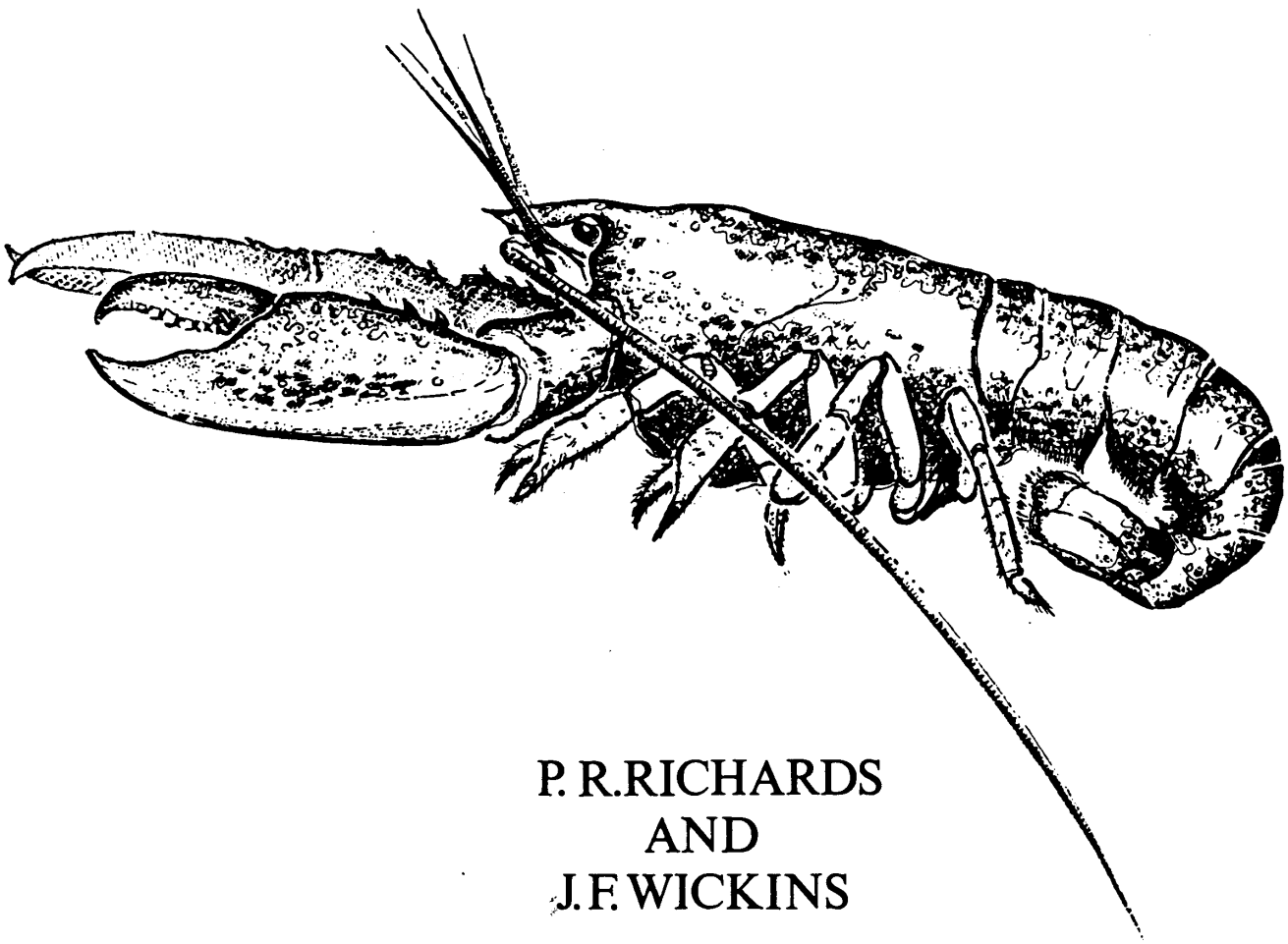
ISSN 0072-6699

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

MINISTRY OF AGRICULTURE,
FISHERIES AND FOOD

LOBSTER CULTURE RESEARCH



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AND
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LABORATORY LEAFLET No. 47

LOWESTOFT

1979

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Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft (47) 33 pp.

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Laboratory Leaflet Number 47

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, LOBSTER CULTURE RESEARCH

by P. R. Richards and J. F. Wickins

1. INTRODUCTION

A research programme to study the intensive culture of lobsters in indoor recirculation systems was started at the Fisheries Experiment Station at Conwy in 1973, aided by a three-year grant from the Honourable Company of Fishmongers.

The biology of the lobster, the native lobster fishery in the United Kingdom, and the place of lobster culture, are discussed in Section 2 of this leaflet. Section 3 outlines the techniques developed for brood stock maintenance and juvenile supply and presents the results of experiments on several of the environmental and nutritional factors affecting growth and survival. Section 4 describes the pilot plant culture system set up in 1977 under further sponsorship from the Fishmongers' Company to study the year-round production of juveniles and the husbandry of individually held animals; this Section also includes some comments on the major costs and the problems yet to be solved before the economic feasibility of lobster culture can be fully assessed.

2. BACKGROUND INFORMATION

2.1 Lobster biology

The lobster belongs to a large class of invertebrate organisms called the Crustacea. Most crustaceans are marine but there are many freshwater types and a few terrestrial representatives. The class is divided into a number of sub-classes of which one, the Malacostraca, contains most of the commercially important species including the lobster (Table 1). There are two species of lobster: Homarus americanus, the American lobster, is found on the Atlantic coast of North America and Canada; Homarus gammarus, the European lobster, occurs in the eastern Atlantic waters from the Arctic Circle to Morocco and into the Mediterranean, with its centre of distribution the British Isles.

The external features of the lobster are shown in Figure 1. Features of the life history are summarised here; details are to be found in Taylor (1975). The female lobster reaches sexual maturity at 5 or 6 years of age, at a carapace length of 75-80 mm, and the male at a slightly smaller size. Mating usually occurs between a hard-shelled male and a soft, newly-moulted, female. Spawning usually occurs in the summer and the female is then said to be 'in berry'. The eggs are carried underneath the abdomen for up to 12 months and their colour changes from olive green through black to red as the embryo develops and the yolk is used up. Hatching occurs at night and the larvae swim to the surface and prey on small zooplankton. Around

Table 1 The taxonomic relationship of the lobster to some other commercially-important crustaceans

Subclass	Malacostraca		
Order	Decapoda		
Suborder	Reptantia		Natantia - shrimps and prawns
		Anomura - squat lobsters	
Section	Macrura	Brachyura - crabs	

includes: (American and European lobsters, Homarus spp;
(Spiny and rock lobsters, e.g. Panilurus spp;
(Freshwater crayfish, e.g. Austropotamobius spp;
('Scampi' Nephrops norvegicus.

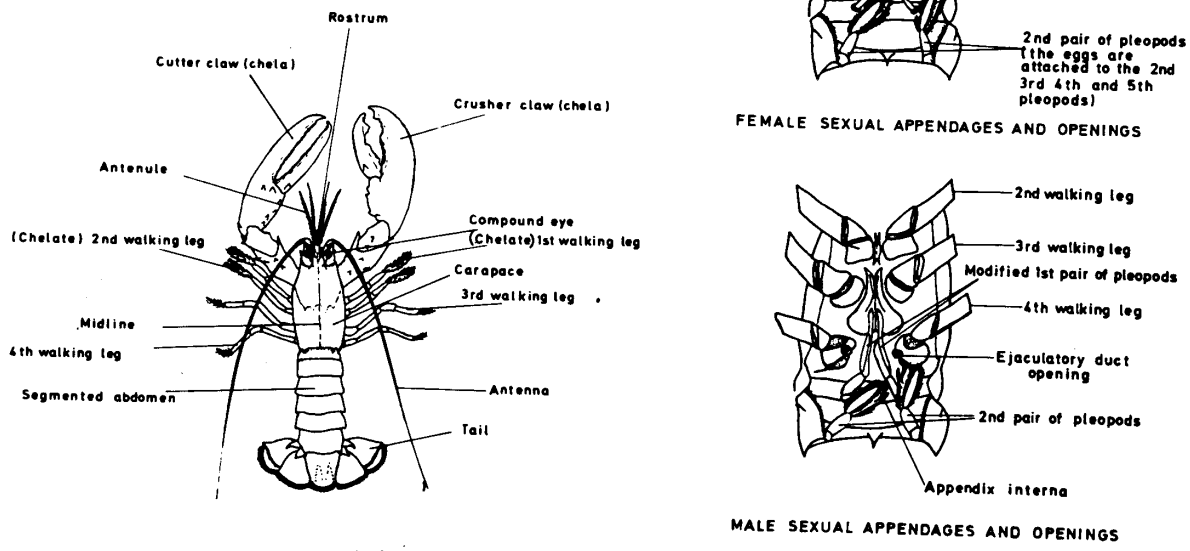

Figure 1 The major external features of the lobster, Homarus gammarus.

the British Isles larval life lasts 15 to 35 days during which the larvae moult 3 times to reach the fourth stage (Figure 2). At the third moult there is a marked change in shape and habit as the young lobsters seek a suitable substrate and settle down to a benthic existence.

Little is known of the diet or habits of juvenile lobsters below about 10 cm total length as these are rarely found in the wild (Bennett and Howard, 1978). It

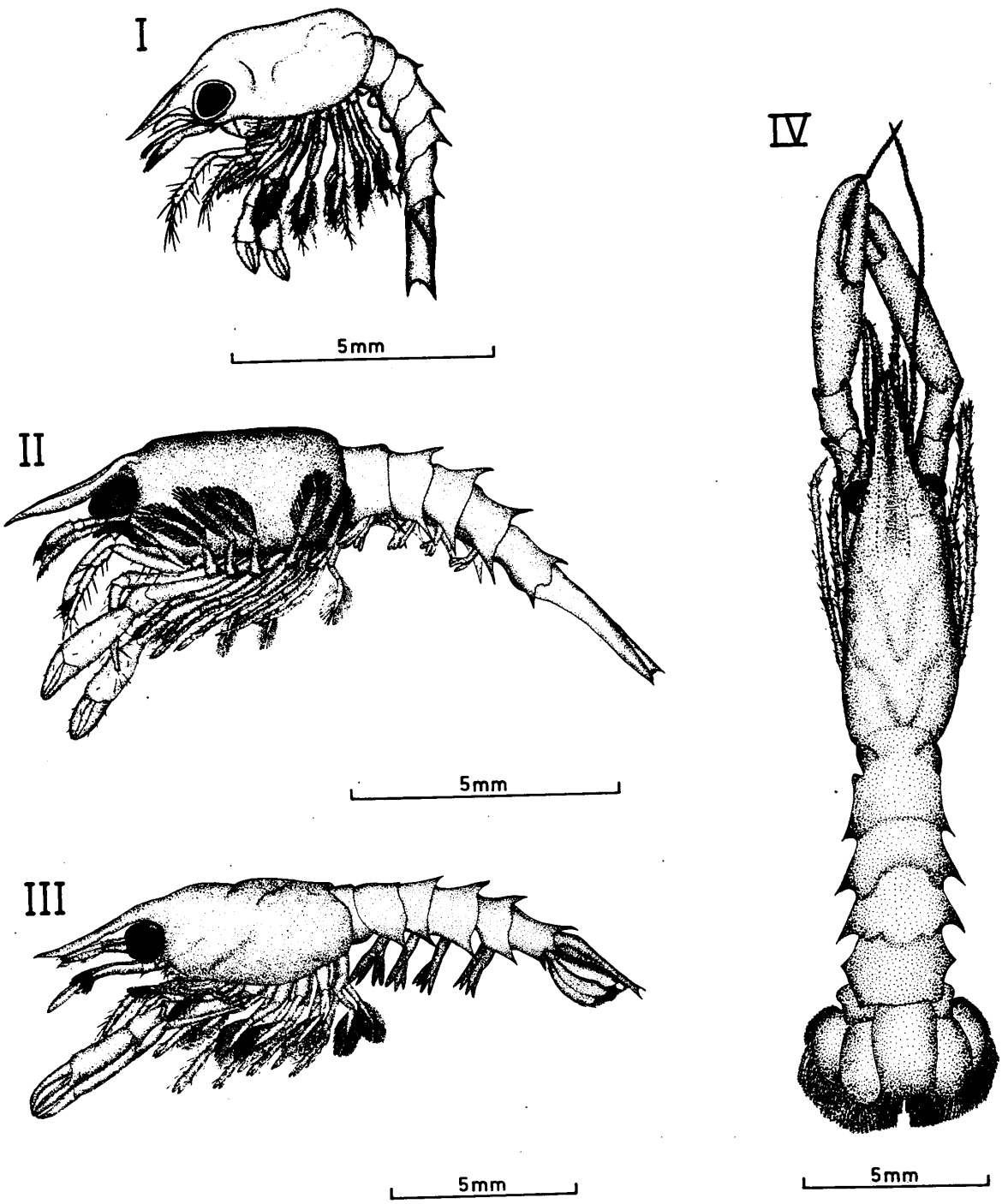

Figure 2 The four larval (free swimming) stages of the lobster, Homarus gammarus. (After Nichols and Lawton, 1978; reproduced by kind permission of the International Council for the Exploration of the Sea).

has been suggested that they may inhabit areas with a different topography to that favoured by the adult.

