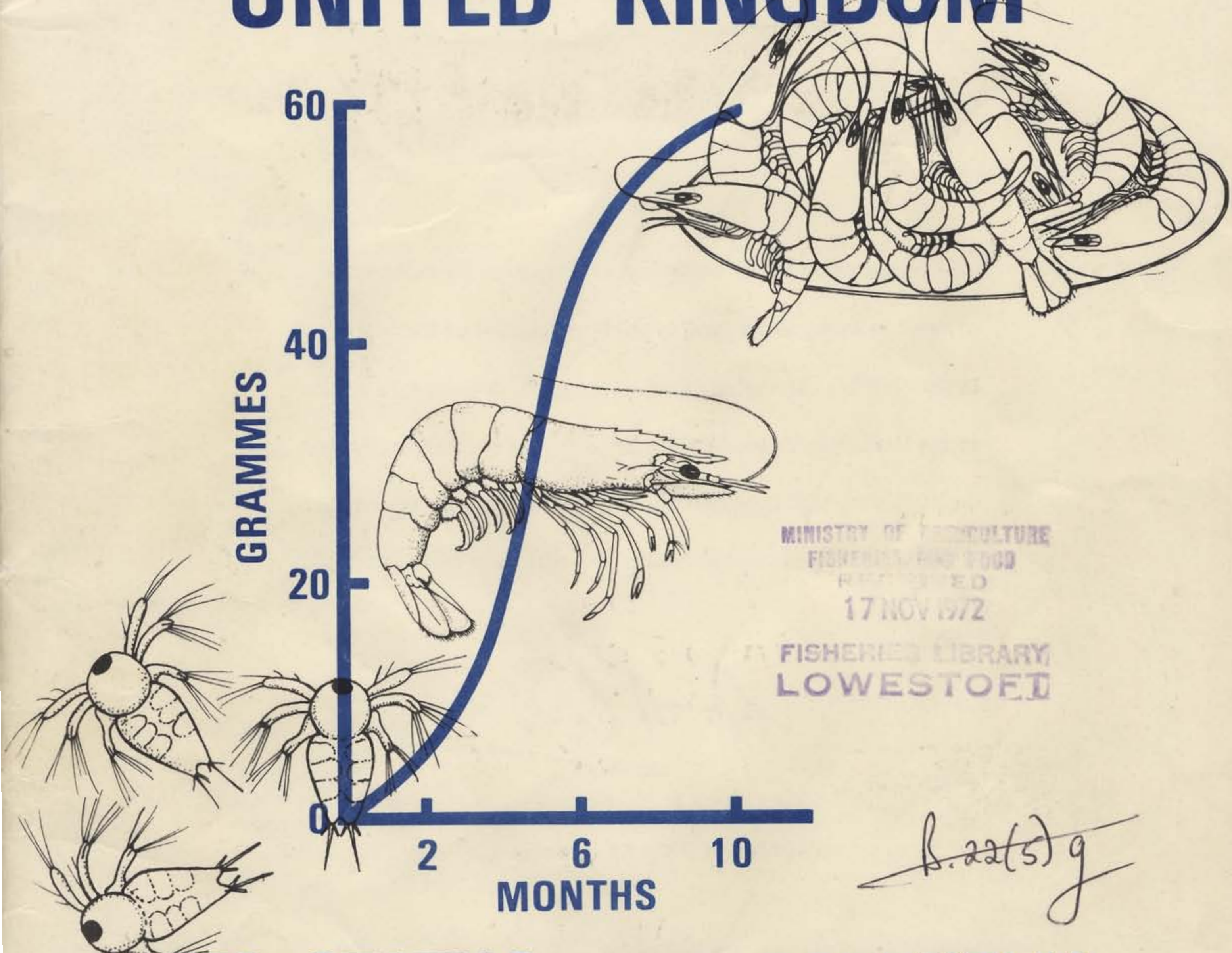
MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

PRAWN CULTURE IN THE UNITED KINGDOM



ITS STATUS AND POTENTIAL

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INTRODUCTION

There is a world-wide interest in the possibility of commercial culture of shrimps* and prawns*. This is generated by their high value in world markets and because demand is continually increasing and is likely to exceed the quantities available from natural fisheries. A ready market is therefore anticipated for cultured or "farm-raised" prawns, which could be harvested to meet specific market requirements and sold fresh at a premium over imported preserved products.

There are several possible ways of cultivating prawns in the UK, but these are based on three fundamental approaches:

1 extensive (low stocking densities) or "free range" culture in very large outdoor ponds or enclosed sea areas;

2 intensive (high stocking densities) outdoor culture in smaller, more controllable ponds, tanks or raceways;

3 very intensive (high stocking densities with frequent cropping) indoor culture in completely controlled environment tank systems.

This leaflet reviews the work done by the Ministry of Agriculture, Fisheries and Food at the Fisheries Experiment Station, Conway, to investigate the potential for commercial prawn culture in the UK and some of the ways in which this might be achieved. Consideration is given to major problems confronting the would-be prawn farmer which have still to be solved. Firstly, however, a general summary of some aspects of prawn biology is given for the benefit of the non-specialist reader, and this is followed by a review of the present status of shrimp and prawn cultivation in other parts of the world.

Throughout the review use is made of certain scientific and specialist terms. These are indicated by an asterisk and explained in Appendix 2 (in alphabetical order).

NOTES ON PRAWN BIOLOGY

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 subclass Malacostraca, order* Decapoda that species occur which are directly

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*see Appendix 2

important as human food. The Decapoda is divided into two sub-orders, Reptantia and Natantia. The Reptantia contains the larger, hard-shelled lobsters, crabs, crawfish, Dublin Bay prawns ("scampi" - see Appendix 2) and freshwater crayfish. Their potential for culture is not considered in the present review and will form the basis for a separate leaflet. 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. 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.

Life cycle

Prawns hatch from the egg as a small, fragile larva (plural - larvae) which is different in form from the adult and is adapted to a free-swimming planktonic life. It passes through a number of distinct stages, each preceded by moulting - see below- before changing into a bottom-living miniature adult. This transformation is called metamorphosis and the young prawn is then called a juvenile until it reaches sexual maturity. 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.

The development of penaeid larvae differs from that of the Caridea. 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 5 or 6 - before passing into the next larval form called a protozoea. The protozoea feeds on microscopic plants, and 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 1).

In the Caridea the nauplius is passed over and becomes an embryonic stage within the egg. The larva hatches as either a protozoea or zoea (see Figure 2). Development is then similar to the penaeids, although there are frequently more than three zoeal stages in the Caridea.

Growth and moulting

All prawns have an external skeleton or shell which serves both for 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 and with age, but during this period the prawn is vulnerable and in tank conditions may be attacked, killed and eaten by its companions.

