WHOI-76-44

PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER *(HOMARUS AMERICANUS)* AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS

by

Dr. John H. Ryther, Joseph S. Levine,
Fredrick M. Mencher, David J. O'Neill,
Barbara Plasman, Jeffrey L. Star,
Jeffrey L. Thielker, Karen Irving
and Greg Redmann

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

April 1976

TECHNICAL REPORT

Prepared under NSF Grant GY-11544.

Approved for Distribution Howard L. Sanders

Howard L. Sanders, Acting Chairman
Department of Biology

TABLE OF CONTENTS

SUMMARY

Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus.

The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

Trophic Intermediary Optimization

In the current phytoplankton-bivalve-macroalgae aquaculture system at the ESL, the primary potential trophic pathways leading to lobsters are bivalve biodeposits, meiofauna, detritovores, herbivores, and macroalgae.

Individually held postlarval lobsters fed oyster biodeposits took twice as long to molt to 5th stage as Artemia fed individuals. Survival was proportionate to amount of biodeposit present. Approximately 7500 µg carbon and 1300 µg nitrogen was the maximum amount available from biodeposits per lobster, however, this varied due to fluctuations in the phyloplankton supply.

Meiofauna experiments showed that 93% of postlarval lobsters fed detrital meiofauna molted to 5th stage compared with 42 of those fed only biodeposits over a 3-week period. Comparative growth experiments over the same period with Nereis and lobsters held together using meiofauna as the food source showed that

Nereis had a greater survival than the postlarval lobsters, 75% vs 54%, but the lobsters had a greater total weight increase, 60% vs 30%. Postlarval lobsters did not eat T1/2 in. Nereis.

Postlarval lobsters held in screened pint plastic containers with oysters and capitellid polychaetes at a density of 10,000/m^2 showed that 4th and 5th stage postlarval lobsters grown with Capitelle had a 40% greater growth increment per molt than the lobsters held only with oysters for a total increase of 71±14% in weight. Capitellids have previously been grown as detritovores in the aquaculture system to densities of 110,000/m^2. Experiments with lower levels of Capitella or else the macroalgae Chondrus crispus showed no significant lobster weight increase compared to controls. Similar feeding experiments with 7th and 8th stage lobsters using components of the epifaunal communities found in the raceway, primarily various amphipods and mussel spat, forming a Ceremium-Jassa-Mytilus association, showed significant weight increase (81±20%) compared to the biodeposit fed controls.

Environmental Structures and Substrates

Wood and Vexar bivalve-holding trays in use at the ESL were modified and made postlarval lobster-tight by covering with fine mesh. Trays holding postlarval lobsters at densities of 50/m^2 and 17/m^2 with live oysters and typical raceway fauna had similar survival, about 60%, and growth after a 40-day period. The mean increase in carapace length over 60 days was from 4.2mm to 13.6mm. Live oysters, or empty shells, with lobsters stocked at 34/m^2 and Artemia added were found to be equally suitable as substrates with over 50% survival over a 25-day period. Artificial substrates also used in a similar experiment at 74/m^2 showed that survival was greater in a 3 cm high vertical maze of corrugated fiberglass

filon roofing material, than in 3m's Conservation Webbing 200, 54% to 13%, respectively.

Molt delay assays with pairs of postlarval lobsters were used to determine what habitat conditions induce the least amount of agonistic interaction. Oyster shells, vertically arrayed fiberglass maze, PVC shelters and lobsters held without claws were compared to a control of individually held lobsters. Fiberglass maze, oyster shell, and lack of claws produced the least difference in time of molt for a pair of lobsters held together, less than 2 days as compared with 3.8 days for pairs of lobsters held with the PVC shelters. Greatest survival and total biomass was achieved by the clawless pairs.

Postlarval lobsters held in .25/m^2 tank divisions, at 50/m^2 under similar conditions and combinations as in the above experiments for 50 days showed greater survival and biomass (although less weight per individual) in the clawless pairs held with maze, having 85% survival and 30g/m^2, whereas clawed lobsters with and without maze had respectively 68% and 40% survival, at 22g/m^2 and 18g/m^2.

Postlarval lobsters were added to a partitioned off area of the raceway with a stock of unmodified bivalve trays, ideally to distribute themselves vertically and settle among the trays. However, Fundulus is one test and grass shrimp in the other somehow entered from adjacent raceways and eliminated all but about 8% of the introduced lobsters. Some sort of tray modifications will probably be necessary to successfully raise postlarval lobsters in the raceways.

Distribution in a multiple-tiered environment was studied in subadult lobsters by a covered, suspended cage and in postlarval lobsters by observations in a smaller scale aquarium set-up. Provided with a variety of potential food items from the raceways, hemitubular shelter and inter-tier ladders, the older lobsters tended to distribute themselves evenly on the several layers, although

cannibalism at molting did not seem to be reduced. Roaming and aggressive behavior didn't mature until 7th stage in the postlarval lobsters, and their tier settlement seemed to be transient and inversely related to light levels.

A mesh-size selection experiment using four equal-sized boxes with varying sized mesh corresponding in hole diameter to different carapace-size classes of lobsters showed that the degree of mesh box occupancy and mortality was inversely proportional to the size and presumably dominance of the lobsters. This set-up for self-induced size selection also can serve as a harvesting method for different size classes of lobster from a communal rearing system, and to reduce agonistic interaction between different size classes. The optimum self-selected stocking density derived from this was about 45 lobsters/m^2 through the 12th stage.

Food Selection, Behavior, and Ecology

Observations on postlarval behavior and interaction with potential food species were done with a light-regulated 20-gallon aquarium. Results show that postlarval lobsters feed readily on the various species potentially found in the raceway, except for the isopod Idolea sp and increase their dietary range at 9th stage. There is little intraspecific interaction and a bimodel activity peak with a photoperiod and an oyster-shell substrate at a lobster density of 50/m^2. There was extensive interaction and some mortality at 100/m^2. Both interaction and vertical distribution in a multiple-tiered system increase in the absence of light. Climbing activity increased with the addition of mesh ladders to the tiers.

Postlarval benthic settlement preferences were examined by releasing the lobsters into a round tank divided into sections containing local bottom types of Chondrus, Zostera, Codium and oyster shells. Lobsters preferred Chondrus somewhat over the other species, but the difference was reduced when rocks were

added with all the species. Chondrus with 40-5cm rocks were greatly preferred over rocks or Chondrus alone, and in all tests the preference for oyster shells equalled that of the preference for the optimal natural substrate.

Food selection preferences were derived for subadult (45-65mm carapace length) lobsters from the determination of electivity indices for 13 possible food species. In order of preference with E' value, are Artemia, .248; Nereis, .221; Fundulus, .220; Palaemonetes, .144; Cancer, .102; Strongylocentratus, .053 Asterias, -.049; Mytilus, -.188; Arbacia, -.330; Littorina, -.385; Homarus, -.525; Gracilaria, -.884, and Chondrus, -.919.

It appears that Homarus can be a viable component of the aquaculture-wastewater treatment systems. Further work is needed and is being done, primarily long-term studies with older lobsters and the development of specific food-related habitat designs.

INTRODUCTION

The comprehension and manipulation of food chains to optimize certain qualities can lead both to the elucidation of trophic mechanisms and result in products for societal benefit. The Environmental Systems Laboratory at Woods Hole Oceanographic Institution is a pilot plant/research facility-designed for the study of artificial foods chains, and marine aquaculture-tertiary sewage treatment processes.

The facility consists of six 36,000 gallon ponds,and eight 13m long x 2m wide x 3m raceways. The food chain utilized for this study was phytoplankton--bivalve--detritovore---lobster with the research focused on aspects of incorporating the lobster (*Homarus americanus*) into the existing experimental food chain. Research centered on the post-larval period, because of its importance in the life cycle of the lobster and time limitations.

The research was divided into three main areas: food source--growth rate studies, evaluating the growth of postlarval lobsters over a short period of time with different potential food sources from the artificial food chain system; environmental structure and substance relationships, evaluating the relative growth, survival and behavior with respect to certain habitat configurations, shelters and densities; and the behavior and ecology studies, examining postlarval feeding and ontogenetic behavior, benthic settlement preferences, and subadult food selection.

These series of experiments were carried out by the nine-person LOBSTAQ team, consisting of a diverse mixture of graduate and undergraduate students, during a 12-week period in the summer of 1974. Dr. John Ryther was project advisor, Greg Redmann project director, and team members were: Joe Levine, Fred Mencher, David O'Neill, Barbara Plasman, Jeffrey Star, Jeff Thielker and Karen Irving.

Acknowledgements

We would like to thank Dr. John H. Ryther for his continued attention and encouragement throughout the project; and J. E. Huguenin for his suggestions in its inception and implementation. Joanie Mitchell kindly provided post-larval lobsters, and John T. Hughes valuable advice. We also appreciate the stimulus and assistance of Dr. Jelle Atema, Dr. Cam Gifford, Dr. Joel Goldman, Anita Gunning, Dr. Wm. Kerfoot, Brian Lapointe, Dr. K. R. Tenore, Asa Wing, Dr. J. Vaughn and all the other members of the ESL staff. We also thank Dr. J. S. Cobb, Dr. J. Carlberg, Dr. J. Von Olst, Dr. R. Schleser, Dr. R. Wigley, the National Marine Fisheries Service who supplied subadult lobsters, the people in Challenger House, and the boys in the shop.

This project was supported by the National Science Foundation Student Originated Studies Program, Grant #GY-11544.

"Oyster Biodeposit as a Food Source for Post-Larval Lobsters"

Jeffrey L. Star

Introduction

In an integrated aquaculture system, a variety of possible detritivors are available, including Capitella capita, Nereis, and perhaps post-larval lobsters (Homarus americanus). In this study, a brief examination is made of the possibility of using biodeposit from the American oyster (Crassostrea virginica) as a complete food for the lobsters. If this were to provide an adequate diet, one might envision a virtually labor-free system wherein the post-larval lobsters are permitted to coexist with the oysters, browsing on the oyster feces and pseudofeces as they desire. Two specific situations were employed: lobsters in groups with oysters, and lobsters held individually and hand-fed the biodeposit material.

Methods and Materials

Specimens of the American oyster, Crassostrea virginica, were obtained from Waquoit, Massachusetts. These animals were scraped clean and weighed, and then sorted into groups of three in which the total weight averaged 124.8 grams ($\sigma = 0.6$ grams). Twelve such groups were placed in plastic compartments of 2.6 liter volume and 350 cm^2 bottom area. A series of linear regressions were performed on other oysters of this same stock; based on a linear correlation coefficient of .85, this represents some 2.97 grams ash-free dry meat weight per group of three oysters. A 100 ml volume of washed beach stones was added to each compartment, providing a coarse substrate and supporting the oysters in such a manner that each formed a possible shelter for a post-larval lobster.

A mixed flow was provided into the compartments of filtered (20 micron) seawater and algae. Flow rates over the course of the experiment provided a turnover or residence time of some 54 minutes. The algae flow originated in a 36,000 gallon pond, which is supplemented by either municipal treated sewage effluent or a mixture of monobasic sodium phosphate and ammonium chloride. For further details on the algae growth system, see Huguenin and Ryther, 1974. Temperatures, flow rates, and cell counts and speciation (performed on a Spencer Bright-Line counting chamber) were recorded daily. Dissolved oxygen measurements were made daily with a YSI Model 54 Oxygen meter during the first week of operation; values remained uniformly between 4 and 5 parts per million and were not measured subsequently.

Two days after the oysters were stocked into the compartments, newly-molted (within the past 24 hours) fifth stage lobsters were added: 5 placed singly (average weight 0.053 grams), and 15 were placed 3 together (average weight 0.060 grams) in separate compartments with the oysters. Two compartments held no lobsters. These were used as controls on the oyster biodeposit production. The conditions of both oysters and lobsters were recorded daily. Biodeposit not consumed was removed every second day to prevent fouling, and particulate carbon and particulate nitrogen measurements on the biodeposit in control compartments were performed weekly.

At the conclusion of the above experiment, 12 newly-molted fourth stage lobsters were stocked into individual compartments of 245 ml volume and 70 cm^2 bottom area. These compartments were provided with a rapid flushing of filtered seawater; turnover or residence time averaged 2.4 minutes. Each group of 4 lobsters received a different quantity of biodeposit, which was collected, diluted, and distributed from the oyster compartments of the previous experiment every second day. These rations were prepared by siphoning material from

the oyster compartments into a single vessel and permitting the fluid to settle for 2 to 3 hours. The supernatant was then decanted to a constant volume, and the biodeposit material serially diluted with distilled water such that each lobster in the first group of 4 received the average output of 1 oyster compartment every two days; the second group of 4 received one-fourth of this quantity; the third received one-sixteenth. Sampling and measurements were performed as before. This experiment ran for 21 days.

Results

The first experiment ran for 12 days. Temperatures averaged 22.8°C with a range of 21.0 to 25.4 (σ = 1.1°C). Twelve replicate cell counts were performed daily on the inflow to the compartments; one each at the fluid entrances. Algae inflow density averaged 3.3 x 10^5 cells per ml with Phaeodactylum tricornutum dominating, accompanied by Nitzchia longissima and N. closterium. The inflow resulted from mixing the algae pond effluent and filtered seawater in the ratio of 1:2 before entrance into the compartments. Counts were also performed on the ambient fluid in the compartments. These varied greatly, between 1 x 10^5 and 6.6 x 10^5 cells per ml, and could not be explained. Incomplete mixing of the compartments is suggested.

The biodeposit produced in the compartments averaged 16,300 µg particulate carbon and 3000 µg particulate nitrogen per day. This corresponds to 5500 µg carbon and 1025 µg nitrogen per day per gram ash-free dry oyster meat weight. Biodeposit was in visible excess throughout; only a negligible fraction was obviously consumed by the lobsters.

At the end of the twelve days, 4 of the 5 lobsters held individually were still alive, exhibiting an average weight gain of 0.032 grams, and one of the survivors had molted to 6th stage. Nine of the 15 lobsters held in groups of 3

were still alive, exhibiting an average weight gain of 0.029 grams, and 3 of the survivors had molted successfully to the 6th stage.

During the second experiment, temperatures in the oyster compartments averaged 23.4°C with a range of 19.9 to 25.0 (σ = 2.0°C). Temperatures in the lobster compartments averaged 22.1°C with a range of 20.7 to 23.0 (σ = 0.7°C). Cell counts on the inflows to the oysters fell severely: 7.1×10^5 cells per ml on the first day to 2.0×10^4 on the last. The 1:2 algae:seawater dilution was ended on day 4 to try to compensate this somewhat; Figure 1 details this further. After the fourth day, no single species dominated the cell counts. P. tricornutum, N. closterium, Dunaliella tertiolecta, and unidentified naviculoid and mobile species were found regularly. On day 18, the algae source was changed to a different pond, thereby changing the dominant species to D. tertiolecta. Biodeposit production promptly fell off, and the experiment was terminated on the 21st day when it was discovered that one-third of the oysters had died in the preceeding 48 hours.

The available food source to the lobsters in this experiment is assumed to be the gross particulate phase of the biodeposit supplied-- the fraction able to settle out of suspension over a time period of 2 to 3 hours. No information is available on either the particulate size distribution of the biodeposit material, or on the ability of the lobsters to ingest or manipulate a given particle size. The gross particulate biodeposit dropped from 30,720 µg carbon and 4184 µg nitrogen per compartment per day on day 7 to 1150 µg carbon and 810 µg nitrogen on day 21. Composition of the biodeposit changed radically during this period, as reflected by the particulate carbon-nitrogen ratios (5.9 vs. 1.4).

After 21 days, all 4 of the lobsters in the group receiving the highest food ration (roughly 7,500 µg carbon per day) were still alive; 2 had molted to 5th stage with one losing a claw in the process. In both the other groups,

receiving one-fourth and one-sixteenth the food ration of the first, 1 of the 4 survived through the 21st day and no molts were recorded. Average day of death for the 3 that did not survive in each of these groups was the 16th and 12th days, respectively.