Larger lobsters are usually found on rocky areas of the sea bed down to depths of 100 m or more, and tend to be most abundant where there are many crevices and shelters. Sandy areas may be colonised if there are suitable rocks and stones under which the lobster can burrow (Berrill, 1974; Dybern, 1973).

Lobsters are primarily nocturnal animals and emerge from cover as darkness falls to forage for food and new shelter, before returning when the light level starts to increase. The adult lobster is carnivorous and eats a wide variety of marine organisms. Stomach analyses have shown the presence of crabs, molluscs, polychaete worms, starfish and fish (Blegvad, 1914; Weiss, 1970). They are not typically gregarious, and competition for shelter and territory forms a major part of their behaviour. Fighting and cannibalism occur when they are held communally in confined conditions where the soft, newly-moulted individuals are the most vulnerable. For this reason claw-banding is widely practised, and the mass culture is unfeasible.

As with all crustaceans, lobsters can only grow in length by shedding the hard shell (moulting). At moult, water is absorbed by the body tissues and this causes the lobster to swell and rupture the old shell. After it has freed itself, further swelling occurs and the new shell begins to harden. Hardening is completed within a period of hours, or weeks, depending on the size of the animal. In the period between moults (intermoult period) new body tissue replaces the water absorbed at moulting. At normal sea temperatures the young juvenile may moult every 2 to 3 weeks but the intermoult period gradually increases as the lobster grows. In the first year the lobster may moult ten times, the annual number of moults then decreases over the following 4 to 6 years until marketable size (80 mm carapace length) is reached after 23-26 moults. At each moult the carapace length increases by 10-15% and the total weight by up to 50%. Appendages lost through injury can be regenerated, but this usually affects both the intermoult period and the moult increment. Figure 3 shows a generalised growth diagram for the lobster and demonstrates the decrease in moult frequency and increase in size after each moult when grown at 18-22°C. At normal sea temperatures the intermoult periods are considerably increased. The relationship between the carapace length and live weight is shown in Figure 4.

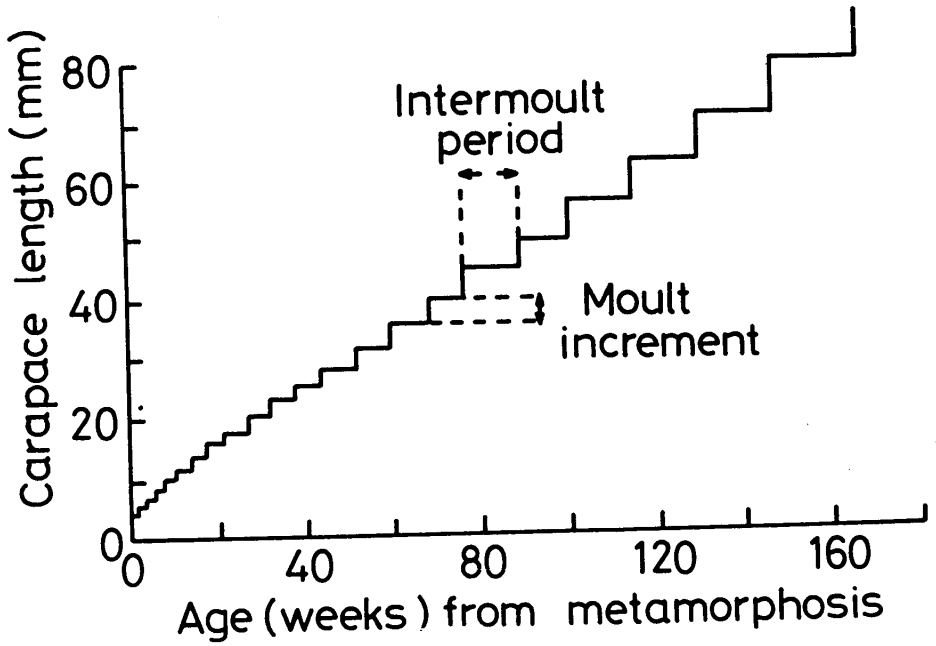

Figure 3 Generalised growth diagram for cultured lobsters, Homarus gammarus.

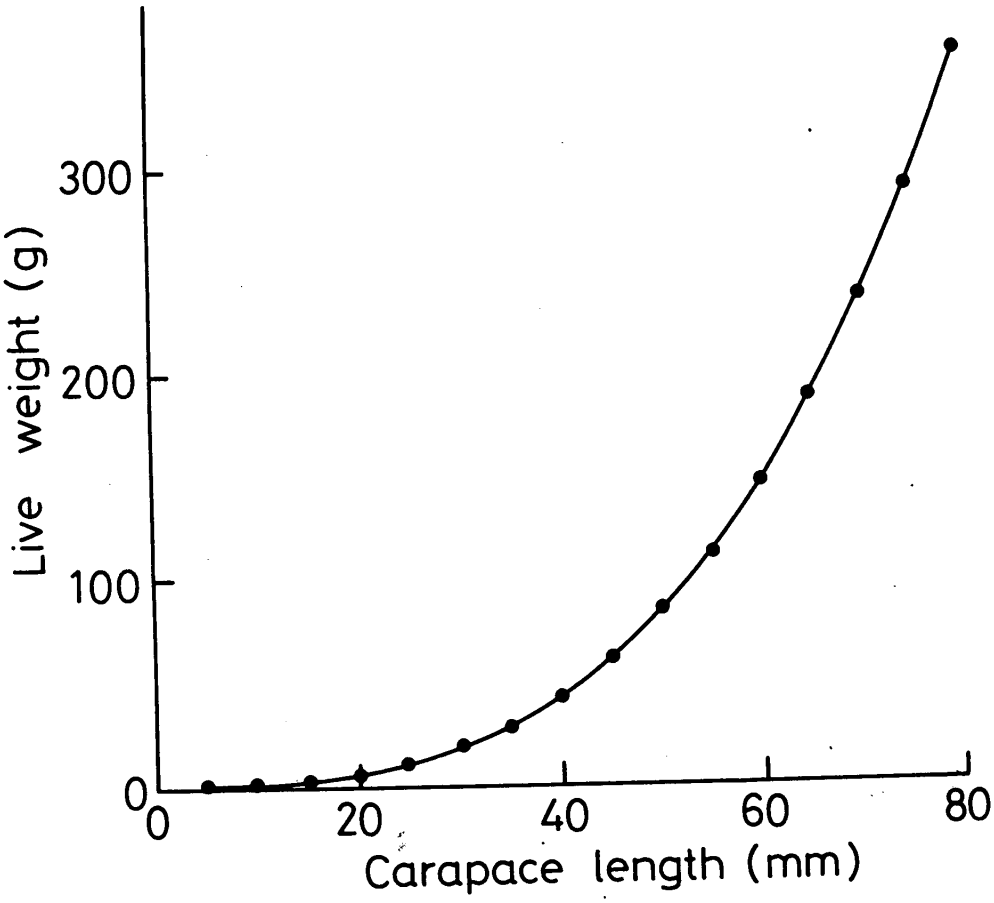

Figure 4 The relationship between carapace length and fresh weight of cultured lobsters, Homarus gammarus.

2.2 The British lobster fishery

The European lobster is one of the most important species of shellfish exploited around the coasts of Great Britain. In 1977 the value of landings (first sale) in England, Wales and Scotland was £3.3 million (MAFF, 1978) and accounted for 15% of the total value of all shellfish landed. They are also our most valuable shellfish export realising, at resale, £6.9 million in 1977 (MAFF Fisheries Statistics Section, Personal Communication); the main export market is France.

Lobsters are caught in baited pots mainly during the months of May to October. The main grounds are off Scotland, north-east England and west Wales. The majority are brought to wholesalers and held in storage pounds to take advantage of seasonal fluctuations in price, and often to accumulate sufficient numbers to supply a consignment. Methods of storage have been described by Ayres and Wood (1977).

Two aspects of the lobster fishery have recently stimulated interest in the possibility of commercial lobster culture:

(a) the decline in lobster stocks indicates that many fisheries are heading for recruitment failure (ICES, 1978);

(b) the value of fresh lobsters on the market is increasing and has reached £9.70/kg (£4.40/lb) for unsorted lobsters (Billingsgate, March 1978)

2.3 The development of lobster culture

In the late nineteenth and early twentieth centuries attempts were made on the east coast of the USA to restock the American lobster. At one time over twenty hatcheries were operating there and in the same period hatcheries were also set up in Norway and some other European countries. In the early hatcheries the eggs were artificially hatched and the larvae released into the sea, while in later developments the larvae were reared to the fourth stage before release. These restocking programmes were not found to significantly improve the fishery, and for this and other political and economic reasons most hatcheries closed down (Kensler, 1970). Only two hatcheries remain operating on a large scale, in the USA and in northern France. At the hatchery on Martha's Vineyard, Massachusetts, USA, egg-bearing females are kept until the eggs hatch and the larvae are reared to the first bottom-living stage before being released into selected areas. In France a project run jointly by the government and professional fishermen rears lobsters to the sixth or seventh stage before they are released into sanctuary areas (ICES, 1978). No information on the outcome of this project is available to the authors.

Another method of increasing the natural productivity of the sea bed is by the provision of artificial 'reefs'. It has long been known that lobsters occur in greatest numbers where the sea bed is rocky, providing crevices and shelter for the lobster population. There have been attempts to attract them to unfavourable areas of flat sand or mud by the provision of large amounts of stone and boulders (Scarratt, 1968) or purpose-built shelters (Sheeky, 1976); these experiments have shown that, while lobsters will occupy these 'reefs', maintaining a population depends on many other factors including food supply and recruitment of young. So far it seems that fishery improvements are unlikely to fill the gap between the natural fishery supply and consumer demand and that an alternative may be provided by commercial lobster culture.

The possibility of more controlled culture operations was stimulated by research carried out at the early lobster hatcheries where it was demonstrated that lobsters could be reared from the egg to a marketable size (350-400 g) under artificial conditions. Early culture techniques were developed in the USA, particularly at the Massachusetts hatchery, and showed that lobsters could be grown to commercial size in 2 years (Hughes, Sullivan and Shleser, 1972). This generated sufficient interest for investigations to begin in the UK with the European lobster. Since then, research into the possibility of intensive culture has greatly increased in the USA and has resulted in the establishment of the first commercial pilot-scale lobster farms.