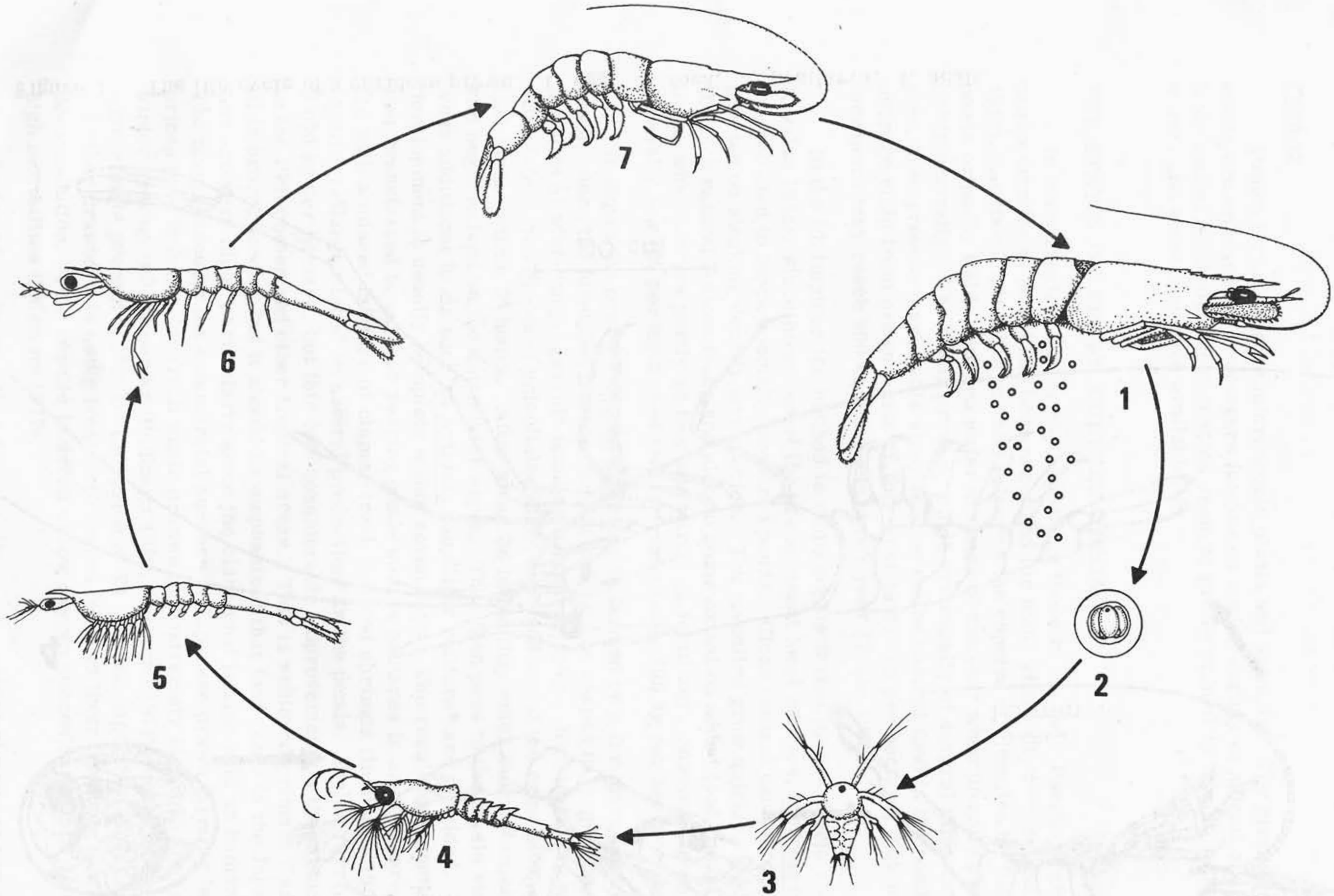

Figure 1 The life cycle of a penaeid prawn. 1, adult female spawning; 2, egg; 3, larva (nauplius); 4, larva (protozoea); 5, larva (mysis); 6, postlarva; 7, juvenile.

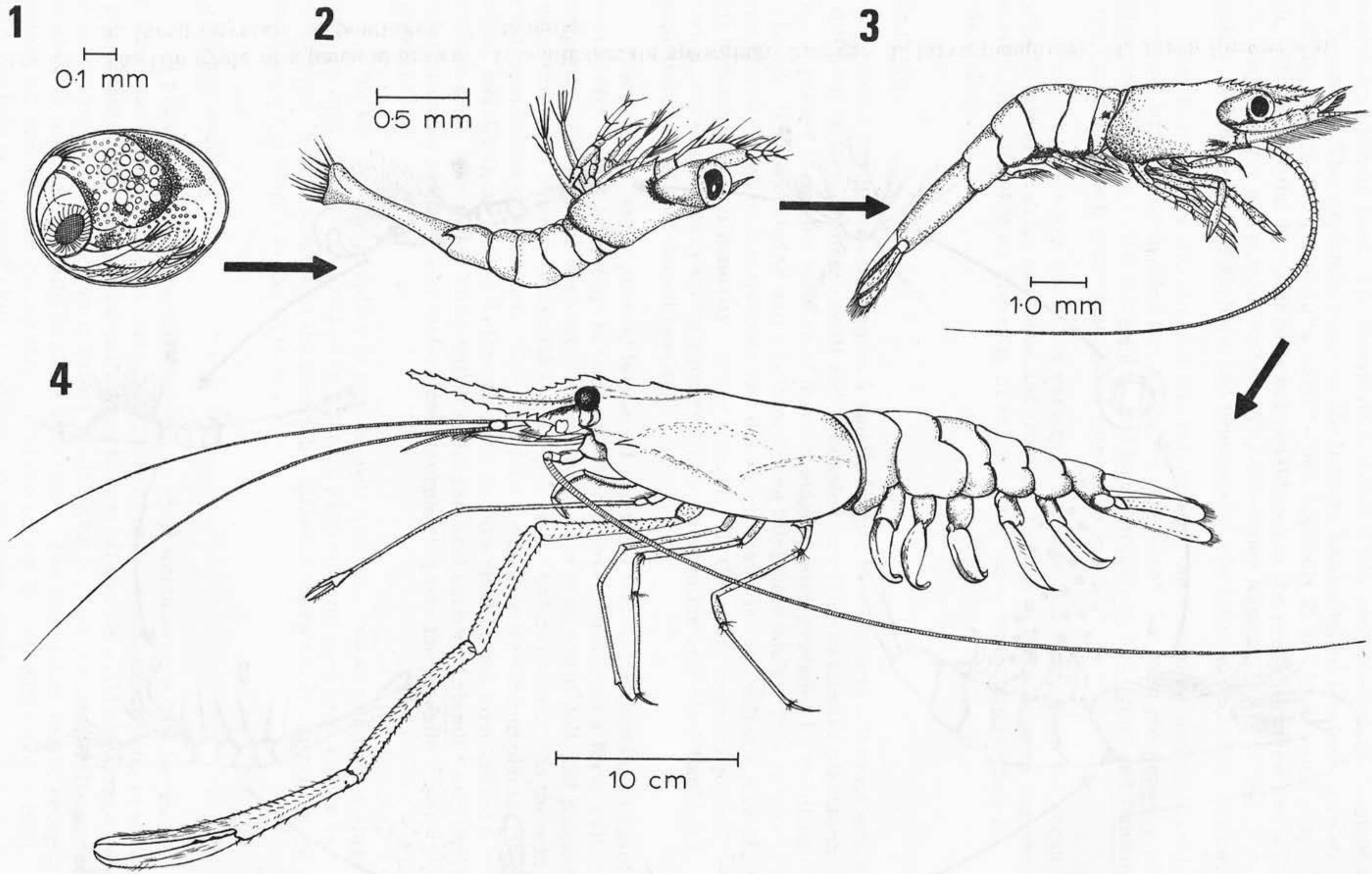

Figure 2 The life cycle of a caridean prawn. 1, egg; 2, zoea; 3, postlarva; 4, adult.

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.

THE STATUS OF PRAWN CULTURE ABROAD

In many tropical countries, especially those in the Indo-Pacific region, prawn farming in ponds has been practised for many years (Ryther and Bardach 1968). At its simplest the method relies on the capture of juveniles by flooding ponds or paddy fields with sea water at times of the year when juvenile prawns occur naturally. The young prawns, which are usually of several different species, then grow to marketable size, feeding on the natural food in the ponds. The average yield from prawn ponds of this kind is 340 kg per hectare, but in Singapore may reach 900 kg per hectare per year (Tham 1968).

In the Philippines the method is more sophisticated (Caces-Borja and Rasalan 1968), since juveniles of the predominant local species, Penaeus monodon, are selected to stock specially prepared ponds. Close control can therefore be exerted on stocking density and species. The juveniles grow quickly, feeding on the rich natural bottom fauna and also to some extent on added food, usually rice bran, which serves partly as food and partly as fertilizer. Survival, however, is generally low (20 per cent), and yields average only 280 kg per hectare per year.