Discussion

In the first feeding experiment, it was not possible to increase the lobster density as originally planned to determine a limiting biodeposit ration, even when separate shelters were available for each lobster and food was in visible excess. The groups of 3 lobsters reduced themselves, on the average, to groups of 2, corresponding to a density of roughly 60 per square meter. These lobsters also had demonstrably smaller weight gain than those held individually. Some insight is available into why this density level was maintained. It has been observed that lobsters of this age periodically leave their shelters for others, for no apparent reason (Joseph Levine, pers. comm.). At the onset, when no shelters were in excess, this kind of behavior forces the animals to interact and form a social hierarchy. At the reduced level of 2 animals per compartment, there is an extra shelter available to accommodate this behavior with a minimum of intereaction and thus a better chance for survival.

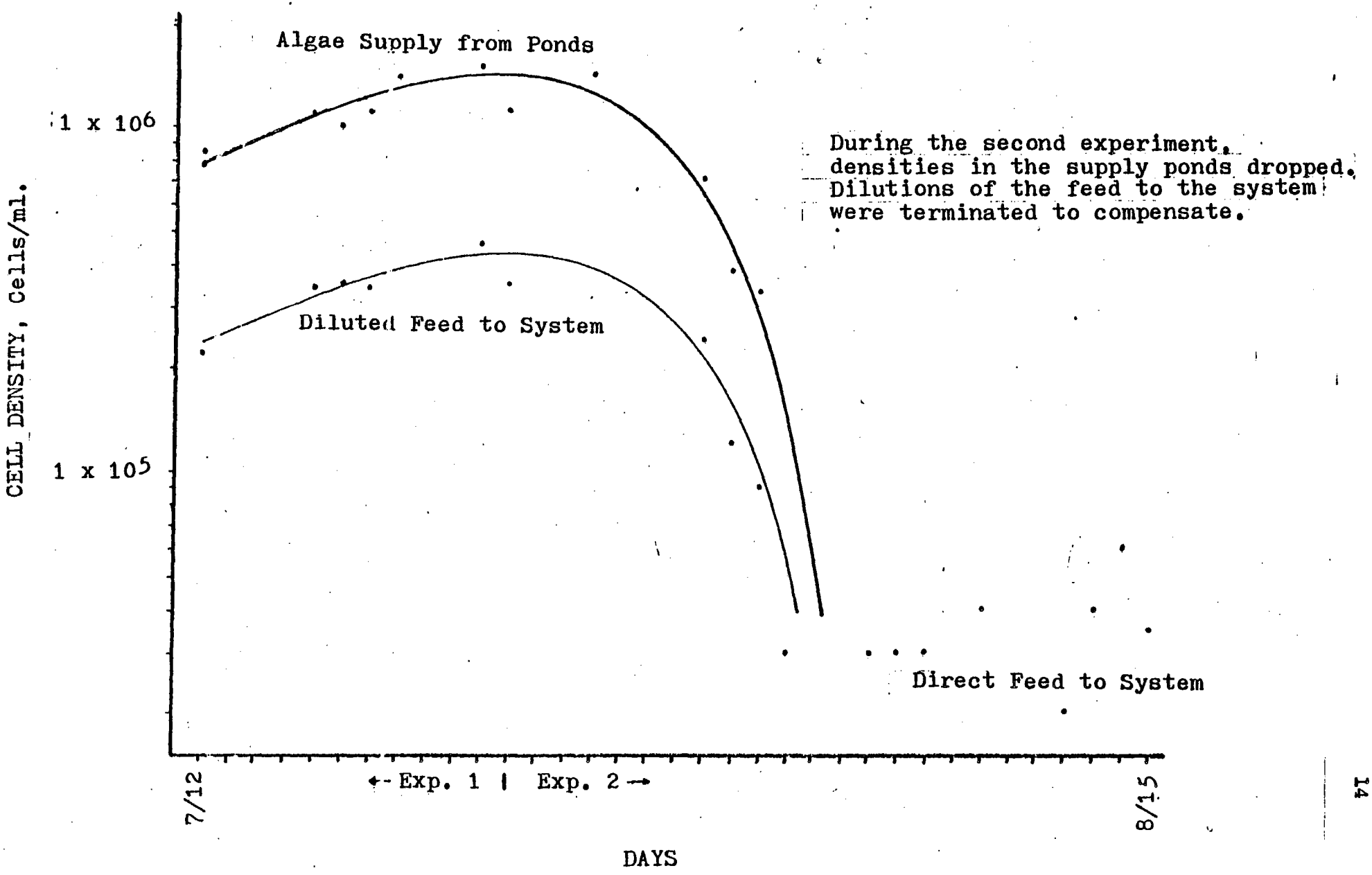
The massive oyster kill of the 21st day of the second experiment, which was observed in other parts of our system, is yet unexplained. As of that day, the remaining oysters were transferred to clean filtered seawater, and their live weights recorded on the following day. Over the 41 day interval, the oysters lost an average 4.9% of their initial live weight. This may be explained in part by the two major species of algae in their diets, P. tricornutum and D. tertiolecta, which are known to be poor food sources for oysters (Walne, 1970; Davis and Guillard, 1958). However, some weight gain should still be observed, particularly when it is noted that oysters elsewhere in the system

appear to have gained weight over this same interval when receiving algae from the same source, albeit with a higher seawater dilution. I believe the shock which caused the sudden mortalities may be responsible for the weight loss overall.

A major unresolved problem lies in the biodeposit measurements. It was not found possible to identify contributions made by settled algae and organic matter. Also, the particulate measurements do not discriminate for a particle size which is below the lobsters' ability to manipulate. Overall, the particulate carbon and nitrogen measurements used throughout this paper should be regarded as purely relative measures.

The results of the second experiment give some indication of a limiting biodeposit ration for individually-held fourth stage lobsters; the difficulty is in interpretation. As indicated, the particulate carbon and nitrogen measures dropped drastically during the experiment as algae density and speciation changed. Hence it becomes difficult to decide on an average value. A simple mean was calculated and assumed representative: 7500 µg carbon and 1300 µg nitrogen per day. This compares very well with the work of Bryden (1973). Time did not permit an examination of precisely what in the biodeposit ration was in fact limiting. Under these conditions, average time until the molt to fifth stage is at least a factor of two longer than with Artemia-fed lobsters under similar conditions (20 or more days vs. 10-11 days). Based on this, the biodeposit does not recommend itself as a complete food.

FIGURE 1. ALGAE INFLOWS



The Role of Meiofauna as a Food Source of *Nereis Virens* and *Homarus Americanus*

Barbara Plasman

Introduction

Little is known about the role of meiofauna in polyspecies aquaculture systems. A need for further work on the role of meiofauna as a food chain intermediary was suggested by Tenore, Browne, and Chesney (1974). One possible polyculture system consists of phytoplankton, oysters, lobsters, *Nereis* and associated biodeposits. Biodeposits are a food source for both *Homarus* (Bryden 1973) and *Nereis* and have associated meiofauna (Tenore and Gopalan 1974). Meiofauna are a potential food source in this system. While eating biodeposits, *Homarus* and *Nereis* may also eat the associated meiofauna.

Studies made by Squires (1970) indicated that fourth stage lobsters settle in gravelly and sandy substrates. Bass and Braffield (1972) state that *Nereis* live in rocky and sandy ocean bottoms. During some of the lobster's life stages, it occupies a niche similar with *Nereis*. The possibility exists that *Homarus* and *Nereis* are in competition for meiofauna as a food supply. Therefore, to simulate these natural conditions in an experiment, *Homarus* and *Nereis* would be placed in containers together along with substrates and shellfish. The following experiment was designed to determine if meiofauna was an important food source for either *Homarus* or *Nereis*. If meiofauna was utilized by both, survival and weight gain rates would indicate possible competition.

Materials and Methods

In this experiment, two systems, one stocked with meiofauna and the other a meiofauna-free control, were run simultaneously. Each system consisted of

four plastic food containers (22.5 x 30.0 x 15.0 cm deep). The containers were filled with 5200 ml of water. Along the ends of the containers, holes were drilled to allow an outflow from the system. Each container was filled with 200 ml substrate. This covered the bottom of the container and allowed for enough shelter to minimize social contact of the experimental animals. When added to the system, the containers were filled with 5 l of a sea water/ algae (220:110 ml) flow. This flow was maintained at a rate of 80 ml/min/ container.

A different habitat was created in each of the four containers. Container 1 had 200 ml rocks added. Container 2 and 3 had 200 ml rocks added and stocked with two mussels and six oysters respectively. The fourth container held 200 ml oyster shells and six oysters. Rocks and oyster shells were chosen as substrates to observe any difference in survival or weight gain rates. Shellfish were added to supply a known food source and a substrate for meiofauna. Only two mussels were added in Container 2 since any greater number caused fouling. Container 1 was the control in each system to observe how the species fared with or without meiofauna as their sole food source. In the group without meiofauna, all materials were brushed clean and rinsed thoroughly before their addition to the system.

The oysters were obtained from Waquoit Bay and the mussels from Sagamore Bridge. To collect the meiofauna, a large mesh (size 18) sieve was placed over a small mesh (size 40) sieve. Rock meiofauna was collected from rocks off the ESL beach. Oyster meiofauna came from oysters held in tanks at ESL. The containers in the meiofauna-fed system were stocked every other day. No exact amount of meiofauna given to each container was made. Meiofauna was evenly distributed in the collection pail and each container was given 1000 ml of this mixture.

After the containers were set up, the systems were allowed to settle two days. Six newly molted fourth stage lobsters and four 3.75 cm Nereis were weighed and added to each container at that time. The lobsters were taken from stocks hatched at ESL. The Nereis were collected from Old Silver Beach in West Falmouth. Only six lobsters were added since more lobsters would cause greater social contact. Social contact was kept minimal to reduce possible deaths due to aggressive interaction. No maximal or minimal stocking density is known for Nereis. The animal/cm value was kept close to that given by Tenore and Gopalan (1974) which was rated "low density".

Lobsters were weighed upon molting to fourth stage, added to the systems and weighed again after molting to fifth stage. If the lobsters had not molted by the end of the experiment, it was weighed before adding to the system and at the end of the experiment.

The temperature was recorded twice daily, in the morning and mid-afternoon. Average temperature was 23.0 ± 1.0°C. Homarus and Nereis were checked daily for survivorship. Lobsters were also checked daily for molts. The experiment ran for 21 days.

Results

Survival

From data obtained on survival Nereis has a significantly greater survivorship rate than Homarus. The presence or absence of meiofauna apparently has no overall effect on survival. However, the 75% survival rate of Nereis is significant at the .01 level.

	Nereis	Homarus
Meiofauna	n = 16 75%	n = 24 42%
No meiofauna	n = 16 56%	n = 24 50%

Figure 1

Weight Increase

	Nereis	Homarus
Meiofauna	n = 12 24%	n = 13 65%
No meiofauna	n = 9 10%	n = 4 26%

Figure 2

Figure 1 indicates that for both species, meiofauna ia an important food source. Both Homarus and Nereis show significant (.01 level) increases in weight over those not fed meiofauna. The data also shows that Homarus has greater weight gains then Nereis. Both Homarus weight gains are significant over those of Nereis at the .01 level. From this data, meiofauna would appear to not only be a significant food source but the hypothesis can be made that Homarus utilized the meiofauna to a greater extent, in terms of weight gain, than Nereis does.

Molt

	Stage	
	fourth	fifth
Meiofauna n = 13	6%	94%
No meiofauna n = 12	58%	42%

Figure 3
% of surviving lobsters in fourth and fifth stages.

Meiofauna is important to Homarus not only for weight gain but for molting to occur at a normal rate. Comparing rates of molting in Figure 3, Homarus fed meiofauna began molting earlier than those not fed meiofauna. Two days after first molting, 50% of the meiofauna-fed lobsters reached fifth stage while lobsters not fed meiofauna only reached 42% by the end of the experiment. Many lobsters in the meiofauna-free group molted to fifth stage, however they have a weight gain of only 26% as compared to 65% in those fifth stagers of the meiofauna group.

Coloration

Along with lower weight gain and slower molt, those lobsters not fed meiofauna showed abnormal coloration. All lobsters in that group had a pinkish tinge to their shells. This abnormality was especially apparent in container 1 where there was no food available.

Discussion

The results obtained from weight gain shows meiofauna to be an important source of food for both Nereis and Homarus. Results from weight gain (Figure 2) were more indicative of the importance of meiofauna than those of survival because all the factors affecting survival could not be controlled. Counts were made each day on the live and dead animals. The cause of death was not determinable. Deaths could have been due to attacks from members of the same species or environmental shock. Some of the dead lobsters had lost one or both claws indicating social interaction. Claw loss would also make food procurement difficult and decrease the individual's ability to defend itself. Nereis bodies had no noticeable marks attributable to attacks by other Nereis. Most deaths were probably caused by environmental shock. From data in Figure 1, the survival of Nereis is greater than Homarus indicating a greater resistance to environmental shock and a lower stocking density, rather than meiofauna as a factor in its survival. For these reasons, weight gain gives a more accurate description of meiofauna as a food source. Possible weight gain from interspecific predation was eliminated by finding all but a very small percentage of the bodies.

Lobsters have a greater weight increase than Nereis when fed meiofauna possibly because they are physically better able to capture most meiofaunal species. Most meiofauna available were amphipods and isopods (App. A), because they are more able to capture both the faster species and the slower moving organisms.

Although there are many variables in the experiment, the conclusions are still valid. Different substrates, shellfish and meiofauna were provided for the experimental animals in the containers. However, an evaluation of the results shows no consistent difference occurs due to any one of these variables. The same amount of substrate was put in each container. A build-up of biodeposits

never occurred. Therefore, one can conclude that the biodeposits were consumed at equal rates even though different quantities were supplied. From the identification made of the meiofauna from each substrate, the predominant species of both substrates were the same. While the variables existed, differences between the containers did not seem to be great enough to affect general conclusions.

APPENDIX A

Meiofaunal species

rock substrate

amphipods
Gammarea

Caprellidea

isopods
Ancinus depressus

Exoshpaerima papillae

aschelminthes
Nectomena agilis

polychaetes
Phyllodocidae

oyster substrate
amphipods
Gammerea
Caprellidea

polychaetes
juvenile worms such as Capitella and Nereis

Capitella capitata and *Chondrus crispus* as Experimental Links in a Lobster Polyculture System

Frederick M. Mencher

Introduction

Bryden (1973) demonstrated that shellfish biodeposits could be used as a food source for juvenile lobsters. This fact is very useful in a mariculture system such as the Environmental Systems Laboratory, where large amounts of oyster biodeposits are produced and, indeed, create a problem of waste disposal. Utilizing part of these biodeposits as a food source provides a possible means of integrating lobster culture into a polyculture system like the ESL. However, as Bryden demonstrated, shellfish feces and pseudofeces do not support

rapid growth of juvenile lobsters unless supplemented by some other food source. In a phytoplankton-oyster-lobster polyculture system, it would be useful to provide a food source that also fed upon either solid wastes or dissolved nutrients released by the oysters. It was therefore decided to attempt to find a detritovore and a suitable species of macroalgae which, if grown in a system with oysters and lobsters, would provide a suitable dietary supplement for lobsters fed on biodeposits.

One detritovore commonly found among the oysters in the ESL aquaculture system is the small polychaete Capitella capitata. Tenore, Browne, and Chesney (1973) demonstrated that this polychaete can be grown in high densities on oyster biodeposits. Brawn, Peer, and Bentley (1968) found that polychaetes have a high caloric content compared to many other marine invertebrates. A large part of the natural diet of lobsters appears to be composed of polychaetes (Miller, Mann, and Scarratt, 1971). The small size (ca. 1 cm) of Capitella and the ease by which it may be captured by a young juvenile lobster also made it appear to be a possibly good food source.

Atema (1974) states that macroalgae provide an important part of the nutritional needs of adult lobsters, as there is a relationship among diet, molting, and production of a sex pheromone. Adult lobsters have been known to eat macroalgae, particularly Chondrus crispus (Hughes, personal communication). Bryden (1973) also states that lobsters may need certain nutrients

present in algae, although these nutrients may also be provided by the biodeposits. As Chondrus crispus has commercial value of its own because of its carrageenan content, and is being grown in large quantities at the ESL, it seemed to be an appropriate species of macroalgae to test as a diet supplement for lobsters.