3. LOBSTER STUDIES AT CONWY

3.1 Juvenile supply

Juveniles were reared for experimental purposes at intervals of three months in January, April, July and October. Female lobsters carrying fertile eggs were purchased from a commercial lobster pound and transported to Conwy in containers filled with damp seaweed to prevent the eggs drying out. The berried females were stored with their claws banded in a communal holding tank supplied with a constant flow of sea water and were fed daily on fresh mussel (Mytilus) flesh. At ambient temperatures (5-15°C) hatching occurred naturally between June and August. More controlled incubation was achieved after selected lobsters were transferred into individual tanks (86 x 48 x 41 cm deep) in a 900 l semi-closed recirculation system (Figure 5). Water was circulated to each tank at 4 l/min and a continuous bleed of 2-3 l/min natural sea water was supplied to the system. An immersion heater was used to heat the water to temperatures up to 12°C above ambient.

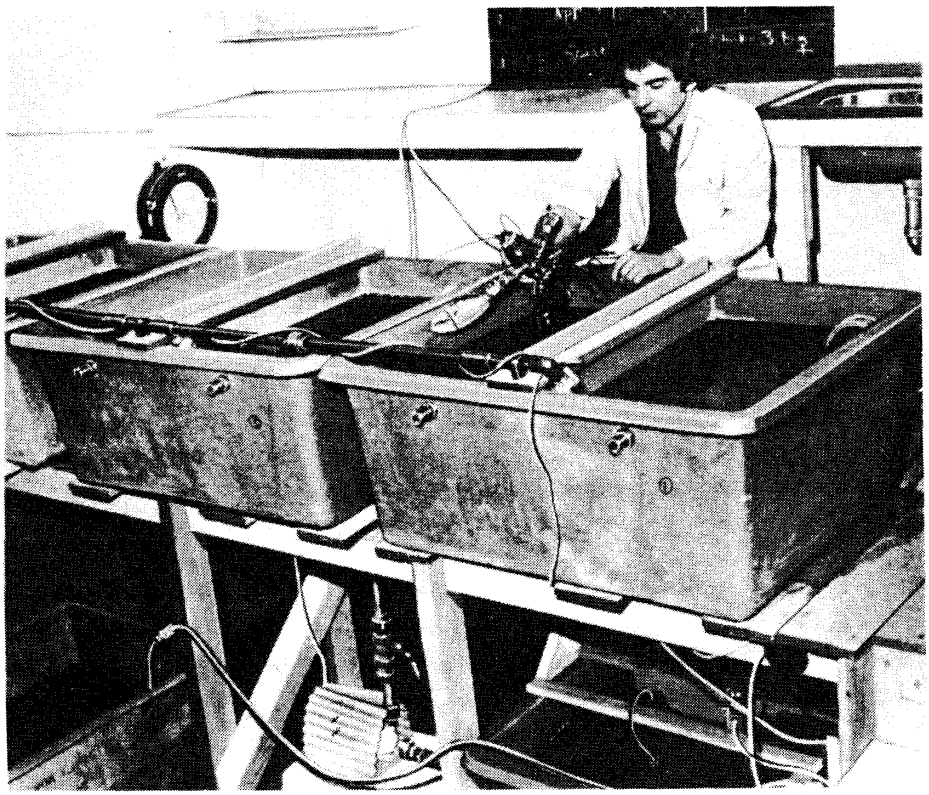

Figure 5 A semi-closed recirculation system for the controlled incubation and hatching of eggs carried by female lobsters, Homarus gammarus. (The submerged biological filter is not visible in the photograph).

The rate of egg development was followed by measuring the increase in size of the embryonic eye on a small sample of eggs, using a low-power microscope fitted with a graduated eyepiece. The relation between the temperature of the water and the weekly increase in the size of the eye, or eye index, of Homarus americanus was first established by Perkins (1972). This enabled him to calculate the time to hatching at temperatures of 10-24°C. The same formula was used as an initial guide to the development of Homarus gammarus:

$$\text{Time to hatch (weeks)} = \frac{\text{Eye index at hatching - initial eye index}}{\text{Increase in eye index each week at the appropriate temperature}}$$

(The eye index is defined as half the sum of the greatest length and breadth of the eye, measured in microns.) The incubation of many broods of H. gammarus at the Conwy laboratory has provided sufficient data to determine the time to hatching from the initial eye index at 13-15°C (Table 2). It should be noted that the eye is not visible for some time after spawning - about 9 weeks at 10°C.

Table 2 The relation between eye index (see text) and incubation period for Homarus gammarus eggs held at 13-15°C

Eye index (microns)	Time to hatch (weeks) ± 2 weeks
50-100	15
100-150	14
150-200	13
200-250	12
250-300	10
300-350	8
350-400	7
400-450	5
450-500	4
500-550	2
Hatch at 600-620	

The timing of larval production involved the regular recording of the eye index of eggs carried by females held at ambient temperature. When accelerated incubation was needed, the females were acclimated to 13-15°C at a time dependent on the eye index and the required hatching date. For example, when the eye index was 250-300, hatching could be induced in 10 weeks by holding the female for that period in water of 13-15°C (Table 2). In this way larvae were produced at all seasons although in winter larval survival tended to be poor.

When the eggs hatched, the larvae were retained in the hatching tanks by a filter screen on the standpipe and netted out each morning for transfer to the larval

rearing system. The average hatch from females of 1-2 kg was 3 500 larvae, some 20-30% of the estimated number of eggs originally spawned. This was mainly due to egg losses under captive conditions, although females were observed to feed on the newly hatched larvae before they swam up to the surface.

Unlike juvenile and adult lobsters the larvae may be reared in mass culture because: (a) a certain amount of mortality due to cannibalism can be tolerated at this stage while still producing sufficient juveniles for ongrowing; (b) individual culture would be a labour-intensive and complicated operation; mass culture simplifies the feeding of large numbers of larvae and probably selects against weak individuals.

Larvae were reared in 40 l fibreglass bins similar to those described by Hughes, Shleser and Tchobanoglous (1974) (Figure 6). Up to six bins were operated on a closed recirculation system (Figure 7). The bins were designed to allow water

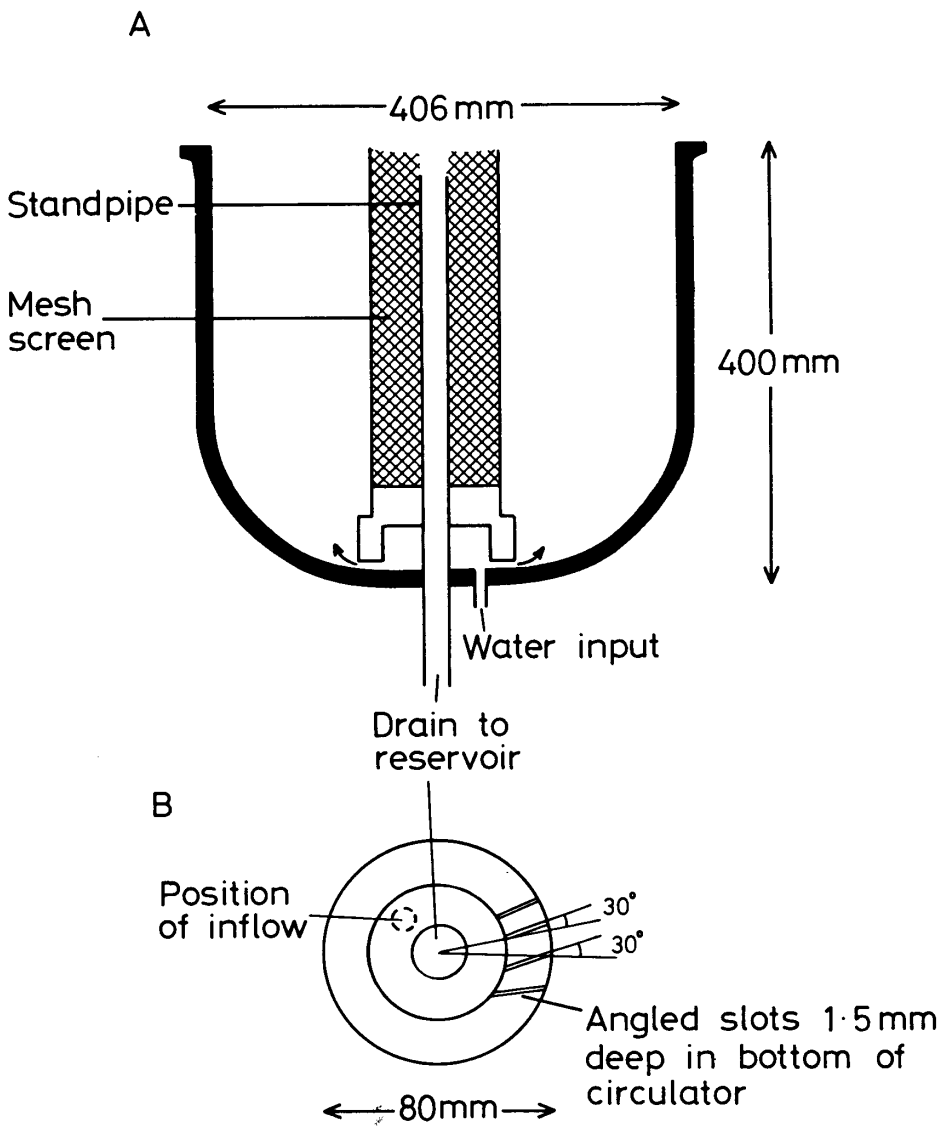

Figure 6 A. Cross-section of larval rearing bin (after Hughes, Shleser and Tchobanoglous, 1974).

B. Detail of circulator.

Figure 7 The closed recirculation larval rearing system used at Conwy.

to be distributed tangentially from a manifold at the bottom of them. This provided a spiral upwelling water flow and kept the larvae and food particles in suspension. A flow rate of 3-4 l/min was supplied to each bin. Big age differences usually resulted in increased cannibalism and thus each bin was stocked with larvae hatched over a period of no more than three days, up to a total of 1 500 larvae. They were fed twice each day on frozen mysids (a small shrimp-like animal 1-2 cm in length), the amount depending upon the age of the larvae. Larvae have been reared on a number of different foods including chopped mussel, but all gave lower survival than did mysids. Live grown Artemia is generally considered to be the best available diet (Hughes, Shleser and Tchobanoglous, 1974) although this was not used at Conwy because the production of sufficient quantities would have taken too much staff time. Deep-frozen mysids provided a simple alternative at the expense of survival. At the optimum temperature of 20-22°C and salinity of 30-34‰ the fourth stage is reached after 11-14 days, with survival rates of 15-20%.

There are still unresolved factors that may have affected larval survival, apart from diet. It is thought that accelerated incubation reduced larval viability, although this has not been tested; it may be better to retard larval development to provide larvae outside the natural hatching period. Effective treatment of water recycled during larval rearing is also important because the heavy feeding necessary to reduce cannibalism resulted in a high and fluctuating organic load on the system. Water treatment is further discussed in Section 4.3. Further research is needed if quantities of good quality larvae are to be obtained at all seasons.

After metamorphosis to the fourth stage, lobsters were removed by handnet each morning and transferred to individual containers 5 x 5 x 9 cm deep, described

in Section 4.2. Some selection of the juveniles was carried out at this stage. Rejection criteria included deformity, lack of chelae and comparatively small size. In general the first larvae to reach stage four were the most suitable. The selected juveniles were fed daily with fresh mussel flesh with a weekly supplement of either mysids or small pieces of the brown shrimp Crangon. Uneaten food was removed each day. Juveniles were held in the individual containers for up to one month before final selection for experimental purposes. During this time most mortality occurred and was between 3 and 62% (average 24%). As only 50-100 juveniles were normally kept from each batch these values are unlikely to be truly representative. At present the reasons for the wide variation in mortality are not known. Variable water quality may have had an effect or there may be an inherent lack of viability in some broods. There was very little mortality (average 3%) among individuals that reached the sixth stage.

