POTENTIAL FOR COMMUNAL REARING OF THE NEPHROPID LOBSTERS (*Homarus* spp.)[1]

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ABSTRACT

A series of experiments was conducted with American lobsters (*Homarus americanus*) and European lobsters (*Homarus gammarus*) to develop methods to reduce cannibalism among communally-reared juveniles. The primary factors studied were substrate type, stocking density and photoperiod. Other conditions investigated were the effects of different water temperatures, food type, segregating large individuals and claw immobilization. Preliminary studies also were conducted on the effects of shelter density, feeding level and tank area. These studies showed that by the use of vertical substrates, segregating techniques and immobilization of claws, carrying capacity can be increased considerably.

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INTRODUCTION

Nephropid lobsters exhibit territorial and aggressive behavior which often results in cannibalism when reared communally at high densities. Yields from communal rearing are usually low and the juvenile lobsters produced vary considerably in size. Such variation apparently is the result of social interaction among the juveniles held in mass culture, since those maintained in single-animal rearing containers under comparable conditions exhibit much more uniform growth and greater survival. However, communal culture systems are generally less expensive and easier to maintain than those required for individual rearing. Therefore, considerable savings might be realized by using communal rearing for a portion of the culture process.

Information on substrate type, stocking density and feeding levels indicated that survival of lobsters in communal rearing systems is improved when sufficient habitat is provided (Van Olst et al., 1975). However, more information was needed to develop culture systems and techniques which reduce the incidence of agonistic encounters that result in cannibalism, and to produce juveniles of a uniformly large size.

METHODS

Series I Experiments

These experiments were designed to evaluate the effects of several different substrate types and shelter densities on the survival and size range of lobsters cultured communally. All experiments were stocked with stage IV larvae which were fed live or frozen adult brine shrimp (*Artemia salina*) once per day. The total number of juveniles surviving and the mean carapace length, based on measurement of 20 randomly selected individuals, were determined at 30-day intervals for periods from 4 to 6 months.

The substrates tested were large oyster shells, plastic cylinders in random distribution, plastic cylinders in rows oriented 45° to the horizontal, strips of corrugated fiberglass arranged in rows, rubber and bare bottom containers. Another substrate material tested was Monsanto Astro-Turf® Marine Surface made of linear, staggered or alternating patterns of tufts of polyethylene "grass." Another study involved a comparison of tanks with no bottom substrate and those fitted with vertical pegs.

The methods used to evaluate netting substrates, shelter density and feeding level are summarized in Table 1. The netting was stretched over plastic pipe frames in a vertical, horizontal or diagonal pattern. To evaluate the effects of shelter density, the number of plastic cylinders available to each lobster was varied. In a study on feeding level, frozen adult brine shrimp were fed daily at 10 or 20% of the mean lobster wet body weight. To assess the effects of tank area, lobsters were reared at the same relative density in 5 different sizes of circular culture tanks.

The final study in this series was a comparison of growth and survival among juvenile lobsters cultured in 8 levels of horizontally stacked trays divided into quarters or into individual compartments. When introduced, the larvae were able to distribute themselves throughout the multiple layers of trays until they molted and became too large to pass through the netting. This "self-stocking" feature might reduce the labor costs in stocking a commercial facility.

Series II Experiments

A second set of experiments was conducted to evaluate the use of vertical substrates which would allow lobsters to utilize the entire water column for refuge and were easy to maintain and harvest. Conditions of these experiments are summarized in Table 2.

Two vertical substrates were evaluated: plastic cylinders cemented together to provide vertical substrates and horizontally-oriented sections of biological trickle filtration media (BTFM). The latter substrate material is fabricated from polyvinyl chloride sheeting arranged to yield a honeycomb pattern of holes with triangular openings. Replicate tanks were supplied with the vertical substrates to be tested or no substrate, which served as controls. The vertical substrates were compared to a single layer of plastic cylinders oriented 45° to the horizontal on the bottom of the tank.

Lobsters are nocturnal, and photoperiod appears to be a major influence on burrow occupancy, foraging and other behavioral activities in the wild. Exposure of communally-reared lobsters to prolonged light might reduce cannibalistic behavior and conserve energy for procurement of food and defense of shelter. Eight controlled photoperiod regimes were tested, as shown in Table 2.