Materials and Methods

Individual lobster containers were constructed by screening two sides and the top of plastic pint refrigerator containers. For the first Capitella experiment, approximately 1 cm of crushed oyster shells was placed in each compartment as a substrate. Two oysters (total live weight approximately 60 g) were placed in each compartment. Twenty Capitella capitata were added to each of the twenty experimental compartments; ten compartments, used as controls, received no worms. As the containers were approximately 10 by 10 cm, the density of Capitella in the experimental containers was approximately 2000 individuals/m^2. The other experiments were conducted in a similar manner, except that in one, the fifteen experimental containers were seeded with 100 Capitella (10,000 individuals/m^2), in the other, twenty containers received 3 g each of Chondrus crispus. Each experiment had 10 control compartments fed only biodeposits.

The ages of the experimental lobsters were determined by the available stock at the beginning of each experiment. Thus,

in the low-density Capitella experiment, fifth-stage lobsters were used, while the other two used fourth-stage animals. One lobster was placed in each container, and the containers for an individual experiment were placed in a tank compartment supplied with both filtered seawater and an algae flow. Because of large fluctuations in algae concentration in the ESL ponds, it was not possible to maintain a uniform density of algae in the experimental compartments. However, it was observed that the oysters produced a large excess of biodeposit at all times during the experiment, although the algal concentration varied from approximately 2×10^5 to less than 10^4 cells/ml.

Each individual container was checked regularly (normally every day). After a lobster had molted, it was weighed; after the second molt, the weight was again recorded. A Sartorius top-loading balance was used for the low-density Capitella experiment; later, for the other experiments, a Mettler H15 balance was used. The temperature of each tank compartment was recorded each day in the early afternoon.

When each lobster in an experiment had molted twice, the growth increment during that period was calculated. Mean growth increments and standard deviations were calculated for each experimental and control group, and a Student's t-test was performed to determine the significance of the results.

The Chondrus containers were exposed to sunlight to allow the seaweed to remain healthy over the observational period. Both Capitella experiments were performed in compartments covered to shade the containers.

Results

The data and results are shown in Tables 1, 2, and 3. The lobsters in the high-density *Capitella* containers exhibited a mean growth increment of 0.0650 g as opposed to 0.0468 g for the controls, an increase of 38.9%. This result was significant at the 0.05 level. The low-density *Capitella* group gave a somewhat higher mean weight gain for the experimental animals than for the controls; however, the result was not significant at the 0.05 level. The *Chondrus* experiment also showed no significant difference between the experimental group and the controls.

Summary and Conclusions

Juvenile lobsters fed the higher density (10,000 ind./m^2) of *Capitella capitata* showed a markedly greater weight gain over a two-molt period than lobsters fed biodeposits alone. This density of *Capitella* is lower than that found by Tenore, Browne, and Chesney (1973) to be sustainable in a phytoplankton-oyster aquaculture system. It therefore appears that this polychaete represents a promising addition to a polyculture system in which lobsters, as well as oysters, are to be grown.

Lobsters fed an excess of *Chondrus crispus* did not exhibit increased growth increments when compared with controls receiving only biodeposits. In addition, the requirement that the containers be exposed to sunlight created fouling problems on

the outside of the containers. It therefore seems that this species of macroalgae, at least, is not a promising addition to the diet of juvenile lobsters.

The controls in each group appeared healthy, and had no apparent difficulty in molting. Mortality was low in all the groups of lobsters. An excess of biodeposits therefore seems to provide an adequate diet for lobsters at this stage of development, although not providing the fastest possible growth.

Table 1

Weight Gain of Lobsters at Lower Density of *Capitella*

Compartment number	Weight, 6th stage (g)	Weight, 7th stage (g)	Gain (g)
1	0.11	0.16	0.05
2	0.11	0.18	0.07
4	0.11	0.21	0.10
5	0.09	0.13	0.04
7	0.12	0.18	0.06
8	0.11	0.14	0.03
10	0.12	0.24	0.12
11	0.11	0.20	0.09
13	0.15	0.19	0.04
14	0.13	0.28	0.15
16	0.10	0.15	0.05
17	0.11	0.20	0.09
19	0.10	0.13	0.03
20	0.11	0.20	0.09
22	died		
23	0.12	0.20	0.08
25	0.12	0.23	0.11
26	0.10	0.17	0.07
28	0.12	0.23	0.11
29	0.12	0.22	0.10
	Controls -- no *Capitella*		
3	0.09	0.11	0.02
6	0.11	0.15	0.04

9	0.11	0.20	0.09
12	died		
15	0.12	0.18	0.06
18	0.11	0.15	0.04
21	0.14	0.25	0.11
24	0.11	0.19	0.08
27	0.10	0.14	0.04
30	0.10	0.15	0.05

mean weight gain of experimental lobsters = 0.078 g, s = 0.033

mean weight gain of controls = 0.059 g, s = 0.029

t = 1.4682

Temperature range = 21.0-23.0°C

Table 2

Weight Gain of Lobsters at Higher Density of *Capitella*

Compartment	Weight, 5th stage (g)	Weight, 6th stage (g)	Gain (g)
1	0.0786	0.1435	0.0649
2	0.1004	0.1593	0.0589
4	0.0779	0.1385	0.0606
5	0.0968	0.1751	0.0783
7	0.1126	0.1944	0.0818
8	missing		
10	0.0863	0.1658	0.0795
11	0.0899	0.1326	0.0477
13	0.0956	0.1470	0.0514
14	0.0894	0.1708	0.0814
16	0.1036	0.1555	0.0519
17	0.0923	0.1525	0.0602
19	0.1063	0.1831	0.0768
20	0.0768	0.1280	0.0494
22	0.0822	0.1497	0.0675
	Controls -- no *Capitella*		
3	0.0793	0.1495	0.0702
6	0.0853	0.1343	0.0490
9	0.0773	0.1211	0.0438
12	0.0895	0.1496	0.0601
15	0.0681	0.1038	0.0357
18	0.0706	0.1138	0.0432

21	0.0853	0.1389	0.0536
23	0.0881	0.1306	0.0425
24	0.0807	0.1174	0.0367
25	0.0881	0.1221	0.0340

mean weight gain of experimental lobsters = 0.0650 g, s = 0.0125

mean weight gain of controls = 0.0468 g, s = 0.0115

t = 3.5952

Temperature range = 22.2-23.7°C

Table 3

Weight Gain of Lobsters with Excess *Chondrus*

Compartment	Weight, 5th stage (g)	Weight, 6th stage (g)	Gain (g)
1	missing		
2	0.0745	0.1060	0.0315
4	0.0925	0.1381	0.0456
5	0.0659	0.1089	0.0430
7	0.0668	0.0990	0.0322
8	died		
10	0.0703	0.1197	0.0494
11	0.0841	0.1244	0.0403
13	0.0865	0.1404	0.0539
14	0.0924	0.1438	0.0514
16	0.0551	0.0870	0.0319
17	0.0952	0.1296	0.0344
19	0.0700	0.1014	0.0314
20	0.0643	0.1016	0.0373
22	0.0718	0.1033	0.0315
23	0.0824	0.1168	0.0344
25	0.0966	0.1320	0.0354
26	0.0625	0.0840	0.0215
28	0.0640	0.1033	0.0393
29	0.0739	0.1054	0.0315
	Controls -- no *Chondrus*		
3	0.0672	0.1027	0.0355
6	0.0689	0.1111	0.0422

9	0.0812	0.1353	0.0541
12	0.0712	0.1154	0.0442
15	0.1037	0.1499	0.0462
18	0.0740	0.1212	0.0472
21	0.0781	0.1329	0.0548
24	0.0906	0.1002	0.0096
27	0.0824	0.0987	0.0163
30	0.0817	0.1353	0.0536

mean weight gain of experimental lobsters = 0.0375 g, s = 0.0083

mean weight gain of controls = 0.0403g, s = 0.0157

t = 0.6238

Temperature range = 22.5-24.1°C

The Ceramium-Jassa-Mytilus Association as an Experimental Link in a Lobster Polyculture System

Joseph Levine

Introduction

In observing the ecosystem extant in the raceways at the Environmental Systems Laboratory, it was noticed that an interesting floral/faunal association had appeared spontaneously in several of the raceways being used to cultivate several species of macro-algae. The assemblage consisted of the two algae Enteromorpha intestinalis and Ceramium rubrum, several amphipods including Jassa falcata, Corophium sp., and Gammarus sp., and isopods Idoltea baltica and I. phosphorea, and the spat of the common mussel Mytilus edulis. A dense mat was formed by the tube building amphipods and mussel spat in enormous numbers, interlaced by the Ceramium. The mat ranged in thickness from 0.5 to 2 cm in thickness and reached from 2-3 cm above the level of the water in the raceway down to within two feet of the bottom. On the side of the raceway which faced west, Enteromorpha replaced Ceramium as the dominant algal species in the upper 5-6 cm of the mat. Idotea roamed in large numbers throughout the system.

The presence of the tube-building amphipods and the mussel spat in unusually high numbers was undoubtedly due to the fact that the water in these raceways was kept in continuous motion by vigorous aeration along the entire length of one side. Although all of the species mentioned were found in raceways lacking this aeration, never were they present in any great numbers. (Tenore, Brown, Chesney, 1974)

In light of the existence of this association in the raceways, a study was undertaken to determine the value of the various elements as food for juvenile lobsters.

Preliminary work evaluating artificial diets for raising lobsters has shown that animals maintained on most of these diets exhibit markedly lower growth and survival rates than those fed live Artemia which is considered the standard for evaluating potential foods (Shleser and Tchobanoglous, 1974; Shleser and Gallagher, MS). Personal observations indicate, however, that even lobsters raised from hatching on live Artemia developed the pale blue color characteristic of insufficient diets (Hughes, pers comm.) by the sixth or seventh molt. Shleser and Tchobanoglous (1974) has shown that algae may be an integral part of the natural diet of Homarus, and there are indications that certain algal vitamins, minerals, and ecdysone precursor may be essential to proper growth and "normal" coloration (Atema, pers comm.).

Bryden (1973) has shown that molluscan pseudofeces contain sufficient algal material to adequately supplement the meat ration in a balanced diet, and more recent investigations (Mencher, Mitchell, O'Neill, pers comm.) confirm that diets which combine pseudofeces with various animal food species produce healthy, vigorous animals which exhibit good growth and low mortality rates.

Materials and Methods

Lobsters were selected for the experiment which appeared to be large enough (.34-.52 gms) to crush the mussel spat unassisted. Animals used were all from the same hatch, and were randomly assigned to four experimental groups. The size of each group was unfortunately restricted to five animals by the limited number of seventh-eighth stage animals available. The animals were maintained in pint refrigerator containers identical to those described in the Capitella feeding report. Two oysters (total live weight approximately 60 grams) were placed in each compartment to provide an excess of feces and pseudofeces.

(Idotea baltica and I. phosphorea were ruled out as potential food species by prior investigation (see Behavioral Observations section in this volume.)

It was deemed unfeasible to provide the lobsters with amphipods alone because of their small size and tendency to escape rapidly from the containers when removed from their tubes. The experimental groups were therefore set up as follows:

Group 1: Cleaned mussel spat only (maintained in excess)

Group 2: Cleaned mussel spat plus Ceramium and Enteromorpha (both maintained in excess)

Group 3: Large pieces of the entire association mat (25 gms wet weight, replaced every two days with fresh material)

Group 4: Controls-- received no food other than biodeposits

The containers were placed under conditions identical to those in the Capitella experiment. The average temperature in the compartment was 23.5°C.

Growth was calculated by allowing each animal to molt twice under the experimental conditions, and weighing each lobster to the nearest hundredth of a gram after each molt. The dates of the molts were also recorded.

Results

Average intermolt times and weight gain are shown in Table 1. Intermolt period did not differ significantly between groups 1, 2, and 3. All these groups, however, exhibited significantly shorter intermolt periods than the controls which received only biodeposits.

Weight gain was significantly (0.02 confidence level) higher in the group which was kept with the entire faunal association. Despite the fact that the lobsters were observed to graze on both the Ceramium and the Enteromorpha,

no difference in growth was evident between groups 1 and 2. Variance observed within each group was quite large.

Discussion

Despite the small sample sizes used in this experiment, there is clear evidence that young lobsters grow extremely well on the Ceramium-Jassa-Mytilus association which arises spontaneously in the raceway system during the spring and early summer. This is not altogether surprising, as this association provides an extremely varied diet which is undoubtedly similar in many respects to natural diets. In addition to growth, color, vigor, and claw differentiation in Group 3 all gave indications that the diet was entirely satisfactory. It has been observed previously that in addition to the presence of algae in the diet, the presence of other crustacea appears to be of paramount importance (Hughes and Matthiessen, 1962). While culturing species such as Carcinus meanas to feed lobsters might be unfeasible, Jassa, Corophium, and Gammarus do extremely well on the detritus present in the ESL aquaculture system provided there is sufficient aeration. In contrast to cultures of Artemia which are subject to periodic crashes, the population of these species in the raceways has remained consistently high (despite rather drastic temperature and salinity fluctuations) for five months, and shows no signs of destabilization at this writing.

Because of the difference in size between the animals used in these experiments and those used in the Capitella study, absolute weight gain cannot be used as a criterion for comparison. Looking at the percentage weight gain for Group 3, however, (81% ± 20) we find that it compares favorably with that calculated from the high density Capitella data (71% ± 14).

The lack of significant difference between groups 1 and 2 is another indication that the molluscan pseudofeces provide whatever algal-based nutrients the lobsters require.

The large variations in growth (from 50 to 100%) exhibited both in these data and in work currently in progress by lobsters maintained individually under identical conditions reinforces the observations of Hughes (Hughes and Matthiessen, 1962) that considerable genetic variation exists in natural lobster populations. The contribution of this inherent variation to the growth differentials observed when large numbers of Homarus are grown together in mass culture must not be overlooked in discussing the effects of intra-specific competition in these situations.

Conclusions

It is apparent that young lobsters grow extremely well on food available in the ESL raceway ecosystem. Further work is desirable to determine whether the growth of these animals might be even greater if Capitella were available in addition to the food species discussed here. Compared with lobster culture systems depending on expensive artificial rations, the finding that Homarus can be reared at least to yearling size in a polyculture system without the addition of any supplementary food whatsoever is indeed heartening. Further studies are underway to determine optimum stocking densities for growth in such a system, as well as the potential for grow-out systems for larger animals.

TABLE 1

Group	Intermolt (av. days)	"t"	Weight gain (av. grams)	"t"
1 (mussel spat)	15.4± 2.7	2.466*	0.43±0.12	2.876+
2 (spat + algae)	16.2±2.9	2.151*	0.44±0.13	3.013+
3 (entire assoc)	16.8±4.1	1.75*	0.72±0.18	3.380#
4 (biodep. only)	22±5.5		0.23±0.03	

*significant to .10 level
+ significant to .02 level
# significant to .01 level

COMMUNAL HABITAT DESIGNS: MULTIPLE TIERS, MESH SIZE SELECTION, AND RACEWAY RELEASE

JEFF THIELKER, JOE LEVINE AND GREG REDMANN

Introduction

High density lobster aquaculture has been hindered by agonistic induced mortality and growth inhibition. As an alternative to individual rearing techniques, a variety of configurations for communal rearing were examined to optimize high density survival and growth.

The first experiment consisted of releasing postlarvae in a raceway to determine settlement patterns and survival. Another set of experiments was to determine lobster inhabitance and survival patterns on multiple level communal environments, done with both adults and postlarva. The third set of experiments was done to measure habitat partitioning in a communal system with varying mesh size habitats.

Raceway Release

To determine the vertical settlement preferences of lobster postlarva and the possibilities for inoculation of a viable lobster population into the ambient ESL oyster tray raceway system, a stack of oyster trays was partitioned off with Vexar 20-DDS-129 mesh which has a .35 cm mesh size, smaller than the 5th stage postlarval carapace diameter. Since the trays rested off the bottom, a mesh frame with oysters was added on the bottom. One hundred eighty-5th stagers were released into the area on July 12, and on July 29, it was observed that *Fundulus* devoured other lobsters that were introduced. The experimental set up was broken down, and 8 lobsters were recovered, 6 on the bottom and 2 on the top tray, the rest having been eaten by *Fundulus*. The fish were removed, and the area re-stocked with 300-4th stagers on July 31, and broken down on

August 23. A large number of grass shrimp, *Paleomonetes* were present, and apparently either ate or outcompeted most of the lobsters, since only 21 were recovered, 18 on the bottom.