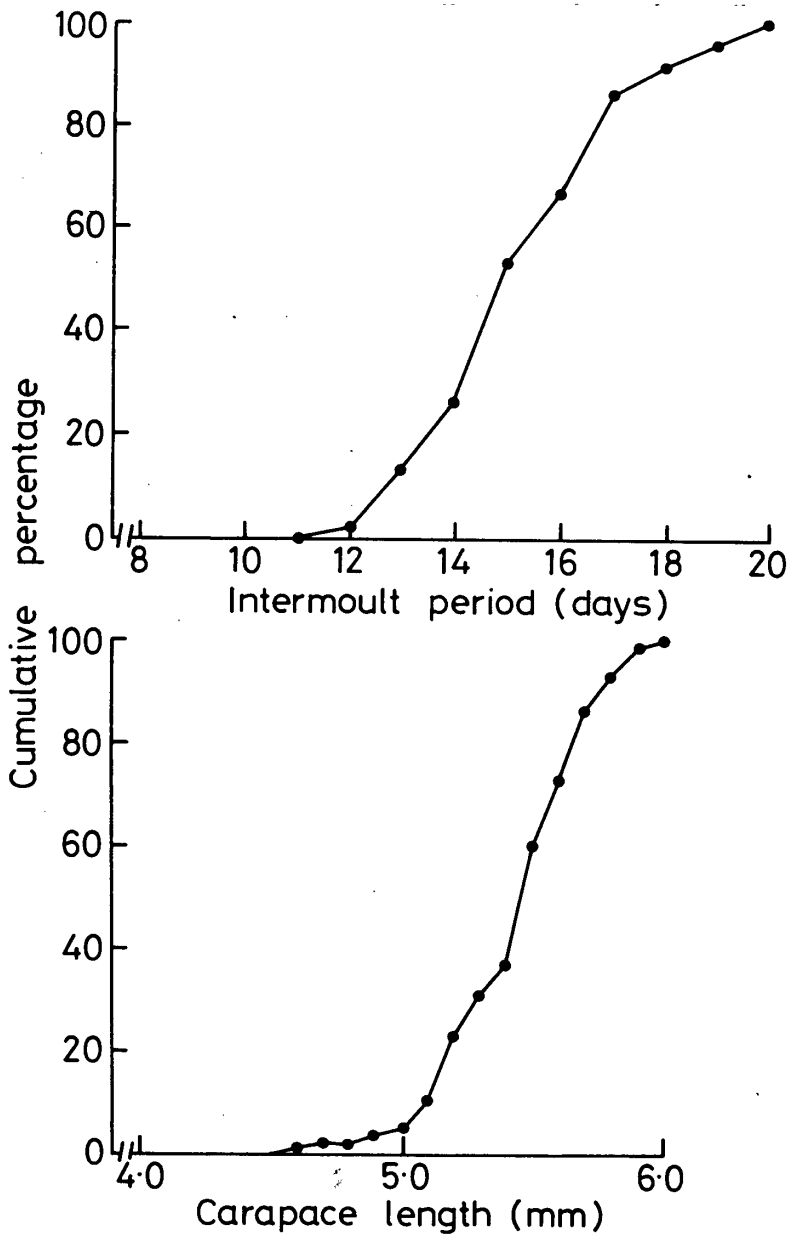

Figure 8 Typical variation in the intermoult period and carapace length among fifth stage juvenile lobsters, Homarus gammarus.

Final section for experimental purposes was based on: (a) successful moulting into the fifth and sixth stages with a full complement of appendages; (b) shortest intermoult period and greatest carapace length. Figure 8 shows a typical variation in intermoult periods and carapace lengths of fifth stage juveniles. Therefore, for example, to select at the sixth stage the 400 fastest growing juveniles from an available 500 (i.e. 80%), rejection criteria would be the 20% with the longest intermoult period (17 days or more) and shortest carapace length (5.2 mm or less).

3.2 Experiments on the growth and survival of juvenile lobsters

Investigations made between 1973 and 1976 helped to determine the effect of various environmental and nutritional factors on the growth and survival of juvenile lobsters up to three months old. In these experiments lobsters were routinely held in 10 x 10 cm individual containers in laboratory recirculation systems similar to those described in Section 4.2, and fed daily on fresh mussel flesh with a weekly supplement of frozen shrimp. From the results of these experiments the conditions found most suitable for the culture of juvenile lobsters were provided for culture through to marketable size in the pilot plant unit described in Section 4.

3.2.1 Temperature and salinity

Juveniles were cultured at four temperatures between 16 and 28°C in combination with five salinity levels between 20 and 36‰. At 28°C survival was poor and the few individuals that did survive at the intermediate salinity levels showed reduced growth. At the lower temperatures survival was much better; at these temperatures the highest yields occurred at salinities of 28 and 32‰. The greatest yield was at temperature 20°C; at both 16 and 24°C the yield was reduced. A statistical analysis (Box, 1956) of the results of the 20 temperature-salinity combinations tested was used to illustrate the overall effect of these two factors and to estimate the effect of other combinations. It is most conveniently expressed in graphical form (Figure 9). Each contour joins points of equal percentage of the

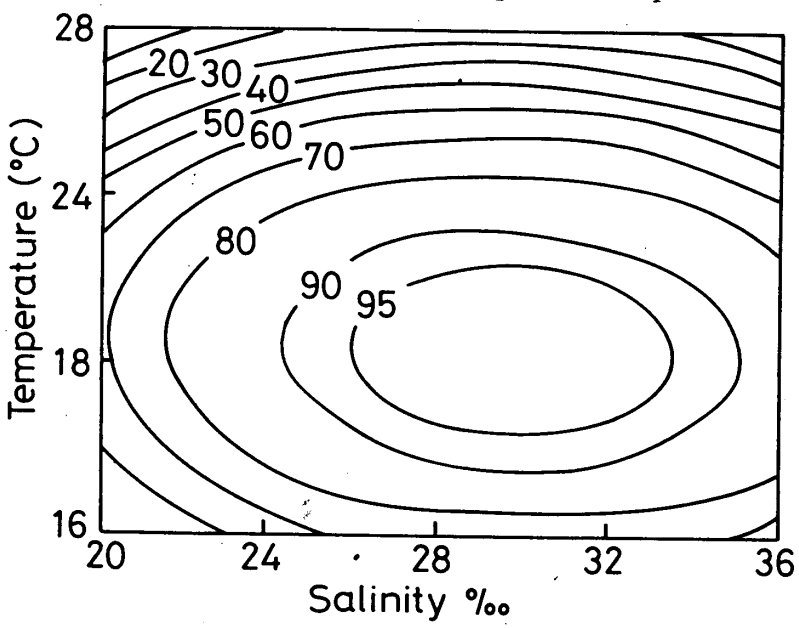

Figure 9 The estimated percentage yield from juvenile lobsters, Homarus gammarus, cultured under various combinations of temperature and salinity.

maximum theoretical yield calculated to occur at 20.8°C/29.8‰. The area inside the 95% yield contour is of most practical importance and encompasses all temperature-salinity combinations that yield in excess of 95% of the maximum. At the optimum temperature of 20.8°C a yield of 95% or more can be achieved with salinities between 26 and 33‰. At the optimum salinity of 29.8‰ similar yields can be achieved at temperatures of 18.5-22°C.

In all subsequent culture trials a temperature of 20-21°C and salinity of 28-32‰ have therefore been maintained.

3.2.2 Container size

In captivity lobsters are cannibalistic at all stages of their life cycle and physical isolation of individuals is necessary to prevent fighting and cannibalism. When cultured in separate compartments the size of each container becomes important. If the containers are too small, growth and survival may be adversely affected; if the containers are too large, space will be wasted. It is therefore desirable to know the minimum amount of space needed to maintain good growth and survival among lobsters of all sizes.

The effect of container size on growth and survival was studied by culturing juvenile lobsters for three months in circular containers ranging in size from 6.6-544 cm^2 floor area. The results are shown in Figure 10. The mean dry weights of the survivors from each size of container was expressed as a percentage of the mean dry weight attained in the largest container which was considered to represent 'unlimited space'. Survival was above 95% in all but the smallest containers. It was found that the smaller final size of lobsters grown in small containers was brought about by a reduced growth rate from an early stage, rather than by a sudden limitation after a period of normal growth. This was an important finding since it indicated that, under our conditions at least, over-zealous

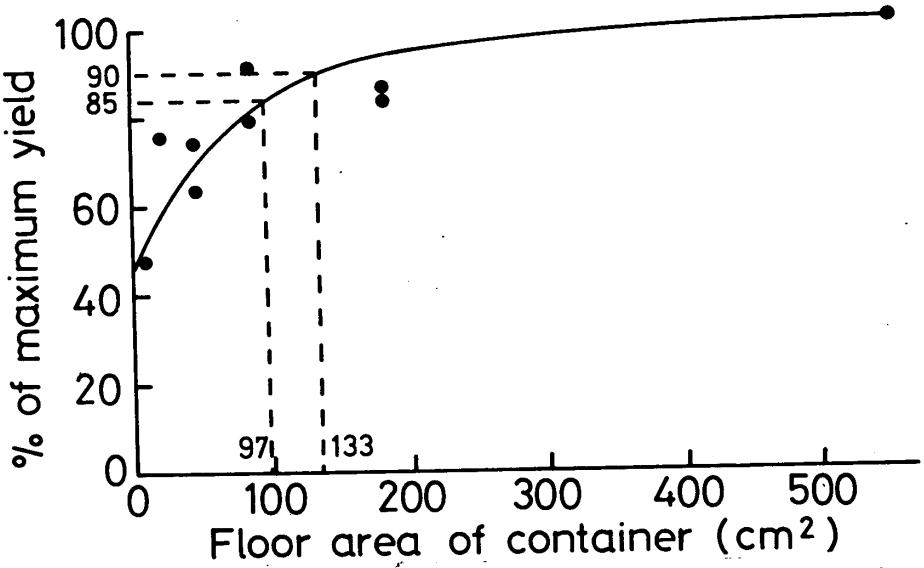

Figure 10 The effect of container size on the growth of juvenile lobsters, Homarus gammarus. The minimum acceptable size range of container for lobster up to three months old was that which gave 85-90% of the maximum yield.

space saving could be a false economy. The estimated 'minimum acceptable size range' of 100-135 cm^2 floor area represents a container size that will give between 85 and 90% of the maximum yield obtained in 'unlimited space' conditions. Smaller containers are unlikely to confer sufficient savings in a commercial system to offset the cost of the increased 'grow-out' time. The shape of the container does not appear to be as critical as the floor area (Shleser, 1974) and for practical purposes squares and rectangles are often more suitable for container fabrication. The minimum area of 100-135 cm^2 can be provided by a square of side 10-11.6 cm. This was approximately twice the total length of a three-month-old lobster and a 'two times the body length' rule was used to estimate the sizes of container suitable for culturing larger lobsters. For example, culture from 3-12 months during which time the total length of the lobster increases from 5-10 cm would require a container size of 20 x 20 cm.

3.2.3 Shelter

Wild lobsters are usually found in some form of shelter, either naturally-occurring crevices or burrows, often beneath and around stones and boulders. In the laboratory, sections of small diameter plastic pipe placed in the individual containers are readily occupied by juvenile lobsters, and when no shelter is available the juvenile occupies the darkest corner of the container. The effect of shelter availability on the growth rate was studied by culturing one group of lobsters provided with hemicylindrical PVC shelters 5 cm long and 1.9 cm diameter, and another group in bare containers. The mean dry weights and survival percentages after 12 weeks growth are shown in Table 3. The faster growth rate of lobsters with shelters was probably the result of several factors including reduced energy expenditure when inside the shelters.

Table 3 The mean dry weight and percentage survival of 20 juvenile lobsters cultured for 12 weeks with and without shelters

Condition	Mean dry weight (mg)	% survival
With shelter	341.6 ± 31.0	100
Without shelter	281.5 ± 29.1	95

$P < 0.05$

3.2.4 Lighting conditions

The culture of lobsters under controlled conditions is necessarily practised indoors. A preliminary experiment was designed to establish whether the lighting conditions affected the growth rate. Juvenile lobsters were cultured for 12 weeks in either constant darkness, constant illumination, or an alternating light-dark regime of 12 hours light and 12 hours dark. The mean dry weights attained and survival percentages are shown in Table 4. The most favourable condition was constant darkness, although the treatment differences were not great. Survival was generally poor. The differences in growth rates may have been caused by differences in the amount of activity of the juveniles. Investigations of the number of walking movements made each hour by juveniles under the three lighting regimes

showed that activity was highest in a 12 h:12 h light-dark regime, and lowest under constant illumination (Figure 11). Constant darkness was presumably most favourable to the basically nocturnal lobster. This experiment demonstrated that growth can be affected by the lighting conditions. Further experiments are needed to determine the optimum combination of photoperiod and light intensity.