In the stocking density experiment culture tanks were stocked initially at densities of 21 to 336 stage IV larvae/m^2. In addition, experiments were conducted to compare the effects of ambient vs. elevated temperature, and live vs. frozen Artemia as food. Survival and growth of the American lobster (Homarus americanus) and the European lobster (H. gammarus) also were compared. A final experiment measured the effects of surveys, which may have acted to disturb the lobsters and influence territoriality.

Series III Experiments

Conditions of these experiments are summarized in Table 3. The purpose of the experiments was to test several methods for segregating larger individuals from smaller, subordinate ones. In three separate trials, after 90 days of communal rearing the single largest, 5 largest and all lobsters with a carapace length greater than 20 mm were removed from their respective culture systems after each subsequent monthly survey. Growth and survival of the remaining population was monitored. A related study involved harvest of all juveniles after 3 months of culture and transfer to individual rearing containers where growth was monitored for an additional 3 months. Other lobsters were reared communally or individually for the entire 6-month culture period for comparison. In this manner, growth rates of previously subordinate individuals could be observed in the absence of the inhibitory influence of larger, dominant individuals. Both experiments were replicated in 2.4 m^2 rectangular fiberglass tanks supplied with thermal effluent seawater, using BTFM as substrate and stocking with stage IV larvae at a density of $84/m^2$. The larvae were fed live adult brine shrimp daily and maintained on a natural photoperiod for the 6-month culture period.

Another experiment investigated 2 methods to immobilize the claws and thereby reduce levels of cannibalism. One technique was to remove both chelae. The other involved removing the dactylopodite, the articulated element of the chelae. This study was conducted in 1.3 m^2 circular fiberglass pools supplied with ambient seawater and BTFM substrate. Stage IV larvae were stocked at a density of $185/m^2$, fed frozen adult brine shrimp daily, on a 12:12 light-dark photoperiod, for 6 months. Each system was replicated twice.

RESULTS

Series I Experiments

To increase the carrying capacity, improve waste removal and ease harvesting of communal rearing systems, it is helpful to provide large numbers of shelters which are uniformly arranged. In a preliminary experiment, ordered shelters were compared to standard oyster shell and unoriented cylinder substrates. As shown in Table 1, the greatest survival occurred in the oriented cylinder and corrugated fiberglass substrates. For the 5 substrates tested, the largest average size attained by juvenile lobsters was for those cultured in oriented substrates or on bare bottom.

In subsequent long-term investigation of ordered substrates (Table 1), the largest average size achieved was for lobsters cultured in bare bottom control tanks. Presumably this is a result of feeding more often on other lobsters, as is indicated by the associated low survivorship values. The oriented substrates of cylinders and corrugated fiberglass produced smaller juveniles; however, they produced the greatest number of individual lobsters per unit area. This study demonstrated that an abundance of oriented refuges decreases mortalities resulting from cannibalism among communally-reared lobsters.

An associated experiment was conducted to evaluate plastic artificial grass as an ordered substrate for communal rearing of lobsters. A chi square test showed that survival was significantly greater ($p < 0.05$) in substrates which have considerable space around the plastic blades (types FH-01 and FH-02) for the lobsters to occupy. An analysis of variance showed no significant differences ($p > 0.05$) between the final average carapace length of lobsters cultured in each of the 6 substrates tested. A Freidman rank correlation analysis indicated a significant inverse correlation ($p < 0.05$) between survivorship and mean carapace length. This conclusion is consistent with previous results which indicated that high survival is associated with smaller average size. Low survivorship values after 4 months of communal culture in these substrates indicated that although Astro Turf® has been used successfully in rearing salmonid fry, it probably is not useful in the communal rearing of juvenile lobsters.

A similar experiment was conducted to evaluate the use of vertical pegs as a type of ordered substrate which might be used to prevent cannibalism among communally-reared lobsters. The hypothesis was that larger dominant lobsters would have difficulty pursuing smaller lobsters through a maze of properly spaced vertical pegs, especially when they have their chelae spread widely in a characteristic threat posture, "meral spread" as described by Scrivener (1971). Based on results of a chi square test, the survivorship in the peg substrate was significantly greater ($p < 0.05$) than in the control (Table 1). The peg substrate produced roughly the same final density as has been obtained previously for other substrates such as rock and PVC tubing (Van Olst et al., 1975).