It appears from these results that given an open raceway polyculture system without enclosed trays, that other tertiary consumers may outcompete or preyed upon the lobsters. The relative survivorship is too low to generalize about the settlement preferences, although the bottom seems preferred. If the lobsters are enclosed in trays, however, it seems likely that high density growth is feasible (see O'Neill this volume; also Mitchell, 1975 and Levine, 1975).

OBSERVATIONS ON POST LARVAL LOBSTERS

MATERIALS AND METHODS

In order to test survival and behavior of sub-adult lobsters when subjected to a three-dimensional environment, a multi-tiered box was constructed and floated in a raceway. The raceway involved was partially filled with stacks of oyster trays, and was supplied with algae and filtered seawater at a ratio of 1 to 10.

The tier box was built of untreated spruce and Conweb NP-5001 mesh. A plywood cover prevented direct sunlight from interfering with the lobster's behavior, yet light diffusing through the water was sufficient to sustain algae growth as evidenced by the propagation of green filimentous algae, and sustained growth of Chondrus which was placed in the box. Dimensions of the box were 60 cm x 55 cm x 100 cm. The 55 cm x 100 cm bottom gave a floor area of .55m^2. A total bottom area of 1.19 m^2, was obtained by the addition of a pair of double-tiered stacks located at both ends of the box. (See Fig. 1.) They were arranged vertically in order to obtain an overhead clearance of 20 cm over each tier. Ladders connecting each level, made of 17 cm wide mesh strips, were staggered so that a climbing lobster had easy access to the middle tiers without going to the top. Each tier, as well as the floor of the box, was constructed of the same mesh that composed the perimeter of the habitat. Four cm long oyster shells were scattered over the entire bottom area, which provided the lobsters with a burrowing and shelter-building substrate as well as nuclei for biodeposit coagulation. Nereis and Capitella growing in the raceway thus had a suitable environment. Thirty 10 cm long oysters supplied the biodeposition for these potential lobster food sources.

One six inch long shelter per lobster was provided so that, though there were sufficient shelters available, competitive interactions would be assured. In Run #1, they were longitudinally cut four inches I.D. polyvinyl chloride piping. The shelters for the second run were made of transite (cement) piping of the same dimensions. Eight of these shelters were placed on the tiers, two on each, and seven on the floor of the habitat.

Two control boxes with the same volume and bottom area per lobster as each of the experimental lobsters, were floated next to the large experimental box.

Seventeen lobsters ranging in carapace length from 4.3 cm to 8.3 cm were weighed, measured and examined for appendage status and identification. Two of these, one roughly one-third the length of the largest lobster, and one one-third times longer than the smallest, were selected and placed in the control boxes. The fifteen animals in the experimental box and those in the control groups each had a bottom area of .08 m^2 per lobster for a total stocking density of 12.5 lobsters m^2.

The mesh size of the plastic Conweb was large enough to permit water flowing through the raceway to carry away excess biodeposits, and allowed the various invertebra fauna growing in the raceway to enter the box. These potential food sources for the lobsters were supplemented twice weekly by a handful of such organisms which were collected along the sides of the raceway. Control lobsters were fed the same ratio of animals.

On August 2 the lobsters were unbanded and introduced to the boxes. A twenty-minute observation followed immediately after stocking. All animals upon introduction went directly to the bottom of the cage. After five minutes, six lobsters were observed climbing walls and ladders. No fighting occurred. By the end of the observation period, three animals were in shelters, one on each of the middle tiers, and one on the cage floor. Both control lobsters were in their shelters. In order to eliminate behavioral disparity due to time period activities, fifteen-minute observation periods were made every other day at 4:30 in the afternoon, during which time tier occupation was recorded and activity noted. After one day three shelters were overturned, which I righted. Each following day an increase of overturned shelters was observed; lobsters occasionally using the side of an uprighted pipe as a shelter, or simply sitting in the bottom of an upset pipe. Because I could see only half of the box without extensive rearrangement of my position, quantitative data of feeding and searching activities could not be made. Two night observations at 9:00 p.m. showed that no lobsters occupied shelters, but were instead engaged in climbing, eating, or searching.

After fourteen days, all shelters were overturned, so the box was lifted from the water and the shelters replaced by heavier, transite pipe. During this time the lobsters were counted and appendage loss recorded. In order to prevent overexposure to the air and sun, the lobsters were immediately lowered back into the raceway, then two lobsters were weighed and measured to replace the two that were missing. A fourteen day duplicate run was then implemented again with six, fifteen-minute observation periods. All shelters remained righted the

TABLE #1

		CARAPACE LENGTH (cm)		WEIGHT (gms)		WEIGHT	CLAWS	
		Original	Final	Original	Final	GAIN	Original	Final
	(1)	8.3	8.3	202.8	203.7	+ .9	Both	Both
	2	7.4	7.4	127.2	129.0	+1.8	Both	Both
	3	7.0	7.0	115.9	97.8	-18.1	Both	Crusher
(*)	4	6.9	-	96.6	-	-	Crusher	-
	5	6.3	6.3	76.8	77.6	+.8	Both	Both
	6	6.2	6.2	66.0	67.5	+1.5	Ripper	Ripper
	7	6.1	6.1	74.9	75.6	+.7	Both	Both
	8	6.1	6.1	66.5	66.9	+.4	Both	Both
*	9	5.3	-	44.2	-	-	Crusher	-
	10	5.3	5.3	42.6	42.8	+.2	Both	Both
*	11	5.2	-	28.5	-	-	None	-
	(12)	5.0	5.0	30.5	31.3	+.8	Both	Both
*	13	4.9	-	27.1	-	-	Crusher	-
	14	4.8	4.8	28.3	28.4	+.1	Crusher	Crusher
+	15	4.7	4.7	25.0	-	-	Ripper	-
	16	4.4	4.4	28.8	29.1	+.3	Both	Both
	17	4.3	4.3	25.3	20.4	-4.9	Both	Crusher
				CONTROLS				
	1	4.9	4.9	29.9	30.6	+.7	Both	Both
	2	6.5	6.5	97.5	98.9	+1.4	Both	Both

+ - Died due to overexposure between experimental runs.

* - Died during first run.

(*) - Survived first run, died during second.

O - New lobsters added at the start of Run #2.

duration of this run. Interestingly, the only lobster with no claws was very rarely found in a shelter. Instead it seemed to spend the majority of its time climbing the walls of the cage. While this conflicts with the hypothesis that subordinate lobsters rarely stray from their shelters, it suggests that the nomadic dominate lobsters constantly evicted this animal from its shelter due to the limited amount of available homes.

Results

As seen by Graph #1 and Table #2, there is an overwhelming occupation by the lobsters of the shelters on the tiers, though there is a significant difference between percentage of occupation in Run #1 as compared to the second run. Apparently no discrimination was made between middle and top tiers. Also, as far as I could tell, there was no size or claw advantage when considering orientation of tier positioning.

From Table #1 one can see that every animal gained weight, with the exception of the two lobsters that lost claws. T-test results showed no significance in weight gain of either experimental or control lobsters. The difference in weight gain between the control and experimental animals also was not significant.

Looking at Table #II, it is seen that an average 83.5% survival was obtained for a two-week period, which gives a final stocking density of 10.5 lobsters per square meter of bottom area. It should be pointed out that this value includes a lobster that had died from overexposure to the sun and air, at the termination of the first run. The mortalities of the other four lobsters are difficult to explain, since no fighting

TABLE #2

SURVIVORSHIP

Run #1	Run #2	Average
87%	80%	83.5%

SHELTER OCCUPATION

	Run #1		Run #2	
	One Shelter	Both Shelters	One Shelter	Both Shelters
Top Tier	67%	58%	100%	92%
Middle Tier	67%	41%	100%	92%

Low percentage occupation in Run #1 when compared to Run #2 may be attributed to the absence of suitable (upright) shelters. High occupancy on the tiers indicates co-existence preference rather than strong competitive conflicts for shelters on the floor of the box.

was observed. This, coupled with the fact that the lobster which died of exposure was not completely eaten whereas remains of the other four were devoid, led me to believe that these mortalities may have been due to cannibalism during or immediately following molt or escape from the box.

The final stocking density may or may not represent an equilibrium condition for the resources available to the lobsters. A longer experimental period would provide basis for this hypothesis formulation or dismissal. Although the 83.5 survival percentage is not outstanding for the time period involved, the remaining density may represent a maximum population stability point, allowing sufficient space for molting and growth.

Discussion

Indications of current work are that during the first three post-larval stages, lobsters will not inhabit the upper layers of a multi-tiered apparatus. Whether this is due to an overriding urge to seek the bottom, or whether it is an indication of behavioral immaturity is not certain. Mitchell (pers. comm.) observed that a number of behavioral patterns appeared to develop extensively for the first time in seventh stage animals. Climbing might be just such an activity. (Burrowing was also noted for the first time in seventh stage animals, as mentioned in the "Behavior" section of this report.) Additionally, maturation and intensification of patterns of social interaction in the seventh stage and sub-adult animals might put pressure on individuals to move to the upper tiers. No social hierarchy was observed in the aquarium or tier box, however, and the lobsters changed levels and moved around apparently unaffected by the other animals in the tank. Several parameters not studied in these experiments may help to understand the behavior exhibited. For example, sex determination may have revealed a social hierarchy occurring in the older animals since males have been shown to be dominant to females, often regardless of size. Further observations are necessary to better understand these parameters.

Other interesting results may have been obtained had the time span of the experiments been lengthened. According to Dunham (1972), animals held together for periods of time become accustomed to "communal" living. The aggressive use of claws may have been reduced in the sub-adults, since they were held together for two weeks with banded claws prior to the experiment.

Observations on Postlarval Lobsters, Multiple Tiers

Materials and Methods

The apparatus used for observation of fourth through seventh stage animals consisted of a glass and plastic aquarium measuring 76 x 31 x 31 cm. The tank was provided with a subsand filter plate modified to accept two ½" polyethylene siphon tubes for water outflow in addition to the two normal airlift tubes. Filtered seawater at an average temperature of 23°C was kept flowing through the system at a rate of 3 liters/minute. A layer of coarse gravel and pebbles 2-3 cm deep was used to cover the filter plate, and an additional 2-3 cm layer of a mixture of live oysters and oyster shells was added as a substrate for the lobsters. Before stocking the aquarium for each experimental run, the aquarium was seeded with large amounts of oyster feces and pseudofeces, *Capitella*, *Corophium*, *Jassa falcata*, and *Idotea baltica*, collected from the existing oyster/macroalgae culture systems in operation at the laboratory.

Observations were carried out in a blind constructed from a double layer of black polyester cloth. Illumination was provided by a 25-watt red ceramic incandescent bulb which burned continually, and a 20-watt cool white fluorescent tube operated by a timer synchronized with the natural light cycle. Nighttime observations were facilitated by the addition of another red bulb in a moveable fixture.

Additional levels were provided in the form of 25 x 25 cm trays constructed of small vexar mesh, Conweb Np-5001, and ½ pvc pipe which were stacked in pairs at both ends of the aquarium. Oysters and shells were placed on each layer to the same depth as on the bottom. "Ladders" of vexar mesh were provided to make it easier for the animals to change levels.

The lobsters used were hatched in the laboratory between late May and early July. All animals were maintained individually prior to use in experiments

and fed live *Artemia* daily. Oysters were obtained from the raceways at the laboratory, and were provided with 15 gallons of algae culture (predominantly *Phaeodactylum*) daily, over a period of eight hours.

Twenty lobsters were introduced to the aquarium in mid-morning and observations were made in groups of four 15-minute sessions one hour apart. Activities were classified into one of the seven categories reported by Joan Mitchell:

body care	general
locomotion	search/explore
social	shelter/substrate
feeding	

Each time an activity was observed it was tallied, and the total number of activity units per observation period was noted.

In order to ascertain that the vertical distribution of the animals in the apparatus was not influenced by a preference for oyster shells over gravel vs oyster shells over vexar, a series of substrate controls were conducted. In these trials a layer of vexar was placed between the oyster shells and the gravel on one half of the tank, the animals were introduced, and their positions noted after several days.

In all experiments, the final positions of the animals were determined by cautiously searching through the substrate and catching the animals one at a time.

Results

The data for fourth, fifth, and sixth stage lobsters (Figure 1) indicate an overwhelming preference for the bottom of the apparatus. Substrate controls for these animals showed no significant difference in substrate preference alone.

Seventh stage animals, however moved up onto the tiers in larger numbers, and were seen constantly climbing up and down the ladders. Paradoxically, the substrate controls for these animals indicated a definite preference for the oyster shells over gravel--a situation in which the animals could construct burrows.

Maintaining the apparatus in continuous low light (red light only) affected settlement only slightly; the majority of the animals remained on the bottom.

Discussion

Indications of the current work are that during the first three postlarval stages, lobsters will not inhabit the upper layers of a multi-tiered apparatus. Whether this is due to an overriding urge to seek the bottom, or whether it is an indication of behavioral immaturity is not certain. Mitchell (pers. comm.) observed that a number of behavioral patterns appeared to develop extensively for the first time in seventh stage animals. Climbing might be just such an activity. (Burrowing was also noted for the first time in seventh stage animals, as mentioned in the "Behavior" section of this report.) Additionally, maturation and intensification of patterns of social interaction in the seventh stage might put pressure on individuals to move to the upper tiers. No social hierarchy was observed in the aquarium, however, and the lobsters changed levels and moved around apparently unaffected by the other animals in the tank. Further observations are necessary to better understand these parameters.

Recent observations on the behavior of juvenile *Homarus* (Mitchell, pers. comm.) confirm that even in much larger habitats such as the raceways at the Environmental Systems Laboratory, the vast majority of the animals seek the bottom.

TABLE II

	Number of lobsters collected (results from three trials)
Top tier	3; 1; 2
Middle tier	4; 3; 4
Bottom	13; 16; 14

Variable Mesh-Size Selection

Materials and Methods

The four boxes used in this experiment were placed in a circular tank, equidistant from each other. The filtered seawater inflow of 2.41 liters per minute initiated a slow circular flow. Algal inflow of .6 liters per minute provided nutrient for the oysters in the boxes. Untreated spruce frames for the boxes had 30 cm dimensions on all sides. The bottom area of .09 m^2 per box was covered with oyster shells and contained two live 10 cm oysters to provide psuedo-feces for *Nereis* and *Capitella*. Each frame was covered with plastic mesh of sizes given by Table III. These mesh openings were slightly larger than the respective carapace widths of the four groups of lobsters given by Table IV. Ten lobsters of each molt stage four, five, eight and twelve were introduced. Two one-week duplicate runs showed no significant (σ = .05) difference between runs in any data points. During the experiment daily observations were made, recording lobsters found outside the boxes. The conclusion of each run involved counting the numbers of lobsters in and outside of the individual cages.

Results and Discussion

Upon introduction to the water, all lobsters went to the bottom of the tank. After a fifteen minute observation period, two twelveth stage lobsters and three eighth stagers were seen going into #4 and #3 boxes, respectively. All other lobsters were engaged in climbing and searching activities. Eight encounters were recorded, none resulting in claw loss. Six of the encounters involved twelveth stage lobsters while two involved eighth stagers. During the course of the two runs, no lobsters other than twelveth stagers were seen out of the boxes during the daylight hours. Frequent entering and vacating of the large mesh box by these older lobsters was observed. Night observations revealed from two to three lobsters of every molt stage outside the boxes.

Three molt shells were found; all shells belonged to twelveth stage lobsters.

On the following tables are listed results and calculations:

As seen by Table IV, the average value of 19.5 lobsters found in the boxes as compared to 11.5 not in the boxes was a significant inhabitance. More importantly, though, is the fact that the inhabitance in each box was predominately one particular age class; the age class that most closely corresponds to mesh opening. For example, 100% of Box #1 occupation is by fifth stage lobsters. This percentage drops to a minimum in Box #4 where 80% of the occupancy was by twelveth stagers. This may be explained by the dominance hierarchy that was established in the tank. The smaller animals, which had the lowest survivorship (Table V) were forced into the small mesh box by the dominant animals. Another explanation for the range of mortalities may be attributed to the fact that only 30% of the twelveth stage lobsters molted whereas 100% of the fourth and fifth stagers did.