Table 4 The mean dry weight and percentage survival of 20 juvenile lobsters cultured for 12 weeks under three different lighting regimes

Condition	Mean dry weight (mg)	% survival
Constant darkness	369.9 ± 36.9	55
Constant illumination	348.6 ± 30.2	70
12 h: 12 h light-dark	338.8 ± 54.8	35

$P > 0.05$

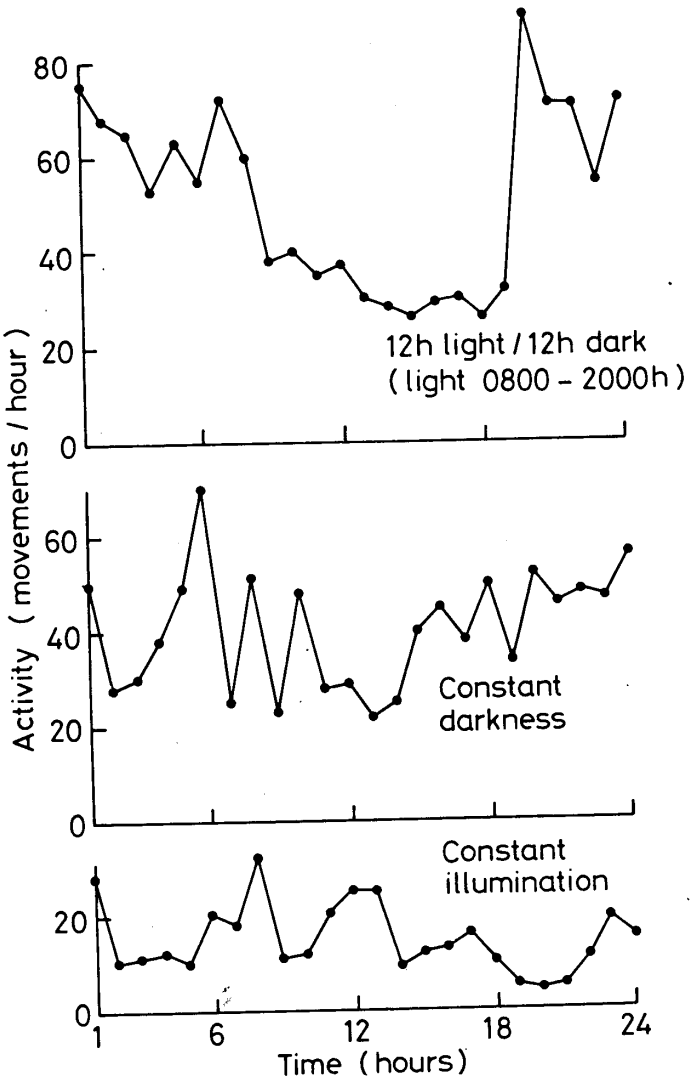

Figure 11 The activity of juvenile lobsters, Homarus gammarus, under three different lighting conditions measured in walking movements each hour.

3.2.5 Nutrition

The future of commercial lobster culture depends to a large extent on the development of an artificial diet able to sustain good growth and survival. It has been observed that the feeding habits of lobsters cultured in individual containers can result in inefficient utilization of the food. To help define the food requirements, the feeding activity and food consumption have been investigated and, in addition, some preliminary dietary studies have been made.

Feeding activity: Electronic recording of feeding times under a natural light-dark regime showed that feeding was normally confined to the first few hours of darkness. It could, however, be induced during the day if the lobsters were kept in a reversed light-dark regime i.e. kept in darkness during daytime and illuminated at night; under constant illumination most feeding occurred during the night. This showed that darkness alone does not determine the time of feeding. Lobsters should therefore be fed before nightfall to coincide with this natural feeding activity. In most of our experiments, however, it was more convenient to feed in the morning. This meant that the nutritive value of the food could have become reduced by the evening due to the leaching of soluble substances and decomposition.

Food consumption: The daily food intake of individual lobsters has been found to be highly variable (J. Munford, personal communication). The amount of food (mussel flesh) eaten each day was measured for 20 lobsters of up to 15 g fresh weight. The average daily consumption over one intermoult period was 3.2% of the body weight, but this could not be used to estimate the daily ration because the daily intake varied through the moult cycle and from animal to animal. In general, the greatest intake occurred at the beginning and at the end of the moult cycle (Figure 12). The relationship between the total amount of food consumed

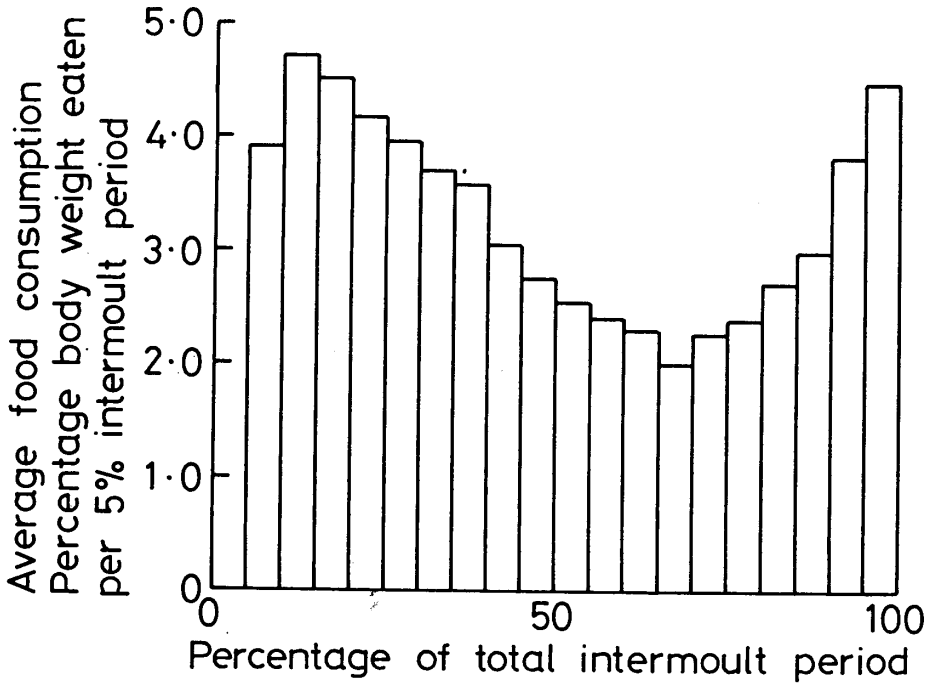

Figure 12 The average food consumption of 20 juvenile lobsters, Homarus gammarus, during one intermoult period.

during one intermoult period and the body weight was

$$\text{total weight eaten} = 1.35 \text{ body weight} - 0.22$$

The maximum daily food intake recorded for any lobster was 13.1% of the body weight, while on some days nothing was eaten. This variation in food intake causes husbandry problems. Feeding at a high enough level to ensure that all individuals have sufficient,leads to considerable wastage of food by those lobsters feeding at lower levels. The results indicate that the number of days on which little food will be consumed increases as the lobster grows and that the intermoult period increases. Unless the amount of uneaten food can be reduced, and methods developed to efficiently remove the waste (at present done manually), this poor food utilisation may be a major problem.

Feeding frequency: Feeding less frequently is one method that has been studied to reduce the amount of food wasted. Juvenile lobsters were cultured under three different feeding regimes: daily feeding, feeding every two days, and feeding every three days. At each feed sufficient food was presented to satiate the lobsters for that day. After 12 weeks the lobsters fed daily had put on the most weight (Table 5), but the weight of those fed every two days was only 9% less. Feeding every three days gave significantly poorer growth. During a similar trial the amount of food consumed under each regime was measured over a 31 day period: the results are shown in Table 6. As expected the amount of food eaten at each feed increased under the less frequent feeding regimes. The food conversion was poorest at daily feeding. These results indicate that although maximum growth will only be achieved when food is continuously available, a small reduction in growth may in some circumstances be offset by the improved food utilisation and reduced labour costs.

Table 5 The mean dry weight and percentage survival of 10 juvenile lobsters cultured for 12 weeks at three feeding regimes

Feeding regime	Mean dry weight (mg)	% survival
Daily	264.7 ± 35.6	80
Every two days	242.3 ± 43.0	80
Every three days	189.7 ± 31.0	90

$P < 0.05$

Table 6 The average amount of food consumed at each feed and food conversion (wet weight basis) of juvenile lobsters over a 31 day period

Feeding regime	The average amount of mussel flesh consumed at each feed as a percentage of the body weight	Food conversion
Daily	20.7	6.2:1
Every two days	26.9	4.6:1
Every three days	42.4	4.5:1

Dietary studies: In the experiments described above lobsters were routinely fed on fresh locally-fished mussels with frozen shrimp provided as a dietary supplement up to twice a week. This diet gave good growth and survival. Fresh foods, however, have a number of disadvantages including:

(i) rapid decomposition which may create areas of local deoxygenation;

(ii) daily preparation from fresh ingredients;

(iii) vulnerability of supplies to the prevailing weather conditions;

(iv) seasonal variation in quality.

As the use of fresh foods is likely to be impracticable on a commercial scale, preliminary studies were made to develop a suitable compounded diet (J. Munford, personal communication). Ten different diets, including some commercial rations, were fed to groups of 15 juvenile lobsters for up to 12 weeks and the growth rates and survivals compared with those of a mussel-fed control group. Survival on four of the diets was very poor and those trials were terminated after six weeks. The yields and percentage survivals on the remaining diets are shown in Table 7. Of the compounded diets the Shigueno prawn diet and the WFA 7 diet gave the best growth but survival was poor. The most promising compounded diets in terms of both growth and survival were the Taiyo and Shiqueno prawn diets and WFA 6, of which WFA 6 was selected for further study because of its availability and known composition.

Various methods of binding the compounded diet were investigated to determine the most suitable form of presentation as judged in terms of reasonable lobster growth, acceptability, water stability, storage and cost. Juvenile lobsters were cultured for up to 12 weeks on WFA 6 bound in five different forms and the yield compared to a control group fed on fresh mussel flesh. The results are shown in Table 8. The best method of feeding WFA 6 was in an agar-bound jelly form. The reduced growth on other preparations was probably due to more rapid breakdown of the diet and loss of nutritive value. Diets bound as a jelly with agar have also been found to be most suitable for culture of the prawn Palaemon serratus (Forster, 1972). However, agar is expensive and requires heating before it can be mixed with the dry meal. This may make it an unsuitable material for a commercial diet, in which case an alternative will be needed. The improvement of an inadequate compounded diet for prawns by providing a fresh food

Table 7 The growth and survival of juvenile lobsters fed on a variety of artificial and natural diets for 12 weeks

Diet	Mean dry weight of survivors as a percentage of the mean dry weight of juveniles fed fresh mussel flesh	% survival
Fresh mussel flesh	100	76.0
Frozen Artemia[1]	106.6	86.7
Shigueno prawn diet[2]	115.4	46.7
Shigueno blend[3]	67.0*	40.0
Taiyo prawn diet[4]	65.1*	86.7
WFA 6[5]	54.9*	66.7
WFA 7[5]	73.8*	33.3

1 Gamma Foods Ltd, Borehamwood, Herts
2 Deshimaru and Shigueno (1972)
3 Shigueno, prawn diet: Kanazawa, prawn diet: β trout diet, 1:2:1 (Deshimaru and Shigueno, 1972; Kanazawa, Shimaya, Kawasati and Kashiwada, 1970; Cooper Nutrition Products.)
4 Taiyo Cyogyo Kaisha Ltd
5 White Fish Authority, turbot diet
* Significantly different from 100%, $P < 0.05$

Table 8 The effect of diet presentation on the growth of juvenile lobsters over a 12 week period

Diet	Binding agent	Mean dry weight of survivors as a percentage of the mean dry weight of juveniles fed fresh mussel flesh	% survival
Mussel flesh	none	100	86.7
WFA 6 pellet	polyvinyl alcohol	33.7	20.0
WFA 6 paste	guar gum	38.8	66.7
WFA 6 jelly	agar	66.9	93.3
WFA 6 flake	agar and carob gum	44.6	86.7
WFA 6 moist pellet	sodium alginate	47.9	60.0

supplement has been demonstrated by Forster and Beard (1972). The same has also been found for juvenile lobsters. In two trials juveniles fed WFA 6 bound as a jelly and provided with a weekly supplement of fresh mussel flesh and frozen shrimp grew at a rate equal to or better than those fed mussel alone. The formulation of WFA 6 as used in these trials is shown in Table 9. With a supplement WFA 6 is a convenient compounded diet for juvenile lobsters. Although nutritional studies have not been exhaustive, lobsters can be grown on a compounded diet and these results provide a platform on which future research can be based.