The results of a preliminary study to assess the use of draped netting as a substrate are shown in Table 1. The greatest survivorship per unit area was for lobsters provided with several horizontal layers of netting. In those provided with diagonal or vertical netting, survival was reduced. All groups attained approximately the same average size.

A related experiment was conducted using several layers of trays which were divided into quarters compared to trays divided into 81 smaller compartments. In theory, lobsters in the smaller compartments would have fewer competitors, thereby reducing intraspecific interactions. However, a chi square test showed no significant difference ($p > 0.05$) in survivorship at the end of 4 months of culture. Both systems sustained high mortality rates. A chi square test also was performed to ascertain whether the animals had randomly distributed themselves horizontally within a tray and vertically throughout the multiple stack. The results of the test ($p > 0.05$) showed that neither in the communal nor in the individually compartmentalized stacked trays did juvenile lobsters distribute themselves randomly. Rather, they appeared to be concentrated near the site of introduction. Due to the non-random distribution of the lobsters, it appears that this method of stocking juveniles does not hold significant promise.

The results of preliminary experiments on the number of unoriented cylinder shelters required to give the highest yields of juveniles are shown in Table 1. Increasing the number of shelters beyond 2 per lobster had no apparent effect on survival or size attained at the end of the 6-month culture period.

A similar study was performed in which lobsters were stocked at the same relative density in 5 different size rearing tanks (Table 1). It was conceivable that increased area for the escape of subordinates from attack and cannibalism by larger, dominant lobsters might contribute to increased survival. There appears to be a trend toward higher survival among lobsters cultured communally in tanks of increasing area, but the average size attained is less.

Providing ample quantities of nutritious and readily eaten food is essential in reducing cannibalism among communally reared lobsters. Therefore, we attempted to determine the level of food required to yield the greatest number of juveniles per unit area in order to conserve expensive feeds and avoid fouling of the culture trays. The higher feeding levels resulted in production of slightly larger lobsters, but the size range was undesirably broad (Table 1). Survivorship was reduced for juveniles cultured at the lower feeding level. In this study relatively high feeding levels were employed and observations of the culture tanks revealed that much of the brine shrimp was uneaten. Therefore, it is possible that lower feeding levels would be sufficient.

Series II Experiments

One method of increasing the survival of cannibalistic crustaceans is to expand the available territory used for shelter and foraging. Development of a substrate which could provide the lobster with sufficient shelter to reduce aggressive encounters and yet afford convenient access for cleaning and harvesting is imperative. We evaluated the use of vertical substrates, which would allow juvenile lobsters to occupy refuges throughout the entire water column. A chi square analyses showed that survivorship was significantly greater ($p < 0.05$) in the BTFM than in the other substrates or the controls. The mean carapace length attained by each group at 6 months is shown in Table 2. An analysis of variance showed no significant difference ($p > 0.05$) in their final size. Again, the larger average size in the barren substrate group probably was due to the fact that only a few large dominant animals survived.

From previous work it appeared that a stocking density of $100/m^2$ would provide a suitable density for communal rearing. However, increasing the stocking density might increase survivorship or mean size if sufficiently high numbers of lobsters were present to disrupt behaviors related to the defense of territory. Conversely, lowering stocking density without reducing yields might reduce associated hatchery costs. The results shown in Table 2 indicate that BTFM had a carrying capacity of approximately 31-35 juveniles per m^2 at an age of 6 months, when the initial stocking density was $84/m^2$ or greater. A chi square test showed lower stocking densities resulted in significantly lower yields ($p < 0.05$). A t-test indicated that the mean carapace lengths of each stocking density group were not significantly different. This experiment indicated that a stocking density of approximately $84/m^2$ may be most economical in terms of hatchery costs and yield per unit area.