A further correlation that should be pointed out is that of percentage of lobsters found in boxes with respect to molt stage. The subordinate animals seemed to seek shelter much more than did older, dominant ones. It should be noted that the percentage of twelveth stage lobsters found in the boxes is misleading, as these animals constantly traveled in and out of the box. It is possible, extrapolating these results, that if larger animals were added such as, perhaps, fourteenth stagers, the percent occupancy for the twelveth stage lobsters would increase.

The final stocking densities obtained are a rough approximation of the tolerance levels of lobsters with respect to their given age class, since homogeny of age class occupation in the boxes was high. Though the lobsters were essentially forced into these boxes, they could escape at their leisure. Exceptions occurred in the first two boxes; as the larvae molted, they became too large to exit through the mesh openings.

Ideally this experiment should be run through several molts. This way stocking densities would reach an equilibrium point and weight gains could be compared with lobsters grown in optimal conditions. The small sample size and limited test period severely inhibit result significance. However, the lobsters did seek shelter, and distributed themselves according to size, delineating a dominance hierarchy.

This method of self-induced size selection could be utilized as a means of harvesting the larger lobsters in a group, which would accelerate the growth of those remaining (Cobb and Tamm, 1974) and produce individuals of a specified, optimal size. Also this could possibly be used as a means of reducing the agonistic interaction in a communal rearing system.

TABLE II

	Type of Mesh	Size of Opening (cm)
Box #I -	Vexar 30CDS89	.25 x .35
Box #II -	Vexar 20PDS129	.25 x .4
Box #III -	Conweb SX2167	.6 x .7
Box #IV -	Vexar CDS 1/2"	1.25 x 1.5

$\bar{x}$ - CARAPACE WIDTH (cm) $\pm$ .02

4th Stage	.3- .4
5th Stage	.35-.45
8th Stage	.5- .6
12th Stage	.9-1.25

TABLE III

LOBSTER RECOVERIES

	BOX #I	BOX #II	BOX #III	BOX #IV	NOT IN BOXES
Run I	5 - 5th Stage	5 - 6th Stage	3 - 8th Stage	1 - 8th Stage 4 - 12th Stage	3 - 6th Stage 4 - 8th Stage 4 - 12th Stage
Run II	6 - 5th Stage	4 - 6th Stage 1 - 5th Stage	5 - 8th Stage	2 - 8th Stage 3 - 12th Stage	2 - 6th Stage 10 - 12th Stage
Total	11	10	8	10	23
Average	5.5	5	4	5	11.5

Note: An experiment termination distinction was not made between 8th and 9th Stage and 12th and 13th stage lobsters.

TABLE IV

% LOCATION OF ORIGINAL 10 RELEASED

	BOX #I	BOX #II	BOX #III	BOX #IV	NOT IN BOXES
Run I	50% of 5th Stagers	50% of 6th Stagers	30% of 8th Stagers	10% of 8th Stagers 40% of 12th Stagers	30% of 6th Stagers 40% of 8th Stagers 40% of 12th Stagers
Run II	60% of 5th Stagers	10% of 5th Stagers 40% of 6th Stagers	50% of 8th Stagers	20% of 8th Stagers 30% of 12th Stagers	20% of 6th Stagers 70% of 12th Stagers
Average	55% of 5th Stagers	5% of 5th Stagers 45% of 6th Stagers	40% of 8th Stagers	15% of 8th Stagers 35% of 12th Stagers	25% of 6th Stagers 20% of 8th Stagers 55% of 12th Stagers

TABLE V

SURVIVORSHIP

STAGE	NO. FOUND	% FOUND	% OF ORIG. 20 FOUND IN BOXES	% OF RETRIEVED FOUND IN BOXES
4th to 5th	12 of 20	60%	60%	100%
5th to 6th	14 of 20	70%	45%	64%
8th & 9th	15 of 20	75%	55%	73%
12th	18 of 20	90%	35%	39%

STOCKING DENSITIES - FINAL

Box #I	Box #II	Box #III	Box #IV
$61.1/m^2$	$55.5/m^2$	$44.4/m^2$	$55.5/m^2$

A Comparison of Survival Between Groups of Postlarval American Lobsters (Homarus americanus) in Different Density and Substrate Regimes in a Tertiary Treatment Aquaculture system

David J. O'Neill

Abstract

During the Summer of 1974, groups of postlarval American Lobsters, Homarus americanus, were reared in floating and submerged screen trays, and in 0.23 m^2 plywood compartments at the Environmental Systems Laboratory of the Woods Hole Oceanographic Institution.

No significant difference in survival was found in groups of lobsters grown in floating trays for periods up to 39 days at stocking densities of 17 and 50/m^2 as fourth stage larvae. Two groups at densities of 34 and 68/m^2 started later in the summer also did not differ significantly. Both late Summer groups had lower survival than the early Summer groups.

No difference in survival was noted between a group of postlarval lobsters grown in a tray with live oysters as a substrate, and a group grown with only empty shell. Abundant oyster pseudofeces were available to both groups.

Addition of a complex substrate to a rearing container appears to be favorable to better survival when lobster larvae are introduced intact to the system, but appears to have no effect if larvae have their claws removed.

Lobsters reared in a floating tray with rigid fiberglass maze substrate had significantly higher survival than lobsters reared in an identical tray with flexible plastic webbing.

The availability of prey in the rearing containers appeared to be the most important factor governing survival of groups of postlarval lobsters. The substrate used in an aquaculture system must then be attractive to prey species, as well as to the postlarval lobsters.

Floating or stacked rearing trays are suggested as an effective and relatively inexpensive method of rearing lobsters for the first two to six months of postlarval development.

Introduction

Active social interaction between lobsters frequently results in injury and death to large percentages of confined groups of postlarval lobsters. This problem must be overcome before effective lobster aquaculture can be achieved. Groups of lobsters stocked at densities of 230/m^2 over different substrates survive at different rates, apparently in relation to the ability of the lobsters to find shelter. On sand 5 survived/m^2, with pvc shelters, 22 survived/m^2, in loose rock cobbles, 24 survived/m^2, and in loose oyster shell, 30 survived/m^2 (Jon C. Van Olst, Ms in Prep, Aquaculture).

Oyster pseudofeces have been shown to be a suboptimal diet which allowed limited survival of postlarval lobsters (Bryden, Ms Thesis). Better survival is obtained when live Artemia is used as a food source. Survival of 94% of postlarval lobsters through six molts have been observed (Carlberg, MS in prep.). Survival of postlarval lobsters is strongly related to the quantity of available food, since as food available increases, canabalism decreases (Jon C. Van Olst, MS in Prep., Aquaculture).

A series of experiments were designed and executed to test the general hypothesis that postlarval lobsters could be integrated into the tertiary sewage treatment-aquaculture system of the Environmental Systems Laboratory of the Woods Hole Oceanographic Institution, in particular that fourth stage larvae could be raised through the postlarval stages in trays in use at the laboratory. Specific experiments test the hypothesis that; addition of a complex substrate to an oyster raceway faunal group would increase survival of lobsters; that the

initial stocking density is inversely related to the percent survival of the lobsters; that a live oyster substrate would be superior to dead, that is empty, shell with regard to lobster survival; and that a flexible synthetic substrate would be superior to a less complex rigid synthetic substrate with regard to lobster survival.

Materials and Methods

Experiments are designated as follows:

I Addition of additional substrate to oysters, associated fauna and lobsters.

IIa Early Summer stocking density 17 and 50 postlarvae/m^2.

IIb Late Summer stocking density 34 and 68/m^2.

III Live oysters vs. empty shells.

IV Artificial substrates.

General

Experiments were conducted at the Environmental Systems Laboratory of the Woods Hole Oceanographic Institution during the Summer of 1974. Experiments took place in the concrete raceways of the laboratory under ambient light and temperature conditions, 16-24°C. Experiment I was conducted in a fiberglass lined plywood compartmented box which was supplied with filtered sea water and phytoplankton culture independant of the raceways.

Postlarval lobsters were obtained from Joan Mitchell of that laboratory.

Species commonly observed in the raceway system and incorporated into all experimental apparatus were the polychaete worm Capitella capitata, the amphipods Jasa sp. and Coryphium sp. and the isopod Idoltea baltica. Oysters used in these experiments were obtained from Dr. John Ryther of the laboratory or purchased from a local shellfish supplier.

I. Additional Substrate Experiment

Six groups of early fifth stage lobsters were placed in 19 cm by 122 cm compartments in a single fiberglassed unit, 10 lobsters per compartment. Ten large (10-15 cm long) oysters (Crassostrea virginica) and an assortment of raceway fauna were placed in each compartment. Three of the compartments had a layer of fiberglass maze beneath the oysters to serve as a more complex substrate. The maze was constructed of $Filon_R$ roofing material which is corrugated. The $Filon_R$ was cut across the corrugations yielding strips of thin fiberglass sheet, 2 cm high with a wavelength of about 6 cm and a wave height of about 1.5 cm. The material was translucent yellow.

Three of the six experimental groups were declawed at the beginning of the experiment and approximately half way through the 47 day experimental run to examine the effect of claw removal on survival. Results of these experiments will be covered elsewhere.

IIa Stocking Density Experiment

Redwood oyster trays, trapazoidal in cross section, 1 m long at the top, 0.9 m long at the bottom, 0.8 m wide and 25 cm deep with coarse plastic webbing on the bottom were modified at the suggestion of Dr. John Ryther of the laboratory. Fiberglass window screen was used to line the bottom of the trays and stretched over a pine frame to form a tight fitting top. All trays were found to successfully contain fourth stage postlarvae.

Each tray contained 2 liters of live oysters 1-5 cm long and a few empty shells. One tray was stocked with 10 fourth stage postlarvae ($17/m^2$), another was stocked with 30 fourth stage postlarvae ($54/m^2$). Both trays were examined at irregular intervals. The $54/m^2$ tray was terminated at 39 days, the $17/m^2$

tray was terminated at 63 days. Numbers of lobsters, carapace length and molt stage (estimate) were recorded.

IIb After the termination of the 54/m^2 tray, it and a third tray were restocked with live oysters. In order to introduce adequate raceway fauna, each tray received 50 gms of Chondrus crispus and 25 gms of Artemia. In addition one tray received 20 fourth stage lobsters (38/m^2), the other received 40 fourth stage lobsters (68/m^2). At 23 days the experiment was terminated, and the survival difference between the trays compared by Chi-square analysis.

III Live Oysters vs. Shell

Two trays identical to those described above were stocked, one with 4 liters of live oysters, 1-5 cm long, the other with empty shells of the same size. Each tray also received 50 gms of Chondrus crispus and 25 gms of live Artemia to serve as a food source until raceway fauna became established. Twenty fourth stage lobsters were placed in each tray. The experiment was terminated at 24 days, and the number of lobsters surviving in each was compared by Chi-square analysis.

IV Artificial Substrates

Two trays were constructed of Vexar$_r$ CDS 89 mesh over a 2 cm by 3.5 cm pine frame. Each tray was 90 cm by 60 cm by 15 cm deep. A heavy plastic mesh was used to connect the bottom and top of the main body of the tray. Each tray had the same internal dimensions, and was fitted with a tight fitting top. Figure 1.

The bottom of one tray was covered with Conservation Webbing 200$_R$ a 3-M$_R$ product which consisted of loosely intertwined plastic filaments in a three dimensional mesh about 1.5 cm thick.

The bottom of the other tray was covered with Filon$_R$ maze placed in two rectangular matrices each 10 by 80 cm. Strips 10 cm wide by 80 cm long were layed horizontally beside the verticle array.

Twenty-four large oysters (10-15 cm long), 50 gms of Chondrus crispus, and 25 gms of Artemia were placed in each tray with 40 fifth stage postlarvae (74/m^2). After 23 days the number of lobsters surviving, and the relative abundance of different types of fauna were recorded. Number of lobsters alive in each group were compared by Chi-square analysis.

Results and Discussion

Postlarval lobsters can be successfully reared in floating or stacked trays containing live oysters. Lobsters were reared from the fourth stage to 13.8 mm mean carapace length in stacked trays in two and one-half months without addition of external food supplies after the day the lobsters were introduced. Van Olst (Ms in prep) grew lobsters from fourth stage to 13.9 mm mean carapace length in oyster shell substrate on a diet of frozen brine shrimp in six months. While temperatures in Van Olst's apparatus were cooler (14.5-21.5 vs 16-24°C), it is likely that the varied natural diet of pseudofeces, amphipods, algae and other prey species is superior to brine shrimp alone as a staple diet. Floating or stacked trays placed in an estuary would be orders of magnitude less expensive than shore installations in terms of physical plant costs, overhead, and power requirements.

I. Additional Substrate.

No clear cut conclusions can be drawn from the addition of substrate experiment. In groups where the lobsters had their claws removed, 8 and 9 lobsters survived when maze was present, 8 survived when oysters alone were present.

In the intact lobster groups, 7 of 10 lobsters survived when maze was present, but only 3 and 4 survived in the two groups where maze was not present. While these results are not statistically significant, I feel that further experimentation will show that lobster survival is likely to be greater in groups where many hiding places are available, such as in the case of the fiberglass maze. The removal of claws appears to reduce the importance of additional substrate.

IIa and IIb Density Experiments

No significant relationship between density and survival was observed in the short term experiments. Of the group of 10 fourth stage lobsters stocked at 17/m^2, 7 or 70% survived for 39 days. Seventeen of the 30 lobsters stocked at 50/m^2 survived to 39 days (57%). No significant difference exists in survival within the numerical framework of this experiment. The late summer results were (based on a 23 day period): Group of 20 (34/m^2) lobsters, 11 survivors (55%); Group of 40 (68/m^2) lobsters, 28 survivors (70%).

The group of 10 lobsters at 17/m^2 after 65 days had 6 surviving lobsters, a density of approximately 10/m^2. Several of these lobsters had lost one claw, apparently through agonistic encounters with other lobsters. Ten lobsters/m^2 seems to be a reasonable estimate of the carrying capacity of the tray environment for lobsters of this size (13.8 mm mean carapace length).

III Live oysters vs empty shell

No significant difference was observed in survival between the two groups. Eleven lobsters (55%) survived for 24 days in the live oyster group, while 10 (50%) survived in the empty shell group. No difference in the fauna present was observed between the two trays. Some detritus sifted into the empty shell tray from the trays above, providing, if not intact pseudofeces, organic matter to attract prey species.

IV Artificial Substrate

A significant difference in the number of lobsters surviving in the different artificial substrates was observed. Twenty-two lobsters survived the 23 day experimental period in the tray containing the rigid $Filon_R$ fiberglass maze. Five lobsters survived in the tray containing the more flexible Conservation Webbing 200_R (Chi-square significant $a = .05$ level).

The Conservation Webbing 200_R while appearing to be a more desirable substrate than the maze because it contained more nooks and crannies to serve as shelter, did not have as many amphipods attached to its surface as the rigid fiberglass structures.

Conclusion

Lobsters can be grown with little labor other than stocking and maintenance of trays in a combined aquaculture tertiary treatment system.

Floating trays are a tangible alternative to individual rearing for the first three months of postlarval life.

Food supply, or prey available to the postlarval lobsters appears to be extremely important in assuring high survival.

Survival of Pairs of Postlarval American Lobsters, Homarus americanus, in Different Substrate and Flow Conditions Through One Molt Cycle

David J. O'Neill

Abstract

One hundred and fifty pairs of postlarval American lobsters Homarus americanus were held from the day of their fourth molt, to the day of their fifth molt (through their fifth stage). Postlarvae were held under three substrate conditions at a moderate rate of water flow, and under low, medium and high flows under one substrate condition. One group had their major claws removed before the experiment. The experiments were conducted at the Environmental Systems lab of Woods Hole Oceanographic Institution during the summer of 1974 under ambient conditions.

No difference in survival was observed between the groups in the three substrates (P.V.C. hemicylinders, oyster shell, fiberglass maze.). Survival of pairs was significantly lower than survival of lobsters separated by a partition. Survival of lobsters which had had their large claws removed prior to the experiment did not significantly differ from the control (individual) lobsters. No difference in survival was noted between the groups held at three flow rates. No apparent difference was observed in average time to molt for the substrate or clawless groups. Mean weight gain per molt ranged from a high of 0.078 gms. in the control group to a low of 0.059 gms. in the clawless group.