Table 9 Formulation of WFA 6 as used in culture trials

Ingredient	% dry weight
White fish meal	61.9
Fuji Pro (soybean concentrate)	12.1
Skim milk	9.4
Reclaimed haddock flesh	6.7
Cod liver oil	5.4
Shrimp flour	2.7
Vitamin mix	1.6
Choline chloride	0.2
Dry ingredients bound with 3% agar solution (prepared as a 1% solution in sea water)	

3.2.6 Disease

Mortalities among cultured lobsters during five years of trials at Conwy have in only a few cases been caused by an identifiable disease. A fungus (Fusarium sp.) has been isolated which causes lesions on the exoskeleton, stomach and gills of infected animals; healthy body tissue is not usually affected. Infection is recognised by dark brown areas on the old shell and larger, light brown areas on the new shell, following moulting. As long as the fungus is restricted to the shell the only apparent symptoms are occasional difficulties in moulting and unsightly blemishes, but further infection may lead to death. Dead lobsters have been found with fungal growth completely filling their stomachs. Respiration may also be impaired if the gills are affected. This fungus appears to be slow growing and does not necessarily infect all individuals. The disease is spread by water-borne spores that probably gain entry at a wound.

Gaffkaemia, a usually lethal infection of the haemolymph caused by the bacterium Aerococcus viridans (formerly Gaffkya homari) and possibly the best known of the lobster diseases, has not occurred. The incidence of this disease in natural populations is low, but it can cause heavy mortality among captive lobsters (Sriesko and Taylor, 1947; Wood, 1965).

Further description of the various diseases to which lobsters are susceptible can be found in Sinderman (1970).

3.2.7 The growth rate of captive lobsters

The experiments described above have only provided information on the factors affecting growth during a relatively short period of the lobster's life. To provide an indication of the growth rate over a longer period small numbers of lobsters have been cultured for over 4 years under various conditions at the Conwy laboratory. In these trials lobsters were reared individually on a diet of fresh mussel flesh with a weekly supplement of frozen shrimp or freshly killed crab (Carcinus maenas). The water temperature was maintained at 18-21°C in closed recirculation systems. The growth rate was determined from measurements of the cast shells and the time intervals between moults.

The growth rates of three batches reared in 1973, 1974 and 1975 are shown in Figure 13. Survival was generally poor, but mortalities were often attributable to failure of the water supply. Other mortalities may have been caused by high ammonia and nitrite levels while the biological filters were maturing. In the two oldest batches, individuals attained market size at between 28 and 44 months old (average 36 months) when at the 22nd or 23rd moult stage. As the conditions in which these lobsters were cultured are now known to have been inadequate, further improvements in the growth rate are to be expected.

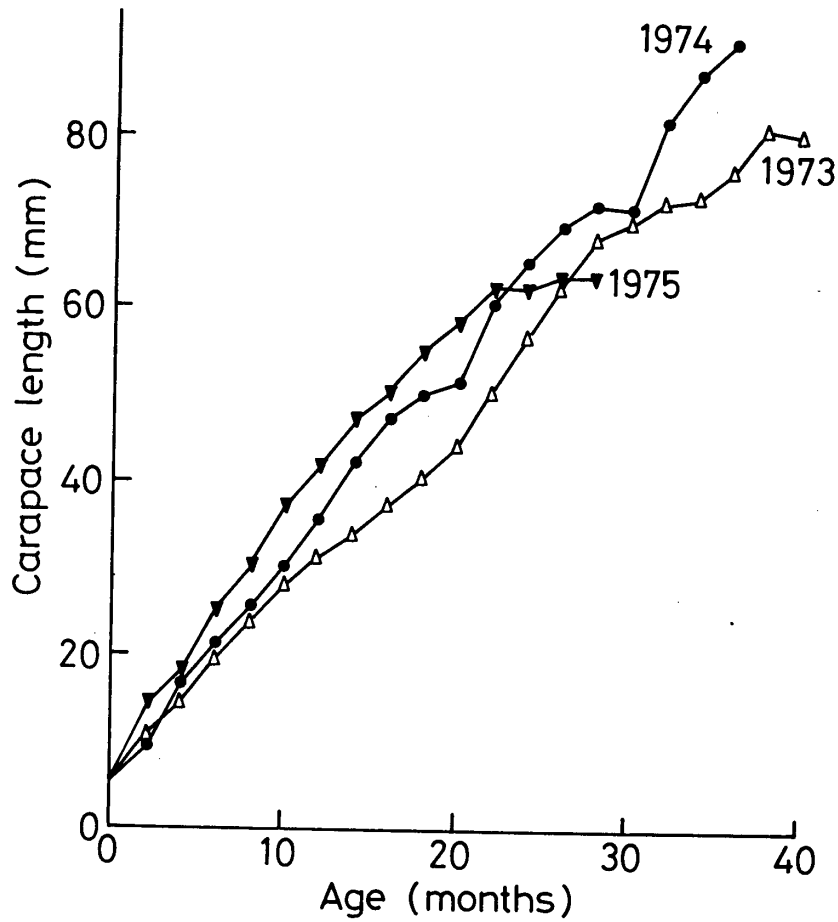

Figure 13 The growth rates of three batches of lobsters, Homarus gammarus, cultured in recirculation systems.

Since Hughes, Sullivan and Shleser (1972), reported that cultured Homarus americanus could reach market size in two years there have been no reports of any large-scale culture operations achieving a similar growth rate. In Table 10 the carapace lengths achieved after 200 days in some recent culture trials are compared (where necessary the average carapace length at 200 days have been estimated from the published results, assuming a linear relation between age and carapace length).

There are many factors that could be responsible for the differences in growth, including water quality, genetic differences and diet, but it seems that a growth rate at which marketable size is reached in 2-2½ years may be achieved under intensive culture conditions with Homarus gammarus.

Table 10 A comparison of the growth rates achieved in some recent lobster culture trials

Species	Author(s)	Carapace length after 200 days (mm)
Homarus americanus	Hughes et al., 1972	26.4
	Hedgecock, Nelson and Shleser, 1976	24.9
	Stewart and Castell, 1976	19.9
	Sastry, 1975	15.6
H. gammarus	Conwy stock reared 1977	21.1

4. PILOT PLANT LOBSTER CULTURE

The information accumulated between 1973 and 1976 was used as a basis for the construction of an experimental unit to study the routine culture of lobsters. The design and management of the pilot plant were based on an estimated growth rate of two years to marketable size and a production target of 50 marketable lobsters every three months. This was estimated to be the maximum sustainable output that could be achieved with the facilities available. The aims of this operation were to study:

(i) the problems associated with broodstock management and the regular production of juveniles;

(ii) the husbandry of individually held animals;

(iii) the effects of recirculation system culture on long-term growth and survival;

(iv) the major cost areas in this form of intensive culture.

4.1 Culture programme

Juvenile production: The methods for broodstock maintenance, control over egg incubation, and larval rearing were as described in Section 3.1. Females carrying eggs at an early stage of development (eye index 150-250) were collected from a commercial lobster pound approximately three months before the required hatching dates of January, April, July and October. The eggs were usually incubated at a temperature of 13-15°C. Some adjustments of the incubation temperature were necessary depending on the availability of females with eggs at the required stage of development. The July hatch was often obtained from females brought in at the end of June with eggs almost ready to hatch and so required no incubation. From each batch, sufficient larvae were reared to provide at least 80 juveniles which were then transferred to individual containers. It was estimated that an initial stock of 80 juveniles would be sufficient to attain the production target of 50 marketable lobsters after allowing for losses due to mortality and selection.

On-growing: For practical reasons it was decided to use four sizes of container during culture to marketable size and the sizes of the individual containers were chosen to make the most efficient use of the materials available. The 'two

times body length' rule described in Section 3.2.2 was used to calculate the size at which lobsters were to be transferred to larger containers and the age at transfer calculated assuming a growth rate at which marketable size is reached in 2 years. However, the largest containers were of a size rather smaller than that appropriate for marketable lobsters of 80 mm carapace length (total length 23 cm) because there was not room to accommodate the total number of lobsters arising from the three-monthly stocking programme in containers of the appropriate size (46 x 46 cm). A reduction in growth rate was therefore to be expected in the final stage.

In detail then, the four on-growing culture stages were:

Stage 1 At least 80 fourth stage juveniles isolated in 5 x 5 x 9 cm deep containers.

Stage 2 After one month, selection of up to 64 juveniles and transfer to 10 x 11.5 x 13 cm deep containers.

Stage 3 After four months, final selection of the 50 fastest growing individuals and transfer to 20 x 23 x 13 cm deep containers.

Stage 4 After twelve months transfer of lobsters to grow-out containers 23 x 46 x 20 cm deep for culture to marketable size.

Diet: Lobsters up to four months old were fed daily on fresh mussel flesh. A supplement of frozen shrimp was given once a week. Older lobsters were fed a portion of whole mussel daily and provided with a twice-weekly shrimp supplement. Each day any uneaten food was removed.

Growth and survival: The first batch of juveniles was stocked into the system in April 1977 and further batches added at approximately three-monthly intervals. The growth and survival of the first six batches are shown in Table 11. Estimated

Table 11 The average carapace lengths (mm) of the first six pilot plant batches after 16-78 weeks. Percentage survival is shown in parentheses. Corresponding sizes at growth rates to reach marketable size in 2 and $2\frac{1}{2}$ years are estimated.

Batch	Starting date	16 weeks	26 weeks	40 weeks	52 weeks	78 weeks
1	5.4.77	13.2 (98)	18.3 (98)	24.7 (98)	30.7 (91)	48.9 (85)
2	30.6.77	13.8 (82)	19.1 (82)	26.0 (80)	33.3 (78)	
3	15.9.77	14.2 (98)	18.9 (98)	28.0 (98)	35.9 (95)	
4	24.1.78	14.5 (100)	20.8 (100)			
5	9.3.78	14.7 (98)	20.3 (98)			
6	13.6.78	13.5 (100)				
$2\frac{1}{2}$ year estimate		13.8	19.6	27.7	34.6	49.8
2 year estimate		16.1	23.4	33.6	42.3	61.2

values are also given for the sizes that need to be reached at each time for 2 and $2\frac{1}{2}$ year grow-out periods to be achieved. Survival was generally good except for

batch 2 which suffered high mortality (18%) during the first 8 weeks growth. Batches 3, 4 and 5 grew faster than the first two batches and are expected to reach marketable size at between 2 and $2\frac{1}{2}$ years. The reason for the improved growth of later batches is not known but may have been due to better control over water quality and improved husbandry techniques.

4.2 Experimental culture systems

The egg incubation and hatching tanks are described with the larval rearing system in Section 3.1.