In Japan the prawn Penaeus japonicus is farmed on a far more controlled basis, since the juveniles used for pond stocking are reared in large tanks from the eggs of wild-caught gravid* females (Hudinaga 1969). Nutrient salts which stimulate a rich bloom of unicellular algae* are added and the eggs hatch as nauplius larvae within 24 hours. After about 36 hours they enter the protozoea stage and begin to feed on the unicellular algae. They then pass to the mysis stage, when additional foods such as Artemia nauplii or rotifers* are provided. Larval development is usually complete within seven days. The resulting juveniles are then transferred to outdoor rearing ponds up to 4 hectares in area, where they are fed with a minced mixture of clams, trash fish and shrimps (Hudinaga 1969); there is little reliance placed on natural production* in the ponds. Yields rarely exceed 3 000 kg per hectare, but this is a considerable improvement on the methods used in the Philippines and other tropical areas. This is achieved primarily as a result of improved feeding but it should be emphasized that food costs in the Japanese system are very high, particularly since the clam used is also sold as human food. The main reason for the commercial success of Japanese prawn farming is that the prices paid in Japan for fresh whole prawns are extremely high and during the winter average £3.32 per kg (Hudinaga 1969, Shigueno 1972), compared with an approximate present (1972) British price of £1.10 (see page 18). Apart from cost, a further drawback to using freshly-prepared feeds is their tendency to rapid decomposition. This results in areas of low oxygen concentration and can cause high mortalities (Shigueno 1972).

As far as we know, other prawn culture enterprises elsewhere are still developmental but all are aimed towards a controlled system of culture relying on hatchery-produced juveniles for stocking farm tanks, ponds or enclosures. Success is reported by many authors in the culture of larval stages and early

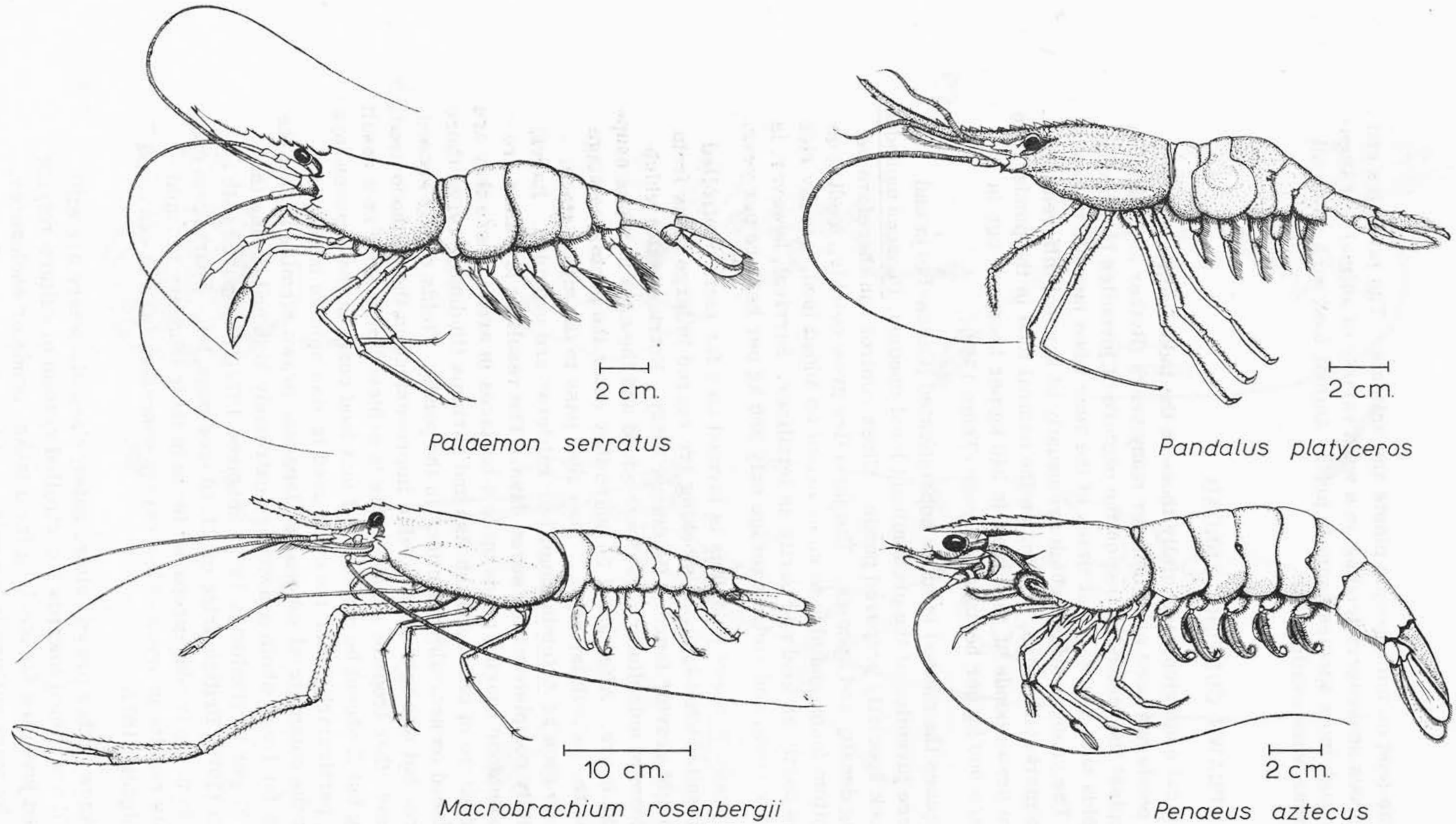

Figure 3 Adult specimens of some of the prawn species that have been used in culture experiments at Conway.

juvenile stages of several different prawn species - for example, Penaeus aztecus, P. duorarum and P. setiferus, Sicyonia brevirostris, Trachypenaeus similis and Xiphopenaeus kroyeri (Cook 1969); Penaeus japonicus, P. monodon, P. semisulcatus, P. teraoi, Metapenaeus monoceros and M. joyneri (Liao and Huang 1970) and Penaeus kerathurus (Lumare, Gozzo and Blundo 1971) - and the production of large numbers of juveniles for farm stocking would not appear to present any insuperable problems.

Difficulties arise during the juvenile growing or "fattening" stage, when satisfactory survival and growth are by themselves no longer the only criteria for success, since they must be achieved within the limits imposed by production costs. Thus the emphasis of much research is directed towards the development of systems for growing juvenile prawns more cheaply. Most attempts have been effectively nothing more than replicas of the Japanese system of pond culture, although some modifications have been tried with the aim of improving efficiency. Such systems are especially attractive in countries where ponds or net enclosures can be constructed cheaply and where the climate favours the maintenance of good growing conditions throughout the year. However, experience is showing that this rather uncontrolled type of cultivation has certain problems, notably those of predator control and harvesting, and there is increasing interest in the development of alternative culture systems. One possibility is the development of highly intensive, environment-controlled systems related in concept to the methods of intensive terrestrial animal husbandry - e.g. for poultry and pigs - which are now so successful.

STUDIES UNDERTAKEN AT CONWAY (Figure 3)

Studies with Palaemon serratus

The first attempts to culture prawns at Conway were made in 1964 with a locally-occurring species, Palaemon serratus. This is a relatively small prawn and the females - which are larger than the males - reach a maximum live-weight* of only 10-12 g. It supports a limited commercial fishery on the south coast of the UK and more extensive fisheries along the Atlantic coasts of France and Spain. It was selected for study not with any firm idea of how its culture might be commercially developed, but rather so that experience could be gained in techniques of larval and juvenile prawn husbandry; accounts of the work have been given by Reeve (1969), Forster (1970) and Wickins (1972a). A summary of the most important aspects of this work follows.

Larvae (measuring about 3.5 mm total length) which hatched from wild-caught egg-bearing* female prawns were fed with the newly hatched nauplii of Artemia. Optimum temperatures for larval development were between 22 and 26°C, and survivals (to metamorphosis) of 30-40 per cent were regularly obtained in laboratory cultures. The larvae normally passed through six stages in three weeks before metamorphosing into juveniles, measuring about 8.0 mm total length.