H. americanus is a nocturnal species, spending the majority of its daylight period in its burrow and venturing forth primarily at night to forage. It is during this nocturnal foraging period that the incidence of intraspecific aggressive encounters increases. Exposure to long periods of light increased survival (Table 2). The results show an increase in survivorship at or above a threshold of 12 hours of light. A chi square test showed that 6-24 hours of light produced significantly higher survival ($p < 0.05$) than conditions of constant dark. This seems to support the hypothesis that the animals remain in their shelters and have a reduced incidence of agonistic encounters during periods of light. A t-test was used to compare the mean carapace lengths of the different photoperiod groups after 6 months of culture. The only significant difference occurred between 24 and 12 hours of light. Although 24 hours of light gave the best survival, it also gave the smallest average size. This reduction in growth rate is probably attributable to reduced levels of foraging activity.

An experiment to compare survivorship of lobsters held communally in ambient and elevated temperature seawater was conducted. Lobsters grown at the two temperatures attained approximately the same final size, yet the survival of those grown at ambient temperatures was significantly less ($p < 0.05$) than for those grown at 22°C in thermal effluent (Table 2).

Due to the high cost of live adult brine shrimp, suitable, less costly foods are needed. Frozen adult brine shrimp are far less expensive than the live form. An experiment was conducted to compare both foods in communal rearing systems, where intraspecific aggression and competition for food occurs. Table 2 gives the final densities and mean carapace lengths obtained after 6 months of culture. Based on chi square and t-test results, no significant differences ($p > 0.05$) in growth rate or survivorship between communally reared lobsters fed live or frozen adult brine shrimp was observed.

In individual rearing experiments, the European lobster (*H. gammarus*) appeared to be more aggressive than the American lobster (*H. americanus*). An experiment was performed to see whether this is also true in communal rearing. At the end of 6 months of culture, there was no significant difference ($p > 0.05$) in size attained (Table 2). Survival of *H. americanus* was significantly greater than for *H. gammarus* ($p < 0.05$), suggesting that the European lobster may be more cannibalistic.

The final experiment in this series measured the effect of survey disturbance on established hierarchies and the degree to which this disturbance influenced rates of cannibalism. After 6 surveys there appeared to be no significant detrimental effects of monthly handling on final size attained ($p > 0.05$); in fact, survival in the non-surveyed group was significantly lower ($p < 0.05$).

Series III Experiments

One potential method to reduce mortalities resulting from cannibalism is to remove the dominant individuals, allowing the previously subordinate ones to accelerate their rates of growth. In the first experiment the largest and presumably the most dominant individuals were removed at each monthly survey during the final 3 months of communal rearing. There were no significant differences in the growth or survival ($p > 0.05$) of groups in which the single largest, 5 largest or all juveniles with a carapace length greater than 20 mm were removed each month (Table 3). During the surveys, an average of 3.4 individuals/m^2 were removed from tanks receiving the first method of segregating, 16.8/m^2 and 10.5/m^2 from tanks receiving the second and third methods. Adding these harvested individuals to the lobsters which remained in communal rearing gives total combined yields of 40.3, 49.9 and 47.4/m^2, respectively for the 3 methods of segregating. This study suggested that the total biomass and the average size of the juveniles from communal rearing systems can be increased if larger, more dominant individuals are repeatedly removed during the final phase of mass culture.

A related study was conducted in which individuals of all sizes resulting from 3 months of communal rearing were held individually to assess subsequent rates of growth. At the end of 6 months of culture, there were no significant differences in size attained among groups reared communally, individually or for those cultured communally for 3 months followed by 3 months of individual rearing (Table 3). Similarly, there were no significant differences in the final densities of lobsters reared communally and then individually compared to those reared communally for the entire 6 months. Both groups showed significantly lower survival than for those grown individually for the entire 6 months. These results showed that a majority of the mortalities occurred during the first 3 months of communal rearing. As indicated by the similarity in final range and mean size attained, the subordinate individuals grew more rapidly when held individually in the absence of dominant pressure; however, isolated dominant individuals grew more slowly. Although the final size range of lobsters produced was narrower, no significant increase in yield was observed.