Individual containers used in the four stages of on-growing were made up in groups for ease of construction and handling. Several groups were arranged in shallow trays supported on a wooden framework at two levels (Figure 14). Trays holding containers for stages 1 and 2 (Figure 15) received water from a water treatment plant separate from but similar to that supplying those for stages 3 and 4.

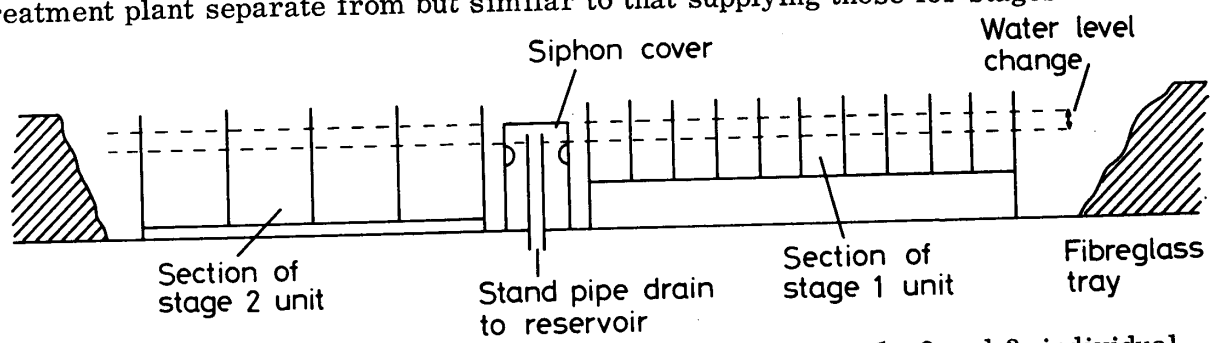

Figure 14 Cross-section of a tray used to hold stages 1, 2 and 3; individual containers, showing automatic siphon device.

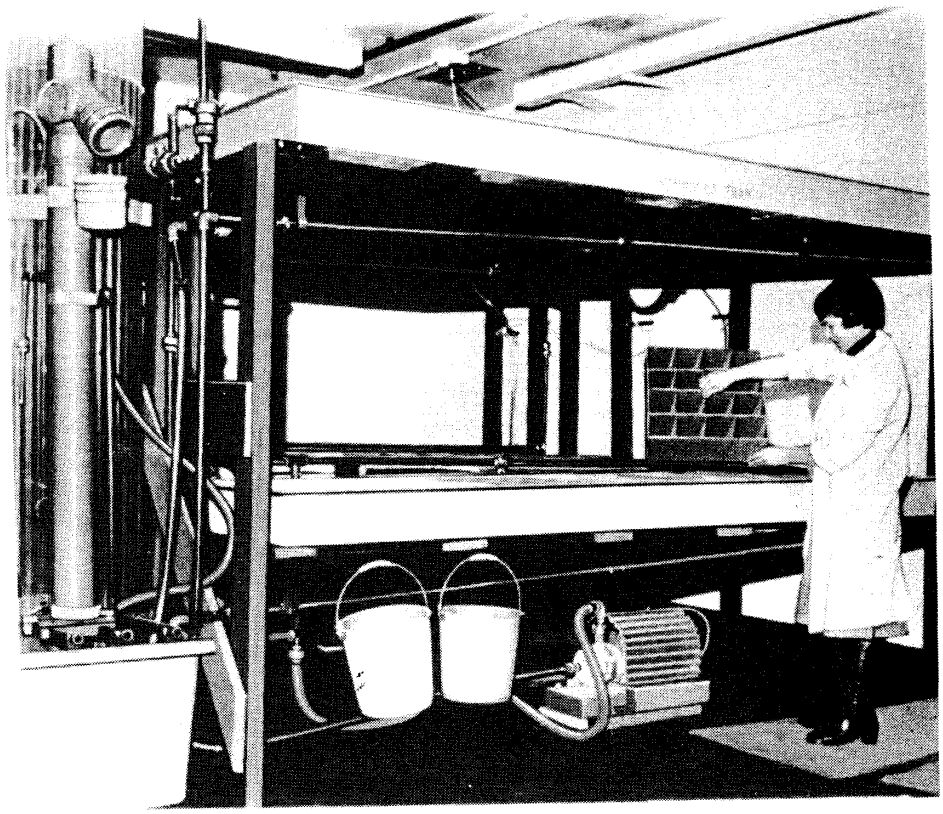

Figure 15 Typical tray system for holding containers for stages 1, 2 and 3 of the on-growing period. The corrugated wall of the percolating biological filter and the foam separation tower can be seen to the left of the tray system.

In Table 12 the dimensions of the containers and trays are shown together with the number of containers within a group. An automatic siphon device operated every 6-8 minutes to produce a regular movement of water within containers for the first three stages. These containers had 2 mm mesh bottoms which allowed good water exchange. An overhead sprinkler system provided water (0.6 l/min) to each of the fourth stage containers. Small spaces beneath the internal partitions allowed the water to pass along the tanks to drain via a central standpipe back to a reservoir. In both systems a proportion (36%) was pumped from the reservoir through a biological filter and foam separation tower while the remainder was recirculated to the tanks.

Table 12 Details of the containers and trays used for the culture of lobsters in the pilot plant at Conwy

On-growing stage	Container dimensions (cm)			No of containers per group	No of groups per tray	No of lobsters per 3-monthly hatch	Minimum and maximum depth of water in each container (cm)	Notes
	Length	Width	Depth					
1	5	5	9	80	up to 4	80	3.8 - 6.4)	Units supported 2-3 cm from
2	11.5	10	13	16	up to 6	64	7.6 - 10.2)	the bottom of trays
3	23	20	13	4	up to 6	50	7.6 - 10.2)	2.94 x 0.51 x 0.15 m deep
4	46	23	20	8	2 or 3	50	constant 25.0	Overhead sprinkler Tray dimensions: 0.91 x 2.74 or 0.91 x 1.82 x 0.30 m deep

Three problems have so far been experienced with this system: (a) some lobsters made holes in the mesh bottom of the third stage containers; (b) there was a gradual accumulation of detritus in the trays which had to be periodically flushed out; (c) some lobsters suffered claw damage in the fourth stage containers, presumably because of injuries inflicted by other lobsters through the spaces below the internal dividers.

4.3 Sea water treatment

The Conwy pilot plant was designed to culture lobsters to marketable size in an indoor closed recirculation system. Such systems have a number of advantages over outdoor and through-flow systems:

(i) optimal conditions for growth can be permanently maintained;

(ii) stock maintenance is greatly simplified and close control is exerted over feeding, harvesting and disease;

(iii) there is less reliance on large quantities of water from natural sources which are always vulnerable to pollution;

(iv) there are no predator or poaching problems;

(v) they are particularly suitable for automation.

A certain amount of replacement water is needed in a closed system. The quantity required determines the major part of the heating costs and depends upon the effectiveness of the methods used to remove soluble materials excreted by the lobsters and leached from the food as well as solid suspended matter, faeces and uneaten food.

Ammonia is the most important toxic waste substance and is produced both by the lobster and many of the micro-organisms that inevitably inhabit a densely

stocked system. Ammonia, normally measured in terms of its nitrogen content, is present in sea water in two forms, an unionised portion (NH_3) which is highly toxic, and an ionised portion (NH_4^+) which is relatively non-toxic. The proportion of each depends mainly on the acidity (pH) of the water, but also on the temperature and salinity; there is approximately ten times more unionised ammonia nitrogen in sea water at pH 8.0 than at pH 7.0. Biological filtration is the most convenient method of ammonia removal in closed systems. Several types of biological filter are used in aquaculture projects but percolating or trickle filters are most favoured at Conwy. These consist of a column of gravel or purpose-made plastic rings which provide an enormous surface area on which nitrifying bacteria grow. These organisms utilise the soluble wastes, particularly ammonia, for their own growth and metabolism. The end products include nitrates which are not harmful to lobsters, except perhaps at high concentrations. Regular dilution with replacement water ensures that nitrate does not accumulate unduly in the Conwy system. During the oxidation of ammonia to nitrate, acid is produced; in the Conwy system this is neutralised by the careful addition of sodium hydroxide solution. In this way the pH is maintained between pH 7.9 and pH 8.0 (Wickins, 1976). Nitrite is a toxic intermediate product of nitrification and harmful levels of it (greater than 1.0 mgN/l) can occur particularly during the initial maturation of a biological filter.

The weight of animals that a filter can support depends on:

(i) the rate of ammonia production by the organisms;

(ii) the maximum permissible concentration of ammonia in the recycled water;

(iii) the rate of nitrification in the filter.

The rate of nitrogen excretion in lobsters is around 0.4 mg total ammonia nitrogen/g body weight per day (see Logan and Epifanio, 1978). In addition ammonia is produced by micro-organisms in the system during the breakdown of solid wastes and soluble compounds leached from the food. The type and quantity of this depends upon the composition of the diet, the efficiency of the binding agent, the time the food remains in the water and the amount left uneaten.

A rough estimate of the amount of ammonia nitrogen that it was necessary to treat in the pilot plant when fresh mussel was used as food was obtained from: (a) the maximum weight of lobsters to be held in the fully stocked system was to be 50 kg; 50 kg of lobsters excrete 50 x 0.4 = 20 g ammonia nitrogen per day; (b) trials showed that when food was given at the rate of 10% of the lobster's body weight/day on average half of this was eaten. Of the remaining half, 80% could be removed manually after 24 hours and 20% was lost within the system. Assuming that all the nitrogen in the 'lost' mussel tissue was converted to ammonia, then some additional 8 g of ammonia nitrogen would be produced.

The nitrogen load on the unit was therefore 20 + 8 = 28 g ammonia nitrogen/day. The maximum level of ammonia nitrogen allowable in the recycled water was 2 mg/l, which at pH 8.2 (the highest pH likely to be encountered) ensured that at 20°C and 30‰ salinity a 'safe' concentration of 0.1 mg/l unionised ammonia nitrogen would not be exceeded (Wickins and Helm, in press). From experience at Conwy, marine percolating filters may reasonably be expected to oxidise 0.3 g ammonia nitrogen/m^2 of surface area per day at input concentrations of 1-2 mgN/l.

Thus $\frac{28}{0.3} = 93.3\ m^2$ of filter surface would be required. The filter built at Conwy was a percolating filter containing slightly more than $0.57\ m^3$ of a plastic filter media with a specific surface area of $164\ m^2/m^3$. The flow through the filter was $95\ 000\ l/m^3$ filter volume per day.

Some settlement of suspended solids took place in the reservoir tanks (900 l capacity) although much was filtered out mechanically by wads of terylene tow which were washed daily. Foam separation towers (Figure 16) helped to remove carbon dioxide from the water and maintained a more stable pH. They also removed some micro-organisms and dissolved and suspended organic matter.