Following metamorphosis the juveniles were weaned on to a diet of the flesh of mussels (Mytilus edulis), crabs (Carcinus maenas) or shrimps (Crangon vulgaris), which are good foods either individually or in combination. Their use on a commercial scale, however, would be impracticable and this problem is discussed further on pages 14 and 15. The fastest growth obtained with P. serratus in laboratory tanks was from metamorphosis to approximately 3.0 g live-weight in nine months; this was under relatively ideal conditions of abundant food and optimum temperatures (20-22°C). In outdoor tanks, growth from 0.1 to 1.2 g live-weight was obtained between June and October, during which time water temperatures averaged nearly 18°C. Before June and after October temperatures would be lower and growth would slow down accordingly.

The main conclusion from our work with P. serratus was that biologically its large-scale culture would be possible, but the commercial viability of such an operation is very doubtful for the following reasons:

1 P. serratus will not survive for more than a few days at temperatures below 4°C, and therefore if prawns were to be overwintered in outdoor tanks or ponds in the UK supplementary heating would be required;

2 only the females reach an optimum commercial size of 6-8 g. Males rarely grow larger than 5 g and therefore would not fetch maximum prices;

3 male P. serratus reach sexual maturity at about 2.0 g live-weight and females at 3.0-3.5 g. After maturation much of the growth effort will go towards the development of the gonads*, which under good conditions may ripen three times a year. Following maturation, therefore, growth will almost certainly slow down and conversion efficiency* will be lower, thereby increasing costs;

4 the growth rate of P. serratus is slow. Under optimum conditions it takes at least a year to reach marketable size, but in outdoor tanks and ponds it would take considerably longer.

It has been suggested that more suitable temperatures for rearing P. serratus could be economically obtained by utilizing the vast supplies of heated sea water discharged as effluent from certain coastal electricity generating stations. This possibility has been investigated by the White Fish Authority at Hunterston, Ayrshire for farming marine flatfish (Anon. 1970). The effluent is normally 6-8°C above ambient and therefore in the UK ranges from 10 to 26°C. Thus lethal low temperatures would not occur and the good growing period would be extended. However, even in these conditions growth would slow down considerably during winter, and it seems unlikely that prawns would reach marketable size in less than two summers. The possible use of power station effluents for prawn cultivation should not be dismissed, but if it is ever to be commercially successful faster growth rates are required than those obtained so far with P. serratus.

Studies with other prawn species

The limitations of P. serratus for commercial culture stimulated us to look for other prawn species which might have more favourable characteristics, particularly faster growth rates. Pertinent information from the literature about some potential candidates is summarized in Appendix Table 1. Without exception the fastest growing prawns are tropical species, mainly in the Penaeidae, although one caridean genus, Macrobrachium, also contains fast growing species. Temperate-water species grow more slowly and are generally smaller than their tropical relatives although both those listed in Appendix Table 1 are larger, when fully grown, than P. serratus. At 6-8 g (marketable size) they would still be sexually immature. This has two advantages: firstly, they could be harvested while still in the fastest phase of their growth cycle and, secondly, it would overcome the problems of early gonad development (see above).

Consideration of the biology of the different species available suggested two possible approaches to their culture.

1 Cold-water or temperate-water species could be cultivated in outdoor enclosures, ponds or tank systems. Cultivation could either be extensive (low stocking density) or intensive (high stocking density), depending on the area of water available and the degree of control which could be exerted over it. This approach would be dependent on naturally occurring water temperatures and therefore subject to seasonal variation in prawn growth and production. Some improvement might be possible if the use of power station effluents was considered.

2 Fast growing tropical prawns could be cultured in closed circulation systems (see page 10) where optimum growing temperatures (about 28°C) could be continuously maintained. Cultivation would have to be highly intensive to compensate for the higher capital and running costs, but the growth rate of some tropical species would permit three or four crops per year and we consider such an approach to be feasible.

Studies have been undertaken at Conway to investigate these possibilities, and the more important results and conclusions are reviewed below.

Culture in unheated water (Pandalus platyceros)

The choice of species for culture in unheated water is restricted, because large, cold- or temperate-water species are few and published information is limited. However, one species, Pandalus platyceros, has been studied in some detail (see Appendix Table 1 and Butler 1964, 1970) and its culture investigated at Conway (Wickins 1972b). This prawn is widely distributed in the North Pacific at water temperatures between 2 and 20°C (Butler 1970). It reaches a live weight of about 7 g after one year and 30-40 g when fully grown. This is much faster than P. serratus, and if the larvae could be successfully cultured the juveniles might be suitable for stocking extensive or intensive outdoor rearing systems in the UK.

Attempts to culture P. platyceros were begun with larvae hatched from live egg-bearing females flown from British Columbia. The newly hatched larvae are larger (8.0 mm total length) than those of P. serratus but were cultured using similar techniques. They grew and survived best at temperatures between 14 and 15°C and salinities* of 30 ± 2°/oo, and metamorphosed after approximately 17 days. Success in our early experiments was spasmodic but in later attempts average survivals of 50 per cent to metamorphosis were achieved. Large-scale culture was not tried but there does not seem to be any inherent reason why this should not be successful.

Experiments with laboratory-reared juvenile P. platyceros showed that the natural growth rates reported by Butler (1964) could be achieved in culture, and growth from 0.4 to 4.9 g live-weight was obtained in outdoor tanks between July and January. The prawns survived and grew, albeit slowly, at temperatures between 0 and 8°C and showed that this species had promise for culture in the UK.

There is, however, one major problem to be solved before the commercial-scale culture of this species could be contemplated; this concerns the regular supply of larvae. It would be impracticable to import sufficient wild-caught egg-bearing females, because of the large numbers required; for example, a relatively small installation with an annual production of 10 000 kg would need about 5 000 females. This is because the fecundity* of P. platyceros is low, and experience has shown that only 1 000-2 000 larvae will hatch from a good-sized egg-bearing female. Larvae would therefore have to be obtained from a captive breeding stock. The management of such a stock would itself be difficult but, more important, the controlled maturation and spawning of P. platyceros in captivity has not yet been accomplished. This species is a protandrous hermaphrodite*, spending two years as a male before changing sex. Research into its controlled breeding would therefore be long-term and it has been decided not to undertake such a programme at Conway.

Apart from P. platyceros the only other cold- or temperate-water species known to us which may have suitable characteristics is Hymenopenaeus müller i. This prawn occurs along the east coast of South America, and since it is a penaeid should have a high fecundity (see Appendix 1). There may well be other species about which there is no published information but, if so, they are probably uncommon and commercially unexploited. Although this does not preclude them as possible candidates for culture, it does make the acquisition of live animals for experimental work more difficult. At present it is considered that there is greater commercial potential in the culture of some of the very fast growing tropical prawn species (Appendix Table 1) in closed circulation systems, and our current research at Conway is directed accordingly.

Culture in closed circulation systems

The culture of tropical prawn species in the UK will require elevated temperatures and its commercial feasibility depends on the development of closed circulation systems in which the water is recycled through the rearing tanks. Thus heat is only required to maintain the water temperature, and if the whole system was housed in an insulated building heat losses could be greatly reduced. The problem with this type of system is that soluble materials excreted by the prawns and leached out of their food can quickly build up to toxic levels. The most economical method for their removal is by using biological filters similar in principle to those used by some local authorities for purifying sewage. Typically these are beds of gravel which provide an enormous surface area that is colonized by many different micro-organisms. These organisms utilize the soluble materials such as ammonia, urea, proteins, and carbohydrates for their own growth and metabolism, the end products of which include nitrates, which are unlikely to be harmful to prawns until quite high concentrations are reached, and carbon dioxide, which can be partly removed by vigorous aeration and the remainder controlled by the buffering capacity* of the culture water. The equilibrium of the buffering system can be maintained by percolating the water through a bed of calcium carbonate such as oyster shell or calcite.