Introduction

Social interaction between postlarval lobsters which results in death, molt inhibition (Cobb 1969, Cobb and Tamm, 1975), differential growth

(Mitchell, pers. comm., Van Olst, Pers. comm.), and cannibalism, presents a problem which must be overcome before mass rearing of lobsters is possible.

Two techniques which might be usefull in decreasing social interaction are mechanical separation of the lobsters, and reduction of the aggressive behavior of the animals. Van Olst (Ms in prep) has shown that lobsters reared im complex substrates have higher survival than groups raised in less complex substrates such as sand. Other investigators have used hemicylindrical pieces of P.V.C. pipe as shelter for postlarval lobsters, and have noted considerable interaction in small containers (Cobb, 1969). Cobb (1969) noted a differential in molting time between dominant and subordinate lobsters. Molt inhibition is a very subtle indication of agonistic interaction. Gross survival of lobsters, number of pairs which both successfully survive, and loss of claws by lobsters are all other measures of interaction, which may prove more easy to deal with statistically.

A second technique of mechanical separation is aggitation of the water in rearing container. High velocity streams of water in a rearing container might cause sufficient turbulence to mechanically reduce interaction, or to interfere with chemical, or tactile communication between lobsters. A large number of bubbles might also interfere with visual communication.

Adult lobsters have been shown to share shelter more frequently if one or both members of a pair are missing one or both of their major claws (O'Neill, MS Thesis). A similar reduction of aggression might be achieved in postlarvae.

The hypotheses: that pairs of postlarvae held together through one molt period would survive as frequently as pairs kept separate by a partition; that pairs with P.V.C. hemicylinders as shelter, pairs with loose oyster shell substrate, and pairs with fiberglass maze substrate would be equally likely to survive; that pair held at three different water flow rates would be equally

likely to survive; and that pairs of lobsters without claws would be as likely to survive as lobsters held individually, will be tested.

Materials and Methods

Experiments were carried out during the summer of 1974 at the Environmental Systems Laboratory of the Woods Hole Oceanographic Institution. Fourth stage lobster postlarvae were obtained from Joan Mitchell of the laboratory, and raised to their fourth molt, that is the beginning of the fifth stage, in individual compartments. On the day of their fourth molt, usually within a few hours of the molt, pairs of postlarvae were chosen at random and placed in the experimental trays.

Eight trays, 115 cm long, 11 cm wide were divided into 13 compartments, 11 cm x 7 cm x 4 cm deep. The trays were constructed of tempered masonite and coated with urathane plastic varnish. Each tray was painted with white epoxy paint to make the postlarvae easier to observe. Each compartment had an individual water supply from a Tygon$_R$ manifold stretched over the trays lengthwise. The strength of the water pressure in the manifolds, and the size of the holes in the manifolds governed the velocity and volume of flow to each compartment. Water drained from each compartment through small holes located below the rim.

Control compartments were made by dividing a standard compartment in half with a masonite partition. Control compartments received one shelter (a 3 cm length of 3/4 in. P.V.C. pipe cut in half lengthwise to form a hemicylinder) and one lobster. Pair compartments received two shelters and two lobsters. Control and pair compartments were alternated within the apparatus. Oyster shell compartments had a substrate of loosely piled small oyster shell (2-4 cm long) piled 1.5 cm deep over the bottom. Oyster shell compartments were

alternated with Maze compartments which had a substrate of Filon$_R$ fiberglass roofing material cut across the corrugations, in strips 10 cm long, 2 cm high and placed vertically (5/compartment) in brackets made from plastic lighting grates.

Fourteen pairs of lobsters had their large claws removed at the beginning of the experiment. They were placed two/compartment with P.V.C. hemicylindrical shelters.

Two replicates of Controls, Pairs, Oyster shell, Maze substrate, and No claw were run.

One replicate of a Pair type of substrate with high (600 ml/min.) and of low flow rate (10 ml/min.) were run for comparison of survival with the flow rate used in the other experiments (60 ml/min.).

If during the course of an experiment a lobster became lost, or was found in a compartment where it did not belong, any data from pairs involved was discarded.

Chi-Square analysis was used to compare survival of both members of pairs within experimental groups. As occasional system failures resulted in fatalities due to causes other than interaction between lobsters the total number of pairs in each experimental group differed. If two groups were to be compared, (control and pairs, control and no claw etc.) the total number of compartments in each experimental group, (t1, t2) were summed to yield the total in both groups (T). The relation $\frac{t1}{T}$ times the total Surviving pairs in both groups (S) yields the expected value for the first group (e1). Likewise $\frac{t2}{T} \times S = e2$. Simple Chi-Square analysis is used to determine if any difference in survival occurred between any groups being compared.

Postlarvae were fed live, frozen or freshly killed Artemia twice a day. Excess food and fecal matter were removed daily. Temperature ranged from

16-20°C. Trays were held in a fiberglassed plywood box, and covered to exclude direct sunlight or precipitation.

Results

Survival differed between the different groups. Table 1 presents the total number of pairs in which interaction was believed to occur during the experimental period, the number of pairs which survived, and the percentage of pairs which survived. Chi-Square values comparing differences in survival within groups, between pooled groups and the control, and between pooled groups are presented.

No difference in survival was observed between groups of postlarvae held at different flow rates, or between the groups held in oyster shell or fiberglass maze. Survival of pairs held in P.V.C. shelters at three different rates of flow was significantly different from the survival of control group. No difference in survival was noted between the lobsters which had had their claws removed before the experiment and the control lobsters. Survival of the lobsters in the more complex substrates, oyster shell and fiberglass maze did not differ significantly from the control group or the groups in P.V.C. shelters at different flow rates. Survival in the complex substrate groups was 63%, intermediate between the control (100%) and the pairs in P.V.C. shelters at different flow rates (54%).

Mean number of days to molt, and mean weight gain by surviving postlarvae are presented in Table 2. No apparent difference occurs in average time to molt. Lobsters held individually gained more weight than any other group, lobsters which had had their claws removed gained the least.

Discussion and Conclusion

Observation of large numbers of pairs of lobster postlarvae through a molt period appears to be a simple method of determining quality of a substrate for mass rearing systems. By using large numbers of test compartments (50 should be large enough), the quality of a substrate relative to individual rearing or to another substrate could be evaluated in about two weeks.

The low survival of pairs is not discouraging in the complex substrate (oyster shell and maze) compartments since the density of lobsters was high ($2/77\ cm^2$ on $284/m^2$), and since the survival of lobsters without the complex substrate, but with simple P.V.C. shelters was, while not statistically different, consistently poorer.

The slightly lower weight gain by lobsters without claws may be offset by their comparatively higher survival. The technique of claw removal as a means for reducing aggression in postlarval lobsters seems to be at least as promising as increasing the complexity of the substrate.

Table 1

Group	n	# Pairs Survived	%	Within Group	Control vs Experimental X^2	Between Group X^2
Control	24	24	100			
Pairs-P.V.C.						
Shelters						
10 ml/min.	15	7	47			
60 ml/min.	21	12	57	0.19		
600 ml/min.	14	8	57			
Pooled	50	27	54		7.39	
No Claws	21	18	86		0.22	
Oyster Shell	17	11	65	0.016		1.73
Maze	18	11	61			
Pooled	35	22	63		2.50	

Table 2

Group	Mean & Days to Molt	Mean Weight Gain (mg.)
Control	11.8	78
60 ml/min. Pairs	12.7	68
Oyster Shell	10.9	62
Maze	11.8	No Data
No Claws	11.9	59

Behavioral Observations on Juvenile *Homarus americanus* in Mass Rearing Systems

Joseph Levine

Introduction

In contrast to the relatively large body of literature on behavior of adult lobsters, relatively little work has been done on young post larvae. Herrick (1896, 1911) and Hadley (1906, 1907, 1908, 1912) did some of the earliest work in this area, but they were concerned either with strict natural history, or responses of lobsters over short periods to stimuli such as food or strong light. This area was then largely ignored until the more recent work of Cobb (1970) describing the influence of social interaction on the length of the intermolt period in fourth stage animals. Joan Mitchell (Ms in prep) described some aspects of the development of behavior in larvae and post-larvae and constructed ethograms for both larvae and post-larval animals through stage eight.

The current work was undertaken in an effort to determine the effect of several potential variables in an aquaculture system on the behavior of post-larvae.

Materials and Methods

All observations were carried out in the aquarium described in the "multi-tier" section of this report. Both the day/night and low light regimes previously described were used. Activities were again tallied in the manner mentioned earlier.

The stocking density was approximately $50/m^2$ in all experiments except for one in which it was doubled to $100/m^2$.

Before one set of observations, food in the form of *Capitella*, molluscan feces and pseudofeces, and several species of amphipods was added in excess. A

control experiment was performed by making a similar disturbance in the tank but adding only filtered seawater.

Animals were allowed to equilibrate in the apparatus for a minimum period of 24 hours before observations were begun, and the apparatus was seeded with food species as previously described.

Results and Discussion

The activities observed in the fifth and sixth stage animals under a normal day/night cycle followed a basically nocturnal pattern with bimodal activity peaks immediately before sunrise and during the twilight hours (Figure 1). The third peak visible in the predawn hours is believed to be an artifact of observation techniques. These data appear to conflict with yet unpublished data obtained elsewhere from observations on adult animals (JM Carlberg and JC Van Olst, MS in prep.) This discrepancy is not surprising as a number of behavioral changes have been observed in seventh stage animals (Mitchell, O'Neil, pers. com). It is not unlikely that this is a juvenile activity pattern which becomes modified as the animals mature.

When kept under a continuous low light regime, the animals exhibited much higher activity levels throughout the 24-hour period. (Figure 2) Animals in this group showed a mean difference of 12.5 activity units from the day/night group. Again, a basically bimodal pattern is evident, with generally higher activity levels during the night. As in the previous experiment, the pre-dawn peak is believed to be an artifact.

When food was added to the system in excess the effect was immediate and dramatic. (Figure 2) All animals immediately shifted to feeding oriented behavior. The amount of activity dropped to zero shortly thereafter and remained depressed until well into the evening. The animals remained in their

shelters for an extended period following this treatment since food was present in such quantity that they either found no need to leave their burrows to feed at all, or found sufficient food only a short distance away. During this period, virtually all social interaction ceased. It should also be noted that both mortality and claw loss were at or near zero during this two week experimental period. These data agreed well with those of Van Olst (Ms in prep, b) which indicated a drop in cannibalism at higher food levels.

The effect of doubling the stocking density on activity was quite pronounced. When the animals were stocked at a density of $100/m^2$, all observed activity cycles disappeared completely and were replaced by an extremely high level of activity (105-120 activity units/fifteen-minute observation period) which was maintained continuously throughout the 24-hour period. At the end of this experiment, which lasted only five days, only 17 out of 20 animals were recovered, and one of these had lost a claw. Further studies utilizing stocking densities intermediate to those mentioned are planned.

Miscellaneous Observations

Shelter related behavior: Fifth and sixth stage lobsters are able to find satisfactory shelter under small (2-4 cm) oysters, and inside empty shell of similar size. Once the animals molt to seventh stage however, they find these shelters insufficient and continually search for larger ones. This phenomenon greatly increases the probability of encounters between animals, and coupled with the observation that fierce aggressive behavior patterns begin to appear at this time (Mitchell, O'Neill, pers. com) foreshadows increased and more violent social interaction at previously satisfactory stocking densities.

Feeding Behavior involving species present in the aquaculture environment:

All stages observed (fourth through tenth) devour Capitella.

Late fifth stage animals learn to eat the females of the small amphipod Jassa falcata (Montagu), while treating the larger males as intruders rather than food.

Sixth stage animals soon learn to feed on Jassa of all sizes as well as the various species of Gammarus and Corophium present in the system.

Seventh and eighth stage animals begin to utilize the spat of the mussel, Mytilus edulis, by crushing the shells with their mandibles.

Palaemonetes proved to be an unsatisfactory food, because although dead shrimp were instantly eaten, even 4-5 year old lobsters seemed unable to catch live ones maintained in the same aquarium over a period of almost four weeks.

Idotea baltica and I. phosphorea proved to be unpalatable to lobsters of all sizes. Additionally, large Idotea have been observed to eat small (fourth-sixth stage) juvenile Homarus.

Conclusion

The current work confirms that several factors (light, size of available shelters, amount of food present, age of animals) in addition to stocking density strongly influence the behavioral interactions among post-larval lobsters and therefore necessarily affect their growth. High food levels, large shelters, and a normal day/night cycle appear to be helpful in minimizing social interaction and resultant injuries. Further studies must be made of these parameters in order to determine the optimum environment to produce maximum yield from a mass culture system.