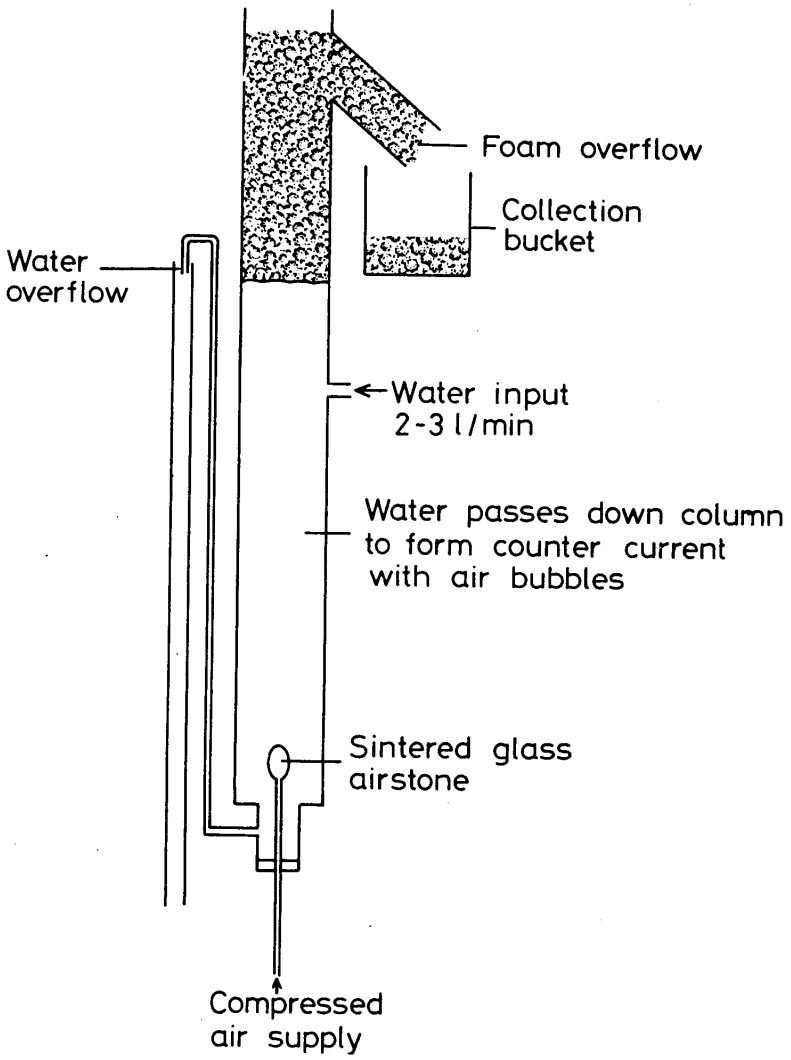

Figure 16 Foam separation tower.

Oxygen levels were maintained at greater than 85% saturation in the individual containers by agitation of the water at various points in the system as well as by water circulation from the foam separators.

Twice weekly 25% of the total system water volume was replaced with sea water from the laboratory supply. This was pretreated by filtration through a

diatomaceous earth pressure filter to remove 90% of the particles above 2.5 microns in diameter. The water was sterilized by ultra-violet irradiation and heated by immersion heater to a temperature of 19-21°C. The salinity was adjusted to 29-32‰ by the addition of either artificial sea salts or tap water. Evaporative losses in the culture system were replaced by the addition of tap water.

4.4 Thoughts on costs

The intensive culture of lobsters will almost certainly be a costly enterprise. This is mainly because individuals must be cultured for a major part of their life in isolation. Mass rearing techniques, which usually involve the provision of large numbers of hides (Van Olst, Carlberg and Ford, 1975), may be feasible for young juveniles up to perhaps two or three months old, but thereafter the low stocking densities required in communal systems are unlikely to be suited to intensive culture. The main cost areas in each part of the operation are briefly discussed below and an attempt is made to extrapolate the data obtained from our pilot plant to the requirements of a larger-scale unit producing 1 000 lobsters each month. The calculations are based on a grow-out period of $2\frac{1}{2}$ years which, judging by the results so far, appears to be a more realistic figure than the original estimate of 2 years on which the Conwy experiments were based.

4.4.1 Juvenile production

The supply and maintenance of berried females and larval rearing took up only a small proportion of the facilities and labour time in the pilot plant unit. Current techniques should allow a production of at least 1 000 juveniles each month to be obtained from the larvae hatched by two females. Thus, with a maximum incubation period of 3-4 months at elevated temperatures, six to eight berried females will need to be maintained at any one time. This could be carried out in a system similar to the 900 l semi-closed recirculation system described in Section 3.1. Rearing the larvae will require up to four culture bins stocked with 1 500 larvae/bin and, with a 20% survival rate to the fourth stage, will yield over 1 000 juveniles, for on-growing. Juvenile production will therefore be a minor part of the culture operation and will only account for a small proportion (2-3%) of the total costs.

4.4.2 On-growing

The most costly part of a culture operation will lie in holding large numbers of on-growing lobsters in individual containers for 2-$2\frac{1}{2}$ years. Major capital items will include a suitably insulated building, manufacture of individual containers and water treatment system; running costs will include heating replacement water, labour, food and pumping.

(a) Space: The amount of space required for a culture unit depends to a large extent on the sizes of the individual containers and it is unlikely that the space requirement for a given size of lobster can be appreciably reduced without adversely affecting the growth rates. There may, however, be economic advantages in using different sizes of container, and corresponding differences in the sizes of the lobsters at transfer from those used at Conwy. The utilisation of the total available space will also be an important aspect. Efficient utilization will depend on the shapes of the individual containers and their arrangement in the holding system. The design will have to take account of the behavioural requirements of the animals

as well as the techniques for feeding, food removal and general maintenance. The pilot plant unit consisted of a simple two-tier system of tanks and trays which allowed enough room (1 m between levels) for easy manual maintenance (Figure 17). Multiple stacking of trays will give a more efficient utilisation of space, but if trays are stacked closer together manual servicing will be more difficult; the trays may need to be moveable, or maintenace automated. Whatever system is used, the manufacture of large numbers of individual holding units will require a substantial capital investment. The estimated area required for a unit producing 1 000 lobsters/month, based on the containers used at Conwy, is shown in Table 13.

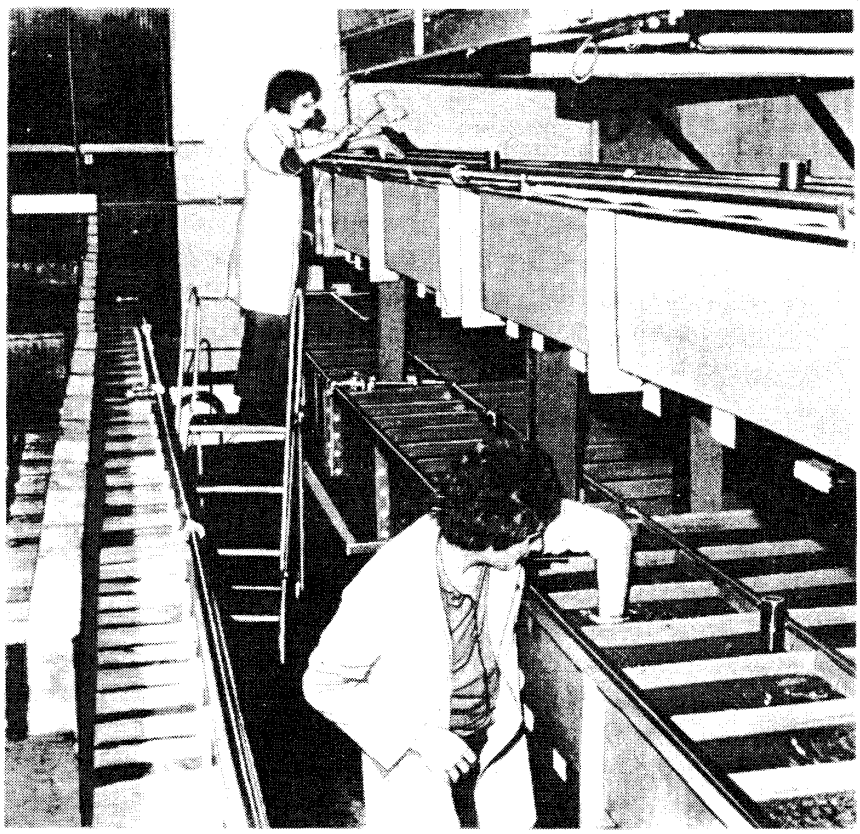

Figure 17 Part of the tank system used at Conwy for the 4th stage (grow-out).

Table 13 Some of the major parameters of intensive lobster culture. Values have been calculated for a unit producing 1 000 marketable lobsters each month assuming a 2½ year growth period and total losses through selection and mortality of 20%

On-growing stage	No of lobsters held at any one time	Area for individual containers (m^2)	Replacement water each week (l)	Manual feeding time per day (h)	Daily food requirement wet weight and dry weight equivalent (kg)	Total weight of lobsters at each stage (kg)
1 (0 - 1 month)	1 234	3.1	306	1.0	0.019 (0.003)	0.197
2 (1 - 4 months)	3 333	38.3	3 360	2.8	0.344 (0.055)	3.44
3 (4 - 12 months)	8 888	408.8	35 088	7.4	5.57 (0.89)	111.4
4 (12 - 30 months)	19 998	2 115.8	282 096	16.7	148.0 (23.7)	3 352.0

(b) Water treatment: The size of the water treatment apparatus for such a unit will depend on further research into water quality. A biological filter of 39.5 m^3 (based on 0.57 m^3/50 kg lobsters) would be required for lobsters in the third and fourth on-growing stages. Data on the type and amount of particulate material likely to be produced in a larger system and using an artificial diet are not available and no reliable estimate can be given of the requirement for mechanical filtration and form separators.

(c) Husbandry and food: The maintenance of large numbers of individually housed animals is at present a labour-intensive operation but, as with any controlled system of animal husbandry, a considerable amount of automation will be possible. Feeding a fresh mussel diet and removal of uneaten food is a particularly time-consuming business and such a method is not envisaged in a commercial unit. As an indication of the time required to feed lobsters by hand, it has been estimated that feeding a suitably prepared diet (e.g. pellets) would take about 1 min/20 animals (Table 13). It is assumed that either self-cleaning tanks will be developed to obviate the need to remove uneaten food, or that the ration size will be reduced. Estimates of the time required for food preparation, water changing and general plant maintenance were not included in Table 13. It is hoped that these will be discussed in another report to be prepared when more information is available.

A suitable compounded diet for lobsters is likely to cost about the same as diets at present used in the intensive culture of other animals such as trout and salmon, i.e. around £300/tonne (1978 price).

Estimates of the food consumption and food conversion have only been made for juvenile lobsters and it is likely that these values overestimate the requirements of larger animals. However, in Section 3.2.5 it was shown that, on a fresh food diet, lobsters up to 15 g live weight consumed an amount of mussel flesh equal to 1.35 x body weight (g) - 0.22 over one intermoult period. This was equivalent to 3.2% body weight/day. On this basis the amount of food consumed up to marketable size would be 3.59 kg. As mussel flesh consists of about 17% dry matter, this represents a food conversion of 1.7:1 (dry weight of food:live weight of lobster). Some food will inevitably be wasted and preliminary results show that juveniles up to about four months old are in practice fed a daily ration of approximately 10% body weight/day, and older lobsters a smaller ration of 5% body weight/day. These values have been used to estimate the daily food requirement for the total number of lobsters held in a unit producing 1 000 lobsters each month, together with the dry weight equivalent (Table 13). The total monthly dry food requirement would therefore be around 740 kg.

The nutrition of lobsters is probably the greatest problem facing commercial lobster culture and it is felt that considerable work has yet to be done before an accurate assessment of the food costs can be made. Some of the factors that must be resolved are:

(i) development of a nutritionally adequate artificial diet that can be easily dispensed;

(ii) determination of ration size and frequency of feeding;

(iii) reduction of food wastage and/or recycling of waste food.

(d) Water replacement: At present large amounts of water are required to replace 50% of the system volume each week, and the cost of heating this water will

be a major cost area in a commercial enterprise. The quantities of water required for a 50% change each week, in a unit producing 1 000 lobsters each month, are shown in Table 13. It is considered, however, that the existing water treatment techniques can be substantially improved so as to reduce the amount of water required, and that heating costs can be reduced by the efficient use of insulation and recovery of heat from waste water.

5. CONCLUSIONS

Reducing the cost of lobster culture depends on further research and development on both biological and technological aspects. The main areas which require study are:

(i) system design for efficient space utilisation and low maintenance;

(ii) development of compounded diets;

(iii) improvement of water treatment techniques;

(iv) control of reproduction and selective breeding.

This report underlines the advances that have been made so far in bringing intensive lobster culture nearer to commercial reality. At this stage the feasibility of culture is unquestionable but it appears in many ways an uneconomic proposition. Results from the pilot plant unit will help in enabling an accurate assessment of the costs to be made. Further progress will depend on the intensity of the research effort which can be concentrated on the main study areas, but it is likely to be several years before cultivation of lobsters in intensive systems becomes profitable.

The reference to proprietary products in this report should not be construed as an official endorsement of these products nor is any critism implied of similar products which have not been mentioned.

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