Biological filters in closed circulation systems have been used successfully for many years for the maintenance of inland public marine aquaria (Spotte 1970), and in recent years their use in the commercial culture of carp (Saeki 1965) and salmon and trout (Burrows and Combs 1968) has been investigated.

Closed circulation systems have several advantages over the outdoor pond or enclosure types of culture. These are:

1 optimum growing conditions can be permanently maintained;

2 stock maintenance is greatly simplified and close control can be exerted over feeding, harvesting and disease;

3 these systems are particularly amenable to automation;

4 there are no predator problems;

5 there is less reliance on large quantities of water from natural sources, which are always vulnerable to pollution;

6 once such systems are developed they can be readily adapted for the culture of other aquatic organisms for which there is a high market demand.

Research undertaken at Conway to study prawn culture in closed circulation systems falls into two parts. Firstly, there is the problem of selecting a prawn species which adapts well to such conditions and will grow fast enough to make its culture commercially feasible. Secondly, there are problems of designing the system itself. These include:

1 the prediction of the biological loadings, in terms of excretory products and materials leached from the food, which can be placed on the system;

2 the estimation of the tolerance of the selected species to accumulations of its own and other soluble waste products;

3 the determination of filter capacity in terms of waste removal at known hydraulic and biological loadings.

A programme to study these latter aspects, i.e. the design parameters of the system, has only recently been initiated at Conway and there are no results which can be reported here; however, some studies on the selection of a suitable species have been made, and experiments with one species, Macrobrachium rosenbergii (see Appendix Table 1 and Wickins 1972b), are summarized below.

The culture of Macrobrachium rosenbergii

M. rosenbergii is a large freshwater prawn found widely distributed in the Indo-Pacific region. It was selected as the first tropical species for investigation at Conway because its culture had been studied elsewhere (Ling and Merican 1962, Ling 1969a, b) and it was reported to grow very quickly and to adapt well to laboratory conditions. In addition, since it is a member of the Caridea, the females incubate the eggs after spawning (see Appendix 1); the acquisition of larvae for our experiments was therefore greatly facilitated, since live egg-bearing females could be imported from abroad.

In its natural habitat M. rosenbergii spawns in river estuaries and the larvae live in brackish water. In experiments at Conway newly hatched larvae which were only 2.0 mm in total length were cultured at 28°C at a salinity of 15°/oo. They were fed Artemia nauplii supplemented with unicellular algae, either Isochrysis galbana or Chlamydomonas coccoides. At the high culture temperatures newly hatched Artemia rapidly depleted their energy reserves and died, usually within 48 hours, unless fed with an algal diet. The addition of algal cells to larval cultures maintained the Artemia in good condition and greatly improved larval growth and survival.

Attempts to culture M. rosenbergii larvae have had mixed success, with some batches doing well, 35 per cent surviving to metamorphosis in mass culture, but the mean survival from all our cultures has only been 14 per cent. The work is still in an early stage, however, and it is anticipated that more consistent results will be achieved when rearing conditions are better defined. Studies on the culture of M. rosenbergii in Hawaii (Fujimura and Okamoto 1970) indicate that considerable success has been achieved there.

In common with other workers (Fujimura and Okamoto 1970), our early attempts to rear the juvenile stages of M. rosenbergii failed to produce the very fast growth reported by Ling (1969a). In an experiment in which populations of between 50 and 400 juveniles were stocked in tanks 83 x 69 x 46 cm deep, some individuals grew quickly from 0.03 g to between 10 and 22 g in three months but the majority lagged well behind, and the mean live-weight of the populations after the same time was only 2-3 g. The range of sizes in these populations was very wide and this, together with the rather slow average growth, would present serious problems in commercial culture. The reasons for this variable growth are not clear. It may be due to natural aggressive or territorial behaviour accentuated by crowded conditions and, if so, may indicate that this species is not suitable for intensive rearing. It may simply reflect inadequate experimental conditions, for example the use of relatively small tanks, and the problem may not arise in further trials under different conditions. Alternatively, it may be genetically determined and might therefore be overcome by a programme of selective breeding.

A particularly successful aspect of our work with M. rosenbergii has been the maintenance of a laboratory-reared breeding stock of two males and eleven females from which over 500 000 viable larvae have been obtained in ten months. This suggests that the controlled supply of seed stock for commercial rearing would be possible.

Studies with penaeid prawns

The problems encountered with M. rosenbergii led us to consider other tropical species to see if they were more amenable to tank culture. Virtually all other likely candidates are in the Penaeidea and the acquisition of larvae for culture work is therefore more difficult; see Appendix 1. Whilst larval culture is obviously an integral part of any future prawn farming enterprise, we consider at present that the most important criteria for selecting or rejecting a prawn species concern their tolerance and adaptability to crowded tank conditions during the juvenile or "fattening" stage. This is the period which will be most costly in terms of time, space and materials (food, heating and pumping) and therefore where the greatest economies could be made by improving growth and survival. Thus, in an attempt to screen quickly a number of potential candidates, it has been decided to study the growth and survival of the juveniles of a number of penaeid species. These will be obtained live from their countries of origin and will be reared in closed circulation systems at Conway. If a promising species is found, an intensive investigation can then be made into its larval culture and controlled breeding. Initial experiments with Penaeus aztecus (Figure 3) and Penaeus monodon have given encouraging results.

TOPICS FOR FURTHER RESEARCH

Consideration of the development of commercial prawn farming in the light of our work to date highlights a number of areas where further research is required. Some of the topics are common to whichever type of culture is to be practised, while others are more specific; they are:

1	species selection	common to all types of culture;
2	seed supply	
3	disease	
4	site selection and construction of ponds or enclosures	- extensive culture only;
5	food for the juveniles	- intensive culture mainly. In extensive culture food will be provided by natural productivity but yields will be limited (see below);
6	tank design, stocking density and cannibalism	- intensive culture only.

These problems, with the exception of species selection which has already been considered, are discussed below.

Seed supply

If prawn farming is to become a fully self-reliant industry, the ability to bring captive stock into a breeding condition and to obtain the spawning of fertile eggs is essential. The success in maintaining a laboratory breeding stock of *M. rosenbergii* has been noted above and is an important point in favour of this prawn as a candidate for commercial culture. As far as we know, the breeding of penaeid prawns in captivity has not yet been achieved routinely in any of the countries in which their culture is being studied, and reliance is placed entirely on supplies of wild-caught gravid females. As shown in Appendix Table 1, penaeid prawns are extremely fecund and sufficient larvae for quite extensive culture operations can be obtained from very few females. For experimental and developmental culture enterprises, therefore, reliance on a supply of wild-caught gravid females is quite practicable, but in full-scale commercial production irregularity of supplies caused by seasonal breeding could be critical. This applies particularly to the development of a penaeid rearing operation in the UK. Other countries are directing increasing research effort towards solving this problem, and a recent report by Idyll (1971), which describes the stimulation of ovarian maturation in adult female *Penaeus duorarum*, gives good grounds for optimism.

Disease

The possibility of disease is a constant threat in any system of animal husbandry. With prawns one of the major difficulties in studying disease is to correlate specific, recognizable symptoms with losses which occur in laboratory tanks; another is the spasmodic nature of such occurrences.

The only disease which has so far been characterized has recurred from time to time in laboratory stocks of both *P. serratus* and *P. platyceros* but not in

M. rosenbergii. Infected prawns frequently showed damage to their abdominal appendages, characterized by black areas in the shell surrounded by a zone of reddening. Microscopic examination of the muscle tissue adjacent to this area showed extensive fungal infection. The same symptoms have been observed in P. serratus by Anderson and Conroy (1968), and the occurrence of fungal disease in cultivated penaeid prawns is reported by Cook (1971). At present there are no plans to study prawn diseases at Conway, but records will be kept of mortalities which show recognizable symptoms and in the event of an epidemic a more detailed investigation will be made.