FIGURE 1
NORMAL DAY / NIGHT CYCLE

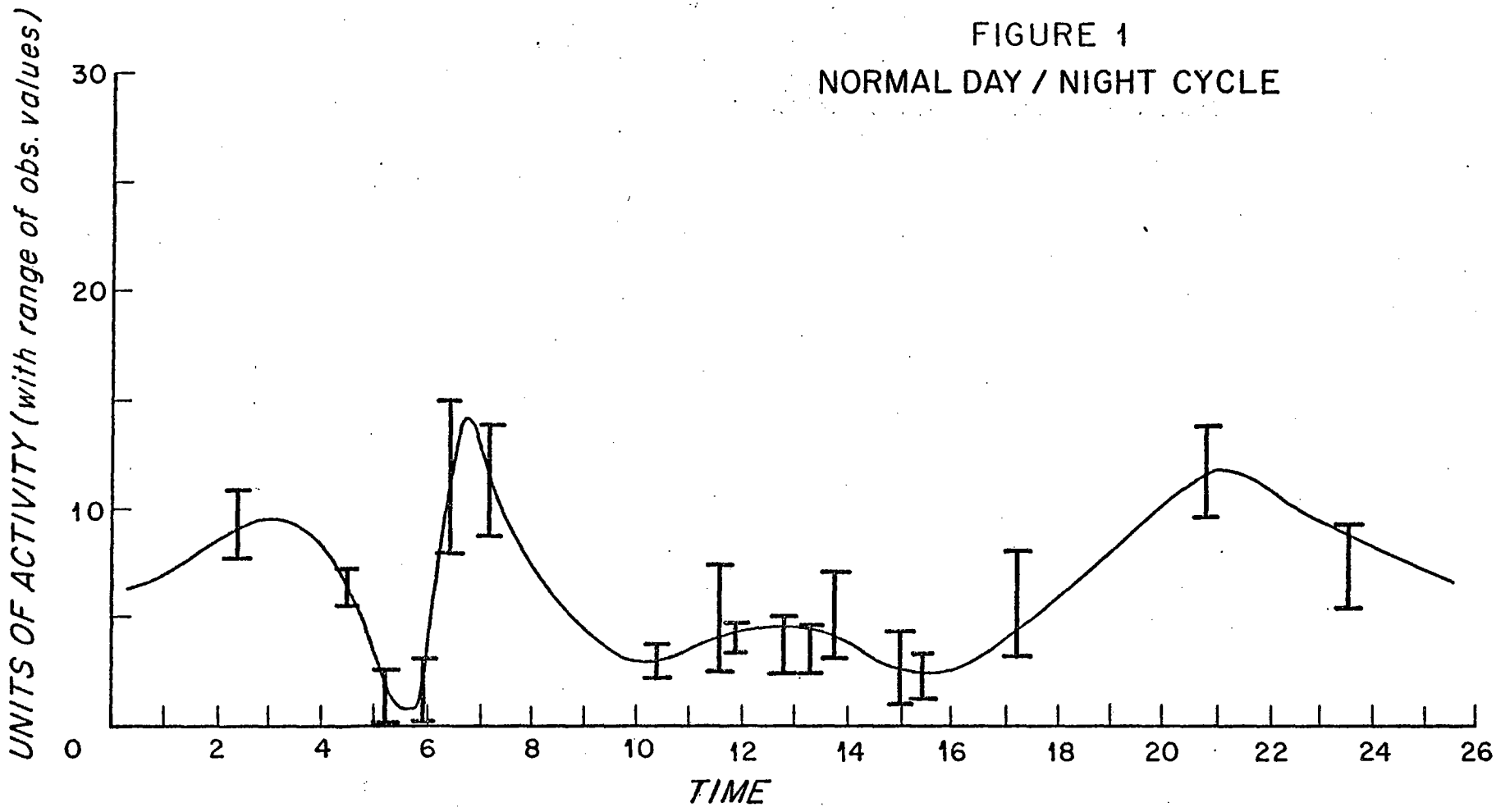
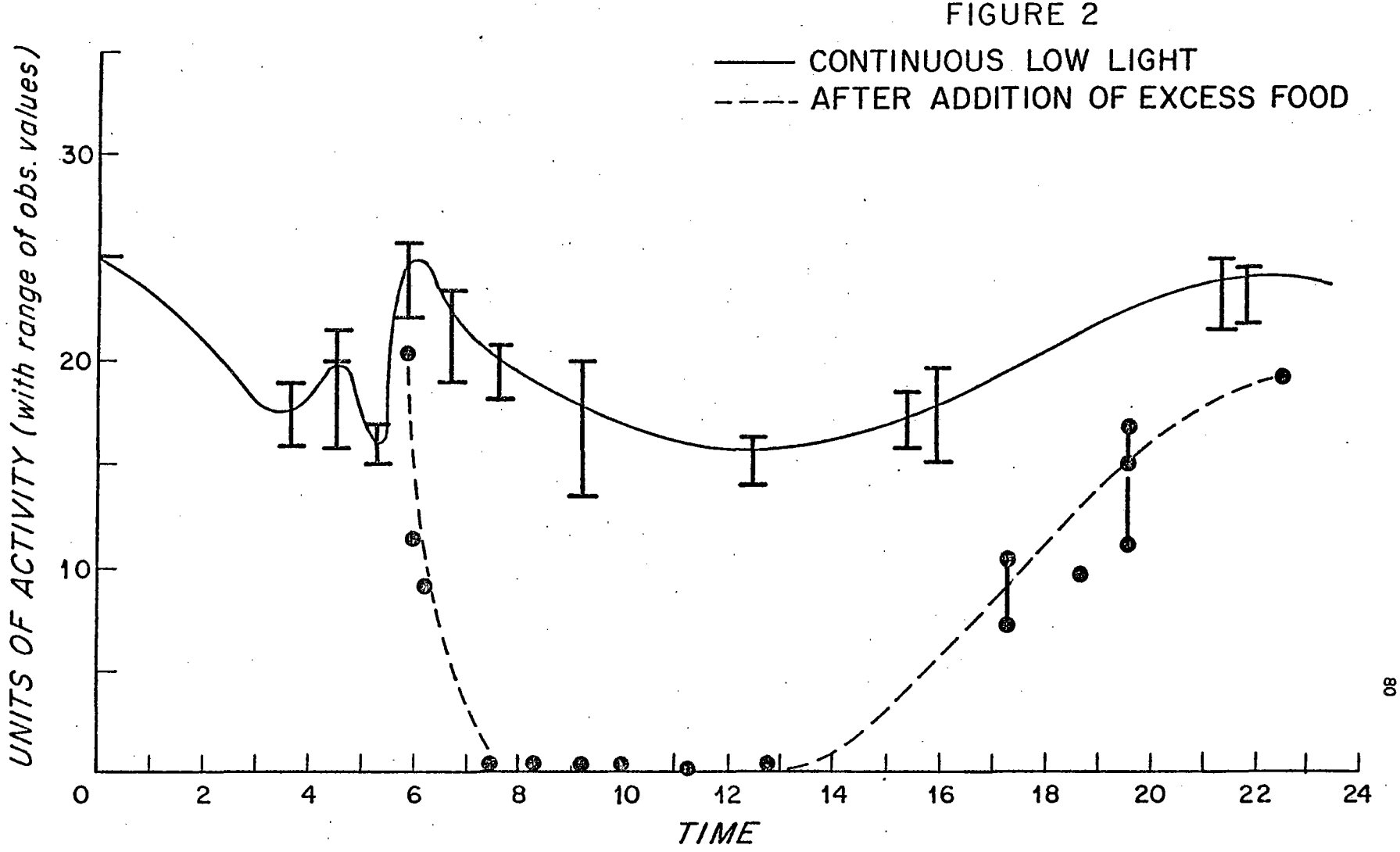


FIGURE 2


CONTINUOUS LOW LIGHT
AFTER ADDITION OF EXCESS FOOD
UNITS OF ACTIVITY (with range of obs. values)
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME

POSTLARVAL BENTHIC SETTLEMENT PREFERENCES

GREG REDMANN and JEFF THIELKER

Introduction

Lobsters usually leave the plankton and assume an epibenthic life style at some point in the fourth larval stage, and the fifth molt can be considered analagous to settling and metamorphosis (Herrick, 1911 ; Cobb, 1968). Cobb (1968) measured the time between fourth and fifth molt as a function of substrate conditions, and found that gravel was preferred over mud, sand, and bare bottom as evidenced by the least mean time to molt. Von Olst (Klopfenstein, 1974) has found that postlarval growth and survival is maximized in mass culture by the use of large oyster shell base material as the substrate, which was determined to minimize encounters and cannibalism between animals. Schleser (1974) has found that postlarval lobsters in opaque tubes had greater survival than groups kept on sand, mud or gravel.

There is some interest in augmenting wild stocks of lobsters with release of hatchery-reared postlarvae, and thus information as to the most preferred bottom type for postlarval settlement could be useful. To help clarify the preferred bottom type for postlarval lobster settlement, both in the field and relevant to aquaculture operations, tests were run allowing postlarval lobsters to select among several bottom types.

Materials and Methods

A round tank 1.02 m in diameter, with a depth of 30.5 cm was divided into four quadrants with a reinforced screen wedge as the bottom for each quadrant, onto which were placed different test substrates. Water turnover time was 1 hour, 50 minutes at a flow rate of .125 l/sec of 21°- 24°C ambient seawater, taken from the ESL lines on Vineyard Sound. Total bottom area was .92 m^2 or

.23 m^2 per quadrat. Fourth or fifth stage postlarvae, 40 in each test, were released and the number of individuals in each type of quadrat was counted six days after release by dismantling the test tank. Local bottom flora from the Woods Hole area, *Codium fragile*, *Chondrus crispus*, and *Zostera* were used in different quadrats; as were medium-sized oyster shells. Beach stones 3-6 cm in diameter were used with some of the natural substrates. Periodic observations were made, and the outdoor tank was covered with vexar mesh during the day to reduce light levels and a plywood cover at night.

Experiments and Results

Three separate experiments were run, and the data are shown in Table 1. In the first , bottom types consisted of *Chondrus* attached to the rocks it was collected on, *Codium* and *Zostera* in sand, and oyster shells. In the second , *Codium*, *Zostera* and *Chondrus* were all run with 40 3-6 cm sized stones; but the *Chondrus* was tied with black fishline to stones rather than using the *in situ* rocks which had a variety of epifaunal species. In the third experiment, *Chondrus* with rocks and sand, *Chondrus* with sand, rocks with sand, and oyster shells were used as the substrates, to isolate which component of the *Chondrus* association was most attractive. Overall survival was generally high, ranging from 75% to 93% from the six day test period.

In the first test, (Table 1) the postlarvae exhibited a definite aversion to the *Codium*-sand and *Zostera*-sand substrates, and an attraction to the *Chondrus*-rock and oyster shell substrates ($P < .005$, by χ^2). In the second test, with clean rocks used with the *Chondrus*, *Zostera*, and *Codium* substrates, no significant differences occurred in the distribution of the lobsters among the 4 quadrats, indicating that there was no selection based on species of plant cover, and that oyster shells seem as attractive as any natural substrate. The third test showed that there was selection for the *Chondrus*-rock-sand and oyster shell substrates, and aversion to the rock-sand and *Chondrus*-sand substrates ($P < .010$).

These results seem to indicate that initial postlarval substrate selection is thigmatropic and possibly negatively phototactic rather than being based on any of the species of bottom cover tested. Initial observations showed that the fourth-stage larvae swam around the surface, bumped into and explored the floating fronds of *Codium* and *Zostera*. Hughes (p.c.) has observed lobsters released in the field to swim around until encountering kelp fronds, then exploring these and descending the stipe. Apparently final substrate selection depends only on near-bottom, or epibenthic thigmataxis, although perhaps one of the cues to settling is off-bottom encounter with some attached object (Cobb, 1968; Herrick, 1911; Hughes, p.c.; Klopfenstein, 1974; Schleser and Tchobanoglous, 1974). The selection of the *Chondrus*-rock substrate over the component substrates could possibly indicate that the thigmatropic response is enhanced by environmental heterogeneity.

These observations correlate well with the work of Cobb, Schleser and Von Alst, all of which can be considered as indicative of postlarval preference for the more thigmatactically complex substrate, which also tends to reduce the probability of intraspecific encounter.

TABLE 1

Number of postlarval lobsters recovered from each quadrant in three different substrate selection tests. A population of 40 postlarvae was released and recovered after six days. Significant (by Chi Square) selection for the more complex environments was shown in Runs I and III.

Substrate	Number of Lobsters Run I	Run II (with Rocks)	Run III
Codium	2	6	
Zostera	3	11	
Chondrus	14	9	
Oyster Shell	11	8	
Total	30	34	
	P <.005	N.S.	
Rock-Sand			3
Chondrus-Sand			5
Chondrus-Rock-Sand			15
Oyster Shells			14
Total			37
			P <.010

FOOD SELECTION IN SUBADULT *HOMARUS AMERICANUS*

GREG REDMANN

Homarus americanus is an omnivorous feeder and the bulk of its natural food is made up of a variety of benthic invertebrates, mainly crabs, polychaetes, mussels, periwinkles and asteroids, but other species are also eaten (Herrick, 1911, Squires, 1970; Weiss, 1970; Ennis, 1973). The percentage occurrence of the various prey species in lobster stomachs varies considerably from one area to another and it has been suggested that lobster stomach contents reflect the relative abundance of prey species in the habitat (Miller *et al*, 1971; Ennis, 1973).

However, most predatory species exhibit a certain degree of selectivity in choosing among prey items (Ivlev, 1961; von Westernhagen, 1974). Since stomach content analyses alone do not distinguish between the availability of prey species and the predator's selection for it, controlled experiments were carried out to determine electivity indices (after Ivlev, 1963), for several potential prey species of *Homarus*. Besides indicating the possible preference for species in the field, such information could be useful in indicating which of an array of species the lobster would choose within an aquaculture system, and what "flavor" might be preferred in artificial foods.

Materials and Methods

The experimental technique used was modified after von Westernhagen (1974). Ten subadult lobsters (between 2-3 years old, cf. Huges and Matthiessen, 1962) carapace lengths varying 48-66 mm (Table 1), were obtained by trap from the Woods Hole, Massachusetts area. Each was held individually in a 14"x24"x8" plastic container, with a flow of 20 l/hr of unfiltered seawater. Temperature was 24°-23°C, and green opaque plastic sheeting covered the shelves with the containers, to reduce ambient light intensity. Vexar covers were put over each container to prevent the lobster from throwing material out. The test

procedure was as follows: Each lobster was given approximately 30g of three different food items, or about 10g each; the food items weighed before being offered to the lobster, the remains removed after 24 hours had elapsed and weighed again. The relative difference in weights was used to calculate the electivity values. To produce comparability among the results, *Nereis virens* was always offered as one of the three food species (after von Westernhagen, 1974).

All food species were killed prior to feeding, and mollusks were crushed. Controls were run with the food species in water to correct for any weight loss. No attempt was made to determine what stage of the molt cycle the lobsters were in. The experiments were run from mid-July to early September, although no molting was observed.

Results and Discussion

Table 2 shows the electivity values for 13 potential prey species for the lobster. Positive selection for a food item is indicated if the E value is between +1 and 0; if a food type is consumed in the same proportion to its presence in the environment, then it has a value of 0; a value between 0 and -1 indicates that its presence in the diet is less than its relative abundance in the environment, or a negative selection.

Artemia have the highest value, but this is with a correction factor due to a 45% washout from the controls, so that this may not be an efficient food source for lobsters. Also the washout rate for *Artemia* may have been higher due to motion of the lobsters in the experimental trays then in the controls which would tend to give a higher E value. *Nereis* seems to be the most preferred food, possibly because it is a relatively frequently encountered benthic food item, and thus the lobster has a well-formed "search image"; and also because of its high caloric value and ease of manipulation by the lobster's mouth parts. *Fundulus* is next, although fish are infrequently found in the natural diet of

lobsters. Table 3 compares the ranks of several food items commonly found in lobster stomach content analysis by several investigators. The E values only indicate the lobster's preference for a food, and not its relative eatability or availability in the environment. Thus the high E value for fish may not reflect the actual degree to which fish would be consumed.

The relatively low E values for mussels and periwinkles is perhaps due to the stage of the molt cycle; Weiss (1970) and Ennis (1973) found that lobsters ingest large amounts of calcereous material following molting, relative to pre-molt consumption. Since these were probably pre-molt animals, the E values may be somewhat lower than for post-molt lobsters.

In general, the E values correlate well with the relative abundances in the various stomach content analyses. although the relative abundances of prey species in the field is an important consideration. However, the fact that significantly different selection is shown for different food items seems to modify the assumption of Miller *et al* (1971) that lobsters consume food only in proportion to the abundance in the environment. However, the maximum E values obtained are low relative to the theoretical maximum for E values, showing that on the whole lobsters are not overly selective in their diets for the range of food items tested. The very low values for the species of algae tested (-.8 and -.9) would seem to indicate that a strong aversion is shown for algae, although there is the possibility that a greater preference may be shown at some other stage of the molt cycle, since it is possible that certain algal constituents serve as ecdysome precursors (Atema, 1974).

In general, the higher E values correlate with the higher caloric contents for the benthic species determined by Brawn *et al* (1968). Ontogenetic variation as well as molt cycle and seasonal variations in feeding rate should be taken into account also, although Weiss (1970) has found only slight differences in the diet of 30 to 100mm carapace length lobsters.

These data may be of use in preparing artificial foods or optimizing the potential food species for lobsters in a polyculture complex; also the data should be of some use in relating stomach content analyses to field abundances, although further work along these lines should be done.

TABLE 1

Individual lobster sizes (CL) in mm and sex, with prey species combinations and time intervals in days of electivity tests. See Table 2 for species code numbers.

Lobster	Size (CL)	Sex	Test Day and Species Tested					
			1	8	10	12	16	18
A	66	M	8, 7, 5	9, 2, 5	13, 3, 2	4, 10, 2	3, 7, 2	1, 11, 2
B	57	M	8, 7, 5	9, 2, 5	13, 3, 2	4, 10, 2	3, 7, 2	1, 11, 2
C	60	F	8, 7, 5	9, 2, 5	13, 3, 2	4, 10, 2	3, 7, 2	1, 11, 2
D	55	F	8, 7, 5	9, 2, 5	13, 3, 2	8, 10, 2	3, 7, 2	1, 11, 2
E	48	M	8, 7, 2	9, 2, 5	13, 7, 2	6, 10, 2	1, 12, 2	1, 4, 2
F	47	M	8, 7, 2		13, 7, 2	6, 10, 2	1, 12, 2	1, 4, 2
G	51	M	8, 7, 5		13, 7, 2	6, 10, 2	1, 12, 2	1, 11, 2
H	52	M	8, 7, 5		13, 7, 2	8, 5, 2	1, 12, 2	1, 11, 2
I	52	F	8, 7, 5	9, 2	13, 7, 2	8, 5, 2	1, 3, 2	1, 9, 2
J	51	M	8, 7, 5	9, 2	13, 7, 2	8, 5, 2	1, 7, 2	1, 9, 2

TABLE 2

Mean electivity values (after Ivlev, 1961) for thirteen potential prey species of *Homarus americanus* in order of preference.