A study was designed to evaluate 2 methods of immobilizing the claws, which are used during aggressive bouts. Groups of lobsters in which both claws were removed or both dactylopodites severed were compared to communally-reared lobsters having 2 normal, functioning claws. There were no significant differences in final mean size attained by all 3 groups, although those with normal claws were slightly larger (Table 3). Survival per unit area was significantly greater in the 2 groups where the claws were immobilized. The group in which both claws were removed also showed significantly higher survival than for those where only the dactylopodites were severed. In previous communal rearing studies, yields greater than $40/m^2$ were rarely achieved; however, by immobilizing the claws, yields of $76-110/m^2$ were obtained.

One group of communally-reared lobsters was cultured for a total of 16 months, at which time the 5 largest individuals were transferred to individual holding containers. At 24 months these individuals had grown to a mean carapace length of 80.1 mm and an average weight of 404 g. This demonstrates that lobsters can be grown to near marketable size at accelerated rates in systems incorporating a communal rearing phase, but relatively low yields can be expected.

One of the primary deterrents to the communal culture of lobsters is the large variation in size of animals produced. This large size range is usually associated with low survival. The results of our experiments indicated that size range and standard deviation values are lower with BTFM as a substrate. Higher stocking densities, photoperiods between 12-22 hours and removal of chelae also decreased size range. Nevertheless, none compare with the more uniform size of lobsters produced by culture in individual holding containers.

At each survey the number of functional claws was noted. The results are shown in Tables 1-3. The amount of injury indicated by loss of claws was greatest in bare bottom control tanks. There was no definite trend under other experimental conditions. About 10% of the lobsters lost both claws, 15-30% lost one, and the remainder had 2 claws. Segregating the large, dominant individuals resulted in production of few juveniles with no claws and only about 15% with one claw.

DISCUSSION

Communal rearing may have potential for the commercial production of early juvenile stage lobsters prior to their being transferred to individual rearing containers (Carlberg and Van Olst, 1977). During this period relatively high losses due to cannibalism can be expected (Van Olst et al., 1975). However, the use of suitable shelter will reduce the numbers of social encounters that lead to fighting and cannibalism (Shleser and Tchobanoglous, 1974; Van Olst et al., 1975; Aiken and Waddy, 1977). The experiments summarized here investigated many of the components of the communal rearing environment in an attempt to identify and eliminate characteristics of the system which contribute to low survival and variable growth. One important result showed that significantly higher survival and less variable growth resulted from the use of vertical substrates which allowed the lobsters to utilize the entire water column for refuge. However, the use of vertical netting, which has been effective in increasing the carrying capacity of systems for the culture of freshwater shrimp Macrobrachium rosenbergii (Eble et al., 1975), did not prove to be as useful in the communal culture of juvenile lobsters.

Adult lobsters held communally are known to be less aggressive than ones maintained in individual tanks (Dunham, 1972). This suggests that high culture density might inhibit aggressive behavior. A study of the effects of density on the culture of stage IV juvenile lobsters held at densities of 27 and $54/cm^2$ showed no significant effect on survival to the next stage (Sastry and Zeitlin-Hale, 1977). However, there was significantly lower survival among communally held lobsters during the molt period, indicating that mortalities were associated with cannibalism during this vulnerable period. Studies on larger individuals, from 50-60 mm carapace length, showed significantly higher mortality at densities of 16 than at 7 $lobsters/m^2$ (Aiken and Waddy, 1978). Higher stocking densities resulted in increased injury as indicated by loss of claws, and increased cannibalism at molt. Polyculture of lobsters with oysters also resulted in rapid growth and high survival when stocked at relatively low densities (Mitchell, 1975).

These results suggest that manipulation of the environment or physiological conditions controlling molting might reduce mortality associated with cannibalism. Several factors are known to influence the time of molt in lobsters. In the laboratory lobsters were observed to molt during the daylight hours, and did so in a darkened shelter when one was provided (Tamm and Cobb, 1976). Increasing the light period might minimize the nocturnal locomotor activities of foraging and shelter exploration which frequently result in agonistic encounters and cannibalism. In our studies, providing constant light conditions yielded the highest levels of survival. However, in a related study, lobsters grown communally in dense algal cultures which prevented visual contact resulted in lower mortalities and higher growth rate (Hand, 1977). This possibly was caused by the algae influencing any chemical communication that may occur between lobsters.