Site selection and construction of ponds and enclosures

In the development of an extensive system of culture, the selection of a suitable site for the construction of ponds or enclosures is pre-eminent. This is primarily an engineering problem about which we are not qualified to comment, and the reader is referred to the work of Allen and Milne (1967) and Milne (1970). Factors which must be considered are the degree of pollution in the selected area and the severity of the climate; thus, in the UK a southerly or westerly site is likely to be more suitable than an easterly situation. Consideration should also be given to the ease with which the culture area could be harvested, and to the likelihood of predator problems.

Food for the juveniles

In extensive culture, food for the growing prawns would be provided by natural productivity, the extent of which would limit yields. These could be increased either by fertilizing the water to increase natural production or by adding supplemental feeds. Fertilization has the disadvantage that the type of natural production it stimulates cannot be controlled; for example, a dense growth of an inedible weed could result. Supplemental feeding is also difficult to control in large water areas and therefore could be wasteful. To increase yields efficiently from extensive culture, greater control must be exercised over the culture area and, as the level of control increases, the transition to intensive culture is made.

In fully intensive culture systems prawns would be fed on prepared diets, since natural productivity would be negligible. In the laboratory fresh foods such as mussels, crabs and shrimps have been found to be very satisfactory and have permitted the maturation and spawning of both P. serratus and M. rosenbergii. However, they have many disadvantages; for example, (1) rapid decomposition may create areas of local deoxygenation; (2) the need for daily preparation from ingredients either obtained fresh each day or stored in freezers; (3) vulnerability of supplies to prevailing weather conditions; and (4) seasonal variation in quality. It is because the use of such foods on a commercial scale would be impracticable that the problems of preparing a compounded formula feed for prawns have been studied at Conway (Forster 1972, Forster and Beard 1972, Forster and Gabbott 1971). Similar studies are also in progress in several other countries, but we know of only two published accounts (Kanazawa et al. 1970, Meyers et al. 1970).

Three aspects of feed formulation were studied at Conway:

1 Tests were made on different binders to prevent the food disintegrating on immersion in water. These showed that a water-stable food could be

prepared in several ways but that some of the preparations reduced the growth of P. serratus juveniles.

2 The ability of P. serratus and P. platyceros to digest and absorb protein and carbohydrate from different common food meal ingredients, e.g. fish meal and soya bean meal, was examined. The results showed that both species could digest the meals very efficiently.

3 Laboratory feeding experiments lasting four weeks were made to evaluate different dietary formulations in terms of prawn growth, using P. serratus juveniles as test animals. The best diet tested consistently gave between 70 and 80 per cent of the growth obtained on fresh mussel, assessed as live-weight gain. A similar result was obtained in an experiment lasting thirteen weeks, in which the prawns grew from 0.067 to 0.990 g.

Further work is required to improve the diet and to test its value to other prawn species, particularly in longer-term experiments over the whole growth range from juvenile to marketable size.

Tank design, stocking density and cannibalism

In an intensive system growing prawns must be maintained in crowded conditions. Although, as yet, we have limited knowledge of the costs involved, it seems that a yield corresponding to about 2 kg per square metre of tank floor, or 200 prawns at 10 g live-weight (approximately 12 cm long), is a realistic target. Yields somewhat higher than this (2.5 kg/m^2) have been achieved on an experimental scale in Japan (Hudinaga 1969).

When prawns are crowded together in the confinement of a laboratory tank they are cannibalistic. Individual prawns are attacked, killed and partially or completely eaten after they have moulted and before their new soft shell has hardened sufficiently to afford protection. In small laboratory tanks with P. serratus and M. rosenbergii this behaviour is related to stocking density, but when prawns are placed in larger tanks at the same stocking density they seem to distribute themselves in such a way that the incidence of cannibalism is reduced (Forster 1970).

Further study is needed on cannibalistic behaviour, which occurs even when the prawns are well fed, and of its relationship to stocking density and tank design (size and shape). It is likely that the tendency towards cannibalism will vary between species, and this will be one of several criteria governing the choice of prawns for intensive farming.

THOUGHTS ON COSTS

Production costs in prawn farming must be considered in relation to the different systems of culture. As previously stated, there are three basically different approaches: (1) extensive or "free range" culture; (2) intensive outdoor culture; and (3) intensive indoor culture. Although it is not yet possible to make accurate assessments of the costs and profitability of these approaches, it is possible to define specific areas requiring expenditure and to speculate on the likely costs and returns involved. The major items are:

1 larval rearing;

2 food - for juveniles from metamorphosis to marketable size;

3 pumping and heating;

4 labour;

5 capital;

6 value of the crop.

There would also be costs of distribution (transport, storage and marketing) but these are not considered in this review.

The relative importance of these items depends on the system of culture adopted. Thus, while larval rearing costs may be similar for all three approaches, food costs will be much higher in intensive than in extensive systems because of the contribution from natural productivity in the latter. Similarly, costs for pumping and heating will apply almost exclusively to intensive systems. Labour requirements and capital expenditure will be major items in any culture operation, but the type of labour required and the capital purchases necessary will vary with the approach adopted. In the following paragraphs we speculate further on the costs of prawn farming in the light of these three approaches.

1 Larval rearing

Larval rearing costs will depend on the species selected, since this governs (1) the length of the larval life and therefore the time for which hatchery culture would be necessary (see Appendix Table 1), and (2) the facility with which larval supplies can be obtained. An indication of the costs involved may be obtained from reports of mass rearing programmes in other countries. In Hawaii Fujimura and Okamoto (1970) cultured M. rosenbergii in 19 000 litre tanks, each stocked with 200 000 larvae, and estimated the cost of producing newly metamorphosed juveniles at £0.79 per 1 000. This figure is based on a larval life lasting 35 days and a survival rate to metamorphosis of 21 per cent. Liao and Huang (1970) quote Shigueno (1969) who gives a cost of £0.43 per 1 000 P. japonicus juveniles in Japan. Liao and Huang (1970) themselves obtained mean survivals to metamorphosis of 25-30 per cent in the culture of six species of penaeids, and estimated production costs at £0.86 per 1 000 juveniles. These figures can only serve as guides to the likely costs of larval rearing in the UK, but a cost of £1.00 per 1 000 juveniles seems a realistic target.

2 Food

Food costs in extensive or "free-range" types of culture would be low because of the contribution from natural production. However, as in the prawn culture systems in Malaysia and the Philippines, described above, yields would be low and higher yields could only be obtained by increasing or supplementing natural production.

For intensive culture total reliance must be placed on prepared diets. Their cost will depend on the price of the ingredients and on the efficiency with which the prawns convert the food into their body tissues. The cost of animal feed in general reflects their protein content and thus the cost of prawn diets will probably be similar to that of certain fish foods, e.g. trout pellets, which cost about £0.10

per kg. Efficiency of conversion in prawns is likely to be somewhat less than in fish since losses occur due to moulting, and values of between 2 and 3 to 1 are anticipated, i.e. 2 or 3 kg of dry food to produce 1 kg live prawns. Food would therefore cost between £0.20 and £0.30 per kg of prawns produced; however, this estimate does not take into account the effect of mortalities which may occur during the growing period.

3 Pumping and heating

Costs for pumping will only be important in intensive culture systems, and for heating only in closed circulation systems. Pumping costs will depend on the water exchange rates that are found to be necessary and this is to be investigated at Conway in connection with studies on closed circulation systems. We believe heating costs should not be excessive, provided that the system is well designed and housed in an insulated building.

4 Labour

In extensive culture systems there would be relatively little routine husbandry since the prawns would, in effect, fend for themselves, but there are likely to be quite heavy demands at certain times for harvesting, for predator control and for structural maintenance of the enclosures. It is difficult to make an estimate of these costs, however, since individual items are likely to vary, depending on the particular features of the culture site.

For intensive culture during developmental and pilot-scale projects, labour costs are likely to be high since maintenance procedures will not be sufficiently routine to permit automation. However, development would allow considerable scope for automation and therefore substantial reduction in labour requirements.