There are other factors that influence behavior and molting in lobsters. Seawater temperature is one parameter controlling growth rate and thus may be useful in minimizing cannibalism. Previous work has shown that lobsters cultured communally at constant elevated temperatures have grown more rapidly than those reared at ambient temperatures (Ford et al., 1975). Results of these experiments indicated that higher survival is also associated with elevated temperature. It is possible that lobsters cultured at elevated temperatures are more synchronous in molting and therefore fewer cannibalistic attacks take place.

The influence of dominance on competition for limited shelter and food in communal culture has been investigated by several workers (O'Neill, 1974; Cobb and Tamm, 1975). Dominant individuals were observed to occupy shelters while subordinates spent more time outside shelters. The dominant individual fed first and would tend to hoard food. The larger dominant individual also would molt first. However, when the largest animal was in the vulnerable, soft-shell condition, dominance would shift, with the previous subordinate animal adopting dominant behavior until the shell of the larger one hardened. Changes in dominance have been associated with changes in the agonistic behavior of lobsters during the phases of the molt cycle (Tamm and Cobb, 1978). Lobsters were observed to be more aggressive just prior to molting than those in the intermolt period or those having just molted.

A better understanding of the establishment and control of these dominant-subordinate relationships would provide the information necessary to regulate the aggressive behavior and minimize mortalities due to cannibalism. One potential method of reducing the dominant pressure is to remove the larger, more dominant individuals from the culture system periodically. Our results showed that this technique greatly enhanced total biomass production. When held individually, the previously subordinate lobsters displayed accelerated rates of growth. In related work when small, slow-growing and larger, faster-growing individuals were separated, each group established new hierarchies of fast- and slow-growing lobsters (Aiken and Waddy, 1977). Therefore, a net increase in biomass produced was achieved by removal of fast-growing dominants, which resulted in the accelerated growth among the previously slow-growing individuals.

Another method of altering aggressive behavior associated with the establishment of dominance hierarchies is to impede the mechanism mediating this action. The size and number of large chelipeds is important (Cobb and Tamm, 1974). Lobsters with the chelae immobilized by rubber bands grew at a rate equivalent to those held individually at the same relative density ($7/m^2$), with no mortality or injury resulting from cannibalism (Aiken and Waddy, 1978).

However, at higher densities ($16/m^2$), some cannibalism was observed at molt. This banding technique has been evaluated for potential application in holding "canner" size lobsters (200-300 g) through 1-2 molts in order to increase their size and to wait for the most appropriate time for marketing (Castell et al., 1977). Lobsters which had their eyestalks ablated and their claws banded grew more rapidly, but a high incidence of cannibalism occurred at molt.

Related work on the removal of chelipeds or immobilization of the claws by severing the dactylopodite is in progress (Aiken and Young-Lai, 1979). Our preliminary study using these techniques indicated that final harvest densities can be increased by a factor of 3 with only minimal reduction in mean size of the lobsters produced.

An economic analysis of the potential for communal rearing as the intermediate phase in the commercial culture of lobsters indicated that if the initial stocking density were less than approximately $200/m^2$, and yields of $30\text{-}40/m^2$ could be achieved, communal rearing might be more economical than individual rearing (Botsford, 1977). Our studies have shown that lower stocking densities result in reduced yields. However, by using vertical substrates, segregating techniques and immobilization of claws, the carrying capacity can be increased markedly. In addition, the lobsters produced are of a more uniform size. Refinement of these techniques should make the communal rearing of early juvenile lobsters and perhaps later stages, preferable to individual rearing from an economic standpoint.

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Table 1.--A summary of the methods and results for Series I experiments concerning the effects of several different substrate conditions and density factors on growth and survival of communally-reared juvenile lobsters.

Experimental Condition	Period (mo)	Temperature (°C)	Initial Density (#/m²)	Final Density (#/m²)	Final Carapace Length: Mean (mm)	Range (mm)	Standard Deviation (mm)	Number of Claws (%): 2	1	0
Substrate Type:										
Bare	4	22±1	50	4.7	12.3	10.9–13.2	1.07	75	25	0
Oyster shell				13.9	11.8	8.5–15.6	2.75	84	8	8
Unoriented cylinders				15.1	11.2	8.0–18.7	3.10	85	15	0
Oriented cylinders				17.4	12.1	9.0–15.4	2.04	100	0	0
Corrugated fiberglass				17.0	13.2	8.9–20.8	5.12	66	17	17
Rubber matting				8.1	14.0	9.8–18.6	3.37	86	14	0
Bare	6	22±1	93	5.2	22.0	13.6–28.8	6.28	56	22	22
Oriented cylinders				8.7	16.9	9.2–28.7	6.71	80	13	7
Corrugated fiberglass				11.6	16.6	9.8–29.4	6.11	70	20	10
Monsanto Astro Turf® Marine Surface										
FB-01	4	22±1	286	40.1	9.4	7.0–12.6	1.56	64	36	0
FB-02				68.6	9.6	7.6–14.2	2.03	67	25	8
FB-03				5.7	16.4	16.4	n=1	100	0	0
FB-04				22.9	11.6	8.4–18.4	4.65	75	25	0
FB-05				17.1	12.6	9.6–15.7	3.05	67	0	33
FB-06				22.9	12.6	10.4–16.1	2.57	100	0	0
Vertical pegs										
Bare	4	16±4	286	5.7	17.7	17.7	n=1	100	0	0
Pegs				34.3	13.2	9.5–17.5	3.15	83	17	0
Draped netting										
Bare	3	16±4	88	10.8	10.0	6.0–15.5	2.66	57	36	7
Vertical				11.5	11.0	7.5–16.3	2.84	60	33	7
Horizontal				18.5	11.6	7.2–15.2	2.83	48	40	12
Diagonal				15.4	10.8	7.8–16.0	2.65	60	25	15
Stacked trays										
4 compartments	4	16±4	1656	31.1	14.5	9.6–18.3	2.56	79	14	7
81 compartments				28.9	11.1	8.0–16.1	2.05	100	0	0
Shelter Density (# tubes/individual):										
0	6	16±4	50	0.8	23.8	23.0–24.5	1.06	100	0	0
1				2.3	18.9	12.5–23.5	4.14	67	33	0
2				5.4	16.0	9.0–26.5	5.73	93	7	0
4				2.3	19.2	14.5–23.0	4.31	100	0	0
8				6.5	17.7	10.5–23.0	4.90	76	18	6
Tank Area (m²):										
0.3	6	16±4	50	5.0	19.7	11.5–25.5	7.29	100	0	0
0.7				4.3	16.5	14.5–24.0	3.74	67	33	0
1.3				2.3	19.2	14.5–23.0	4.31	100	0	0
2.0				6.0	16.2	9.5–27.5	5.49	71	29	0
2.5				8.8	15.8	8.5–27.0	4.94	77	23	0
Feeding Level (%) (Dry wt. food:wet wt. lobster):										
10	4	16±4	46	6.2	12.7	9.3–16.8	3.00	100	0	0
20				8.5	13.2	8.4–17.8	3.17	73	9	18

Table 2.--A summary of the methods and results for Series II experiments concerning the use of vertical substrates and manipulation of other culture conditions influencing growth and survival of communally reared juvenile lobsters.