5 Capital

The major item of capital expenditure for extensive culture would be a suitable site. In the UK, suitable coastal situations for the construction of large areas of shallow ponds are scarce and may be expensive. An alternative might be to enclose with barriers certain natural inlets or sheltered bays; however, this would involve considerable engineering difficulties and would be very expensive (Allen and Milne 1967, Milne 1970).

Intensive culture systems would require large tanks and pumps; closed circulation systems would also require an insulated building and heating equipment. Plant of this type would be expensive, but the much higher yield potential of these systems should offset the larger investment involved.

6 Value of the crop

Profitability will depend on the yield from a particular culture operation and on the value of the prawns produced. We have already discussed the yields which might be achieved from different systems, but the market value of prawns in the UK is difficult to assess because it depends on several different factors; these include the size of the prawns, whether they are shelled or whole, their state of preservation (i.e. fresh, frozen, canned or dried), and the flavour and texture of the species in question.

Initial attempts to cultivate prawns commercially should be directed at the highest priced market, which is probably the market for fresh, unshelled prawns. Prices paid may be as high as £2.20 per kg but the demand is likely to be restricted and will almost certainly be subject to seasonal fluctuations. In the longer term, cultured prawns will have to compete with preserved wild-caught prawns used in standard dishes such as prawn cocktails and salads. There is little doubt that, in terms of quality, the cultured product - since it can be supplied fresh - will be highly competitive, but buyers may not be prepared to pay significantly higher prices. An approximate estimate of the price which might be expected, therefore, would be about £1.10 per kg for whole prawns.

Eventually, cultured prawns may be able to compete in the market for the slightly larger crustacean tails which are nowadays sold as scampi*. The prices paid may be rather less than for the cocktail type of prawn but consumption is much higher, and this market may offer the best long-term prospects. This market requires larger prawns - approximately 20 g live-weight - which it should be possible to rear as techniques improve and in view of the growth potential of the species now under consideration. Alternatively, a new market could be created in the UK for large fresh prawns which could be served as a high quality main course dish. Prawns are eaten like this in many countries where natural fisheries for the larger species exist, but in the UK, where there are no large, naturally occurring species, this market would have to be developed.

CONCLUSIONS

In the foregoing paragraphs experimental work at Conway on the culture of three species of prawns has been reviewed and the outstanding problems discussed. Of three different approaches to prawn culture which might be possible in the UK, it is considered that intensive cultivation of fast-growing, tropical prawn species in closed circulation systems has the greatest and most immediate potential, and our current research is directed accordingly. Progress will depend on the intensity of research effort which can be concentrated on specific problems and on the level of developmental effort by interested commercial bodies, but it is likely to be several years yet before the commercial cultivation of prawns in these systems will be profitable.

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APPENDIX 1 Notes on prawn biology and possible species for culture

This appendix summarizes, in Appendix Table 1, information about individual prawn species which may be suitable for one or other of the possible approaches to culture in the UK. It is prefaced by a discussion on differences in two aspects of the biology of Penaeidea and Caridea which are particularly relevant to their possible cultivation.

1 Female penaeid prawns spawn* their eggs directly into the sea prior to hatching. Very large numbers are released and hatch in a few hours as nauplius larvae. Female carideans, on the other hand, spawn eggs which immediately become attached to specially adapted appendages beneath the abdomen (tail) where they are incubated before hatching as protozoea or zoea larvae. Sufficient food reserves must be present in caridean eggs to sustain development during incubation and, in consequence, caridean fecundity* is lower than in penaeids (Appendix Table 1). In this respect some Macrobrachium species are exceptional, since they have a fecundity intermediate between the penaeids and other caridea.

These different breeding characteristics have important implications for culture. In experimental work where wild-caught adult breeding stock are used it is easier to handle caridean than penaeid prawns, because identification and transport of egg-bearing caridean females is simple and careful treatment will ensure a supply of healthy larvae. Identification of gravid female penaeids is not so straightforward and experience of workers abroad, e.g. Cook (1969), shows that only about one-third of those selected will release viable eggs, and this usually occurs within 24 hours of capture. If such animals were to be imported into the UK it is likely that the eggs would be spawned during the journey and fail to develop normally. This could possibly be overcome by reducing water temperatures or by anaesthetizing the prawns during transit, but it introduces extra complications. On a commercial scale, penaeid culture would require fewer breeding animals than caridean culture - an important advantage - but this assumes that problems of controlled breeding in penaeids will be solved and that the larvae can be cultured successfully. Evidence from the literature suggests that the latter assumption is reasonable.

2 The tail weight (edible meat + shell) expressed as a percentage of the total weight of Caridea is less than in the Penaeidea; average values are approximately 40 and 60 per cent respectively. This is important because the edible meat yield 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.

These differences between the two prawn groups show two advantages of culturing a penaeid, but other factors must be considered before a selection can be made. These include:

1 growth rate;

2 the ease with which larvae can be obtained and reared;

3 environmental requirements such as temperature, salinity or the need for a substrate in which to burrow (many penaeids burrow into sand or mud in their natural environment); if this should prove an absolute requirement for a particular species, it would greatly complicate the design and maintenance of culture tanks.

Ideally the selection of a prawn for culture should not be restricted to those which are abundant in nature but should consider both well known and lesser known species. In practice, and certainly for initial research, the task is greatly simplified if the choice is limited to common species which can be readily obtained for experimental work. In Appendix Table 1 a number of prawns which meet this requirement and which we consider may have potential for culture are listed, together with some relevant details of their biology.

APPENDIX 2 Explanation of scientific terms used in the text

Artemia (species, Artemia salina) - the brine shrimp - a small branchiopod crustacean adapted to living in temporary bodies of saline water such as salt lakes. In times of drought it lays eggs which are resistant to desiccation and hatch only when remoistened. The newly hatched brine shrimp is called a nauplius and is about 0.6 mm long. The eggs are collected and the nauplii are widely used by aquarists as an extremely convenient live food for fish larvae and other small aquatic species.

BUFFERING CAPACITY - the capacity of a solution to absorb quantities of acid or alkali with only a slight effect on the pH. The pH is a measure of the degree of acidity of a solution.

CLASS - the classification of animal species divides and sub-divides them into increasingly smaller and more closely related groups. The Class Crustacea is one of two classes in the larger group - termed a phylum - Arthropoda. Classes are sub-divided into sub-classes which are further sub-divided into orders. Within an order there are usually a number of sub-divisions called sub-orders, tribes and families, separating eventually into groups of very closely related animals called genera (singular: genus). Within each genus there are a number of individual species. In written accounts of biological work the genus and species names are usually underlined or in italics.

CONVERSION EFFICIENCY - the efficiency with which an animal converts its food into its own body tissues; this is normally expressed as a ratio, weight of food eaten:weight of animal produced. Confusion can be caused since this ratio is sometimes calculated on the basis of weight of fresh or live food fed - containing large amounts of water - and sometimes on the basis of dry foods such as chicken or trout pellets. This point should be checked when referring to animal conversion efficiencies.

EGG-BEARING - after they have spawned, female caridean prawns carry their eggs attached to the abdominal appendages (under the tail) for a period of incubation. In this condition they are said to be egg-bearing, ovigerous or "berried".

FECUNDITY - the ability of a female animal to produce numbers of eggs; thus a "high fecundity" means the production of many eggs.

GENUS - group of closely related animals; see Class.

GONAD - general term used for either ovary or testis.

GRAVID - term used to describe female penaeid prawns which have been fertilized by a male and have fully developed ovaries - liberation or spawning of fertile eggs is imminent. Wild-caught females in this condition provide workers abroad with supplies of larvae for culture work.

HERMAPHRODITE - bisexual, an animal capable of producing both eggs and sperm. A "protandrous hermaphrodite" is one that changes sex, functioning first as a male before becoming a female.

LARVAL-LIFE - the time between hatching from the egg and metamorphosis.

LIVE-WEIGHT - weight of the live animal. For prawns this is determined after they have been netted out of the culture tanks and water clinging to the outside of their shells has been removed with absorbent tissue paper.

NATURAL PRODUCTION - naturally-occurring growth of plants and animals, some of which provides suitable food for the growing prawns.