EXPERIMENTAL CONDITION							RESULTS							
Substrate Type	Stocking Density ($\#/m^2$)	Photoperiod Light:Dark	Temperature (°C)	Food Type	Species	Survey Interval (days)	Final Density ($\#/m^2$)	Final Carapace Length Mean (mm)	Final Carapace Length Range (mm)	Final Carapace Length S.D. (mm)	Number of Claws (%) 2	Number of Claws (%) 1	Number of Claws (%) 0
Bare	83.8	Natural =13:11	22±1	Live adult brine shrimp	*Homarus americanus*	30	4.2	20.4	12.0-31.2	7.37	60	30	10
Two-dimensional tubes	"	"	"	"	"	"	15.1	17.3	10.3-33.1	5.04	75	25	0
Three dimensional tubes	"	"	"	"	"	"	15.1	16.8	8.7-34.2	4.68	81	11	8
Bio-trickle filtration media	"	"	"	"	"	"	27.3	17.5	11.2-35.1	3.83	72	26	2
"	21.0	"	$\bar{X}$=20.9 Range 14.5-23.5 S.D.=1.58	"	"	"	9.6	20.8	12.0-31.7	5.25	83	4	13
"	41.9	"		"	"	"	21.4	18.3	9.7-29.9	4.27	82	12	6
"	83.8	"		"	"	"	35.6	15.6	10.6-32.4	4.28	78	15	7
"	167.6	"		"	"	"	32.3	18.7	11.8-43.7	5.53	73	19	8
"	335.3	"		"	"	"	31.4	17.3	11.9-27.3	3.64	58	37	5
"	83.8	0:24	$\bar{X}$=20.7 Range 17.0-26.5 S.D.=1.43	"	"	"	15.1	18.5	12.8-42.7	6.33	72	22	6
"	"	6:18		"	"	"	20.5	19.2	11.4-33.9	5.72	76	16	8
"	"	12:12		"	"	"	31.9	20.5	12.7-36.5	4.55	75	22	3
"	"	16: 8		"	"	"	23.9	19.3	9.4-29.6	4.21	80	18	2
"	"	18: 6		"	"	"	25.6	19.7	11.7-34.1	4.94	82	16	2
"	"	20: 4		"	"	"	28.1	18.0	10.6-29.6	4.15	77	21	2
"	"	22: 2		"	"	"	27.7	19.2	13.7-31.0	3.47	73	21	6
"	"	24: 0		"	"	"	37.7	17.4	10.4-30.3	5.09	75	21	4
"	"	Natural =13:11	$\bar{X}$=17.9 Range 13.5-25.0 S.D.=3.01	"	"	"	12.6	18.4	13.5-29.0	4.04	66	27	7
"	"	"	22±1	"	"	"	30.6	18.0	11.2-32.6	4.39	64	30	6
"	"	"	$\bar{X}$=20.3 Range 11.0-23.0 S.D.=1.66	"	"	"	27.3	17.5	11.2-35.1	3.81	72	26	2
"	"	"		Frozen adult brine shrimp	"	"	25.2	18.2	9.7-30.4	4.60	60	33	7
"	"	"	22±1	Live adult brine shrimp	"	"	29.4	16.2	9.0-20.3	3.03	74	20	6
"	"	"	"	"	*Homarus gammarus*	"	14.3	14.1	9.2-22.5	2.76	65	26	9
"	"	"	"	"	*Homarus americanus*	"	30.6	18.0	11.2-32.6	4.39	64	30	6
"	"	"	"	"	"	180	15.9	18.1	10.3-27.4	4.05	87	8	5

Table 3.--A summary of the methods and results for Series III experiments concerning techniques for segregating larger individuals and methods to immobilize claws to increase the yield from communal rearing systems.

Experimental Condition	Period (mo)	Temperature (°C)	Initial Density (#/m²)	Final Density (#/m²)	Final Carapace Length: Mean (mm)	Final Carapace Length: Range (mm)	Final Carapace Length: Standard Deviation (mm)	Number of Claws (%): 2	Number of Claws (%): 1	Number of Claws (%): 0	Sex Ratio (% M:F)
Segregating (after 3 mo):											
None removed	6	22±1	84	40.3	16.1	9.7-29.4	3.94	81	15	4	47-53
Removal of single largest				36.9	16.5	11.7-24.2	3.32	86	14	0	49-51
Removal of five largest				33.1	15.5	10.1-19.9	2.87	85	15	0	43-57
Removal of all over 20 mm carapace length				36.9	16.0	10.3-22.3	3.72	82	17	1	55-45
Catch-Up:											
Communal	6	22±1	84	31.4	17.0	8.0-26.7	4.66	68	27	5	33:67
Individual			60	45.9	18.1	14.5-21.0	1.73	100	0	0	60:40
Communal/individual	3/3		84	27.7	18.1	13.0-24.2	2.44	100	0	0	45:55
Claw Immobilization:											
Normal claws	6	16±4	185	31.9	14.3	9.3-27.1	3.89	65	30	5	-
Cut dactylopodite				76.5	12.3	7.7-25.8	3.48	67	16	17	-
Chelae removal				113.1	11.1	7.9-20.5	2.80	90	8	2	-

*Functional claws were regenerated between 30-day surveys.