ORDER - see Class.

PRAWN AND SHRIMP - these terms are used throughout the literature as common names. There is no internationally accepted relationship between these terms and the taxonomic affinities of the animals under consideration, and their use varies at random from country to country. In the UK the term "shrimp" is applied to the pink shrimp Pandalus montagui and the brown sand-dwelling shrimp Crangon vulgaris, while the term "prawn" is applied to the somewhat larger species such as Palaemon serratus and Pandalus borealis. The term "prawn" is used for all species considered in this review.

ROTIFERS - a group of minute aquatic animals which swim and feed by means of a motile ring of hairs called cilia. Brachionus plicatilis is between 0.1 and 0.2 mm in length and is a convenient size for a larval food.

SALINITY - the amount of salts dissolved in sea water; normally expressed on a weight basis as parts per thousand - written $^{o}/oo$.

SCAMPI - a culinary term used in the UK to describe certain dishes made with crustacean tails which are somewhat larger than a normal cocktail-size prawn. In most cases these are the tails of Nephrops norvegicus, otherwise known as the Dublin Bay prawn or the Norway lobster.

SPAWNING - not to be confused with hatching. Spawning is the release of the eggs from the ovary to the outside of the body. Hatching is the escape of the larva from the egg - in penaeids this occurs a few hours after spawning; in carideans the larvae hatch only after incubation of the eggs attached to the female.

SPECIES - the smallest unit of classification; see Class.

SUB-CLASS - see Class.

UNICELLULAR ALGAE - microscopic single-celled plants.

APPENDIX 3 Weights and measures conversion table

In this review all values for weights and measurements have been expressed in metric units. In order to assist readers who are more conversant with British units some conversions are given below:

Lengths

Millimetre (mm)	=	0.1 cm or 0.03937 inches
Centimetre (cm)	=	10 mm or 0.3937 inches (2.540004 cm = 1 inch)
Metre (m)	=	3.2808 feet or 1.0936 yards

Area

Hectare (R) = 10 000 square metres or 2.47105 acres

Weight

Gramme (g)	=	0.035274 ounces (453.59 g = 1 pound)
Kilogramme (kg)	=	1 000 g or 2.2046 pounds (1 000 kg = 0.98420 ton)

Liquid measure

Litre (l) = 1 000 cubic centimetres or 0.26418 gallons
(3.7854 litres = 1 gallon)

Temperature

One degree centigrade, $1^{o}C$ = 1.8^{o} Fahrenheit

APPENDIX TABLE 1 Summary of data on some prawn species which have been and are being considered for culture at Conway. NR = not recorded

Species	Fecundity	Approximate length of larval life in culture (days)	Growth rate from metamorphosis		Approximate maximum weight (g)	Temperatures suitable for culture (^{o}C)	Habitat O ≡ offshore I ≡ inshore E ≡ estuarine F ≡ fresh water (rivers)		
			Cultured	Wild			Larvae	Juveniles	Adults
TEMPERATE WATER									
Penaeidea									
Hymenopenaeus mülleri Camaro serro Langostino	NR	NR	NR	NR	> 40	9–20 (range in natural habitat)	NR	I	I
Caridea									
Palaemon serratus Common prawn	1 500– 4 000	19–30	3 g in 9 months (laboratory)	3 g in 15 months	12	15–24	I	I	I
Pandalus platyceros Spot prawn	1 400– 3 200	15–29	5 g in 6 months (laboratory)	7 g in 12 months	> 30	10–19	O	I	O
WARM WATER									
Penaeidea									
Penaeus japonicus Kuruma prawn	100 000– 1 200 000	7–10	15 g in 5 months (ponds)	20 g in 6 months	> 100	25–28	O	I	O
Penaeus indicus Indian prawn	68 000– 731 000	NR	NR	22 g in 12 months	> 100	23–33 (range in natural habitat)	O	IE	O

Species	Fecundity	Approximate length of larval life in culture (days)	Growth rate from metamorphosis		Approximate maximum weight (g)	Temperatures suitable for culture (°C)	Habitat O ≡ offshore I ≡ inshore E ≡ estuarine F ≡ fresh water (rivers)		
			Cultured	Wild			Larvae	Juveniles	Adults
Penaeus monodon Sugpo Jumbo tiger prawn	300 000	9-12	22 g in 6 months (ponds)	NR	> 100	21-35	O	IE	O
Penaeus orientalis Pok	NR	21	30 g in 4 months (ponds)	40-50 g in 6 months	> 50	20-27	I	IE	I
Penaeus aztecus Brown shrimp	NR	12	7 g in 3 months (laboratory, Conway)	NR	> 70	20-30	O	IE	O
Penaeus duorarum Pink shrimp	NR	15	NR	20 g in 12 months	> 100	20-30	O	IE	O
Penaeus setiferus White shrimp	500 000- 1 000 000	10-12	30 g in 12 months (ponds)	20 g in 6 months	> 70	20-30	O	Mainly E	O
Penaeus kerathurus Caramote	800 000- 1 300 000	14	NR	NR	> 50	15-23 (range in natural habitat)	O	I	O
Caridea									
Macrobrachium rosenbergii Giant freshwater prawn	10 000- 100 000	24-35 (variable)	60 g in 6 months (ponds), 3 g in 3 months (laboratory, Conway)	NR	> 100	22-35	E	F	E

APPENDIX TABLE 1 (continued)

Species	Occurrence - areas where most abundant	Notes	Reference number (see pages 18-22)
TEMPERATE WATER			
Penaeidea			
Hymenopenaeus müller Camaro serro Langostino	Western South America	Little information available. We assume that it has high fecundity like other penaeids	35, 5, 4
Caridea			
Palaemon serratus Common prawn	Mediterranean, and also on the Atlantic coasts of Europe	It is largely the slow growth of this prawn which makes its commercial culture in the UK unlikely to succeed	42, 15, 51
Pandalus platyceros Spot prawn	Northern Pacific	Good growth and survival achieved in culture, but it has a low fecundity and has not been bred in captivity	9, 52
WARM WATER			
Penaeidea			
Penaeus japonicus Kuruma prawn	Tropical and sub-tropical, Indopacific. Particularly common in Japan	Biology well documented. Various attempts to culture this species following Japanese methods are being made throughout the world	22, 21, 27, 47
Penaeus indicus Indian prawn	Tropical and sub-tropical, Indopacific	Tends not to burrow. No detailed published results of its culture	20, 41, 36

Species	Occurrence - areas where most abundant	Notes	Reference number (see pages 18-22)
Penaeus monodon Sugpo Jumbo tiger prawn	Tropical and sub-tropical, Indopacific. Particularly common in the Philippines	Tends not to burrow. Fecundity may well exceed reported figure of 300 000.	13, 10, 27, 37
Penaeus orientalis Pok	China and Korea	Growth rate appears particularly rapid. Adults may need a sandy substrate in which to burrow	26, 38-40
Penaeus aztecus* Brown shrimp	Widely distributed in and about the Gulf of Mexico	Fecundity and growth probably similar to P. setiferus	14
Penaeus duorarum* Pink shrimp	Similar to P. aztecus but also found in Western Africa	Fecundity and growth probably similar to P. setiferus	14, 6
Penaeus setiferus* White shrimp	Similar to P. aztecus	Juveniles prefer low salinity 'nursery' grounds. Considered less hardy than P. aztecus and P. duorarum	24, 6, 28
Penaeus kerathurus Caramote	Mediterranean	Experimental culture of larvae and juveniles is just beginning in southern Europe	45, 32
Caridea			
Macrobrachium rosenbergii Giant freshwater prawn	Tropical and sub-tropical, Indopacific region - inhabiting fresh water	Maturation, spawning and hatching of viable larvae in the laboratory is now routine. The very fast growth, 60 g in 6 months, has been achieved by Ling 1969a, but not by other authors	29, 30, 19, 52

*All three species are fished commercially in the Gulf of Mexico and are receiving attention for culture in the United States.

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NOTE

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