Species	E Value	Standard Deviation	95% Confidence Limits of Mean	N
1 *Artemia*	.248	.148	.165 to .330	15
2 *Nereis*	.221	.194	.202 to .239	49
3 *Fundulus*	.220	.106	.118 to .324	7
4 *Palaeomonetes* sp.	.144	.080	.030 to .258	5
5 *Cancer* sp.	.102	.194	-.067 to .269	8
6 *Strongylocentrotus*	.053	.051	-.317 to .424	3
7 *Asterias*	-.049	.268	-.199 to .099	15
8 *Mytilus* (w/shell)	-.188	.229	-.387 to .010	8
9 *Arbacia*	-.330	.289	-.658 to -.003	6
10 *Littorina* (w/shell)	-.385	.074	-.457 to -.313	7
11 dead *Homarus*	-.525	.458	-.100 to -.006	6
12 *Gracilaria*	-.884	.051	-.994 to -.774	4
13 *Chondrus*	-.919	.123	- 100 to -.829	10

TABLE 3

Lobster prey species ranks by electivity value and stomach content analysis.

Prey Species	Stomach Content Analysis A	B	C	D	E Value
Crabs	2	2	1	1	3
Mussels (bivalves)	1	4	3	4	6
Polychaetes	3	1	4	3	1
Periwinkles (Gastropods)	4	3	6	2	7
Echinoids	5	5	2	8	4
Asteroids	6	6	5	8	5
Fish		(bait)	8	5	2
Zostera and Algae		7	7	6	8
Hydrozoa		8		7	

A. Prince Edward Island; Scarret (in Miller *et al*, 1971)

B. Port Au Port Bay, Newfoundland; Squires, 1970

C. Bonavista Bay, Newfoundland; Ennis, 1973

D. Long Island Sound; Weiss, 1970

DISCUSSION AND CONCLUSIONS

The use of a multitrophic level combined marine aquaculture-tertiary sewage treatment system can produce nutrient-free effluent and a variety of biological marine products. The studies presented in this report covered various aspects of incorporating lobsters into this simplified food chain, chiefly as primary carnivores on the detrital trophic level. Table I compares postlarval lobster growth rates using various component food species from the Environmental Systems Laboratory raceways with growth rates achieved by Bryden (1973) using quahog meat and biodeposits and Wilder's theoretical values (1953). Weight to carapace length conversions were taken from Wilder (1953), where $\log W = 3.2068 \log CL - 3.4806$. The growth increments per molt are less than those given by Wilder, but in all cases the ESL food species lead to greater lobster weight increases than either quahog meat or oyster biodeposits. The molting frequency data (Table II) shows a similar trend, particularly in the later stages with the epifaunal raceway communities as the food source, although the data is not as amenable for comparisons.

Since a variety of food species is better for lobster growth than only a few (Hughes and Mathiesson, 1962; Atema, 1974) it would appear that the variety of food species normally available to lobsters in the Woods Hole multitrophic level system would lead to a high rate of growth, particularly when the lobsters are enclosed in the bivalve rearing trays.

Sizeable communities of three genera of amphipods (*Corophium* sp., *Gammarus* sp., and *Jassa fulcata*), the polychaete worm *Capitella capitata* and seasonally spat of the mussel *Mytilus edulis* appear in the system. This use of a natural type food chain as a food source will allow a minimum of operational input necessary to feed and maintain the lobsters, once they are placed into sealed bivalve trays. Levine (1975) and Mitchell (1975) have extended the

growth studies from the postlarval stages over a period of several months and have achieved impressive growth rates. Mitchell (1975) grew lobsters in the raceway oyster trays for 7 months, and in communally held lobsters had 3.8 individuals/m^2 survive in a raceway at 15°C, which would have produced 113.0 g lobster/m^2/yr. Several held individually would have given a density of 92.3 individuals/m^2 for an annual production of 499.2 g/m^2/yr of lobsters, although with smaller individuals than in the communal set up. Levine (1975) found similar results, with up to possibly 500 g/m^2/yr of lobsters, although larger individuals at a lower density. He also suggested ways of optimizing the population structure for growth/unit area from postlarvae to adult in the ESL system, and work is currently in progress in this area.

To predict the maximum potential lobster production/unit area in a simplified food chain system, we need to consider the productivity of the potential food species and the food chain dynamics of an experimental system incorporating lobsters. Tenore *et al* (1974), found that 6 approximately 1m^2 trays of oysters can produce enough biodeposits to give 37.3 g C of the polychaete *Capitella* and 3.0 g C of the amphipod *Corophium*. Conversion factors used were .053 g C/g wet weight (from Tenore *et al*, 1974; Tenore and Gopalan, 1974) with .85 Kcal/g wet weight for *Capitella* and 1.050 Kcal/g wet weight for *Corophium* (assumed from Brawn, *et al*, 1968). This gives an annual production of 59.77 g C or 758.57 Kcal of *Capitella* per oyster tray (= m^2), and 4.56 g C or 90.39 Kcal of *Corophium*/m^2. Miller *et al* (1971) studied the production potential of a Nova Scotia benthic community and calcualted that .266 Kcal of lobster or .844 g wet weight, is produced per Kcal of prey species consumed. Assuming the 26.6% ecological efficiency given by Miller *et al*, and using the detritovore production values given by Tenore *et al*, we have an energetically feasible production of 885.33 g wet weight of lobster/tray/yr. With 50 trays/raceway (14.4m^2), this gives 6.98 tons/ha/yr of lobsters.

This falls in the range of 2.5 - 12 tone/ha/yr of primary carnivores which could result from natural systems (Ryther *et al*, 1972), although in this case, the 20-40 tons of herbivores produced can also be harvested, greatly increasing the utilizable productivity per ha.

To determine if the 885.33 g lobster/m^2/yr is a viable figure, it is necessary to ascertain that the caloric conversion of *Capitella* to lobster is valid, since Castell and Budson (1974) have shown that with isocaloric diets, optimum growth occurred only at the higher protein levels.

Mencher's data (this volume) on postlarval growth rates with *Capitella* as the food source bears out this optimum conversion efficiency. Growth of .065 g/ 28 days/.01m^2 occurred, or 84.73 g/m^2/yr, at a *Caprilla* density 1/11 of that achieved by Tenore *et al* (10,000 ind/m^2 vs 110,000 ind/m^2). However, it should be kept in mind that at higher densities of lobsters increased density dependent intraspecific growth inhibition may occur, although it should be possible to optimize the number of animals/unit area so to maximize total growth or size specific (e.g. 454 g) individuals are produced. To approach the energetic potential though, losses due to behavioral interactions need to be minimized, possibly by increasing the structural complexity of the tray--containers, in a way also attractive to the food species.

In addition to lobster density optimization, such as is being done by Levine (1975), growth rates can be enhanced by additional food sources such as mussel spat feeding on the phytoplankton can contribute, and perhaps be supplemented by separately raised brine shrimp (Ryther *et al*, 1974; Hamman and Botsford, 1975). Alternate food sources such as *Nereis* could be used instead of *Capitella*, but the *Nereis* production values obtained from Tenore *et al* (1974) indicate that only 129.3 g wet weight of lobster/tray/yr could be obtained from solely *Nereis*.

There is some ontogenetic variation in feeding behavior in lobsters in the postlarval stages (Levine, this volume) but little variation in feeding habits from 30mm CL (13th - 14th stage) on (Weiss, 1970). Thus perhaps a two stage food-complex supply might be the best bet for an aquaculture enterprise.

The role of lobsters in the natural benthic communities is probably diminishing due to fishing efforts in recent years, but its role as a Keystone predator (Mann and Breen, 1972) on *Strongylocentrotus* is interesting. Considering the neutral electivity value evidenced toward this species, and the low values of other species would seem to indicate that the lobster perhaps plays an important role in stabilizing other benthic prey populations, whose fluctuations aren't so easily evidenced by dramatic changes such as the kelp bed reductions.

TABLE I

Postlarval mean growth increments per molt in grams for Lobstaq experimental food sources compared with those of Bryden (1973) and Wilder's theoretical values (1953).

Molt	Growth Increment per Molt (g)			
	Experimental	Bryden (1973)		Wilder (1953)
		Quahog Meat	Oyster Biodeposits	
4-5	.040[a], .017[b]	.023	.018	.061
5-6	.065[c], .046[d], .029[e]	.029	.010	.139
6-7		.053	.011	.288
7-8		.078	.014	.614
8-9	.72[f], .43[g], .44[h], .23[i]	.167	.025	1.209

Experimental food sources:

a - meiofauna fed

b - biodeposits (Plasman)

c - 10,000 *Capitella*/m^2

d - biodeposits (Mencher)

e - biodeposits (Star)

f - entire raceway "mat" association

g - mussel spat

h - mussel spat and algae

i - biodeposits (Levine)

TABLE II

Molting frequency for postlarval lobsters expressed as mean time to molt and total percentage molt within a given time period. Mean molt times are expressed as 50%-molting. Data from Lobstaq experiments, mean temperature 22.8°C, are compared with Bryden (1973), mean temperature about 20°C, and Templeman (1948) mean temperature at 19.7°C.

Molt	% Lobsters Molting	Time (Days)	Conditions
4-5	50.3%	21	Biodeposits (Star)
	94%	21	Mesofauna (Plasman)
	42%	21	Biodeposits (Plasman)
	50%	14.4	Copepods and clam gonads (Templeman, 1948)
	50%	23.3	Oyster biodeposits (Bryden)
	50%	13.1	Quahog meat (Bryden)
5-6	100%	28	*Capitella* (Mencher)
	100%	28	Biodeposits (Mencher)
	33.3%	12	Biodeposits (Star)
	50%	18.3	(Templeman, 1948)
	50%	20.5	Oyster biodeposits (Bryden, 1973)
	50%	12.2	Quahog meat (Bryden, 1973)
8-9	50%	15.4	Mussel spat (Levine)
	50%	16.2	Spat and algae (Levine)
	50%	16.8	Mat association (Levine)
	50%	22.5	Biodeposits (Levine)
	50%	24.4	(Templeman, 1948)
	50%	21.1	Quahog meat (Bryden, 1973)

LITERATURE CITED

Atema, J. 1974. Interim report on a diet-pheromone-molting relationship in lobsters.

Bass, N.R. and A.E. Braffield. 1972. The life cycle of a polychaeta, *Nereis virens*. J. Mar. Biol. Ass., U.K. 52: 701-726

Brawn, V.M., D.L. Peer, and R.J. Bentley, 1968. Caloric content of the standing crop of benthic and epibenthic invertebrates of St. Margaret's Bay, Nova Scotia. J. Fish. Res. Bd. Can. 25 (9): 1803-1811.

Bryden, C.G. 1973. The use of shellfish feces as a food source for juvenile lobsters in aquaculture. Boston University Master's Thesis. 61 pp.

Castell, J.D. and S.D. Budson. 1974. Lobster nutrition: The effect on *Homarus americanus* of dietary protein levels. J. Fish. Res. Bd. Can. 31: 1363-1370.

Carlberg, J.M. (MS in prep. For Fish. Bull. Nat. Mar. Fish. Serv.) "Food Preference, Feeding Activity Patterns, and Potential Competition of the American Lobster, *Homarus americanus* and Ecologically Similar Crustaceans Native to California".

Cobb, J.S. 1968. Delay of Moult by the larvae of *Homarus americanus*. J. Fish. Res. Bd. Can., 25 (10): 2251-2253.

Cobb, J.S. 1970. "Effects of Solitude on Time Between Fourth and Fifth Molt in the American Lobster (*Homarus americanus*)". J. Fish. Res. Bd. Can. 27: 1653-1655.

Cobb, J.S. 1969. Activity, growth and shelter selection in the American lobster, *Homarus americanus*. Ph.D. thesis, University of Rhode Island.

Cobb, Stanley, "Ecology", Vol. 52, #1 p. 71.

Cobb, J.S. and Tamm, G. 1975. In press, J. Fish. Res. Bd. Can.

Davis, H.C. and R.R. Guillard. 1958. Relative Value of 10 Genera of Micro-Organisms as Foods for Oyster and Clam Larvae. Fishery Bulletin of the Fish and Wildlife Service, 58: 293-304.

Dane, R. F. 1972. Comparison of Various Allometric Relationships in Intertidal and Subtidal American Oysters. Fishery Bulletin of the Fish and Wildlife Service, 70: 1121-1126.

Duhnam, Philip. "Some Effects of Group Housing upon Aggressive Behavior of the Lobster, *Homarus americanus*". J. Fish. Res. Bd. Can. 29: 598-601.

Ennis, G. P. 1973. Food, feeding, and condition of lobsters, *Homarus americanus*, throughout the seasonal cycle in Bonavista Bay, Newfoundland. J. Fish. Res. Bd. Can. 30: 1905-1909.

Hadley, P. B. 1906. "Observations on some Influences of Light upon the Larval and Early Adolescent Stages of *Homarus americanus*". (Preliminary report), R. I. Comm. Inland Fish., 36th Ann. Rept., pp 237-257.

Hadley, P. B. 1907. "Continued Observation on some Influences of Light upon the Larval and Early Adolescent Stages of the American Lobster." (Continued report), R. I. Comm. Inalnd Fish., 37th Ann. Rept., pp 181-216.

Hadley, P. B. 1908. "The Behavior of the Larval and Adolescent Stages of the American Lobster (*Homarus americanus*)". J. Comp. Neurol. Psychol., 18: 199-310.

Hadley, P. B. 1912. "Reaction of Young Lobsters Determined by Food Stimuli". Science (Washington) 35: 1000-1002.

Hamman, M. and L. Botsford. 1975. Culture of lobsters in "green water". Sea Grant Lobster Workshop, April 21 at URI.

Herrick, F. H. 1896. "The American Lobster: A Study of its Habits and Development". Bull. U.S. Fish. Comm., 15: 1-252.

Herrick, F. H. 1911. "Natural History of the American Lobster". Bull. U.S. Bur. Fish., 29: 149-408.

Huguenin & Ryther. 1974. Waste Water Use in the Production of Food and Fiber - Proceedings, Oklahoma City, Mar 5-7, 1974, EPA-660/2-74-041.

Hughes, J. T. and G. Matthiessen. 1962. "Observations on the Biology of the American lobster, *Homarus americanus*." Limnology and Oceanography, Vol 7 #3: 414-421.

Hughes, J. T., J. J. Sulliven, and R. Shleser. 1972. Enhancement of lobster growth. Sci. 177: 1110-1111.

Ivlev, V. S. 1961. Experimental Ecology of the Feeding of Fishes. Yale University Press, New Haven, Conn., 302 pp.

Klopfenstein, D. and I. 1974. Lobsters are grown in cooling water. Fish Farming Intl. 6: 40-48.

Levine, J. S. 1975. Growth observations on *Homarus americanus* in a poly-species aquaculture system with *Crassostrea virginica*. Sea Grant Lobster Workshop, April 21, at URI.

Mann, K. H. and P. A. Breen. 1972. The relation between lobster abundance, sea urchins, and kelp beds. J. Fish. Res. Bd. Can. 29: 603-609.

Miller, R. J., K. H. Mann, and D. J. Scarratt. 1971. Production potential of a weaweed-lobster community in eastern Canada. J. Fish. Res. Bd. Can. 28: 1733-1738.

Mitchell, J. (MS in prep.) "The Development of Behavior in the American Lobster (*Homarus americanus*): Stages 1 to 8".

Mitchell, J. R. 1975. A polyculture approach to rearing lobsters. Sea Grant Lobster Workshop, April 21, at URI.

O'Neill, David J. Some factors influencing the outcome of shelter competition in the American lobster, *Homarus americanus* (Decapoda, Crustacea). MS thesis, University of Rhode Island.

Ryther, J. H., W. M. Dunstan, K. R. Tenore and J. E. Huguenin. 1972. Controlled eutrophication--increasing food production from the sea by recycling human wastes. Bioscience 22(3): 144-152.

Ryther, J.H., K.R. Tenore, J.C. Goldman, N. Corwin, J.E. Huguenin, C.E. Gifford, and J.M. Vaughn. 1973. The use of flowing biological systems in aquaculture, sewage treatment, pollution assay and food chain studies. Progress Rept. NSF - RANN GI-32/40.

Ryther, J.H., J.C. Goldman, C.E. Gifford, J.E. Huguenin, A.A. Wing, L.D. Williams, and B.E. Lapointe. 1974. Physical models of integrated waste recycling-marine polyculture systems. WHOI Contribution No. 3411.

Shleser, R. and G. Tchobanoglous. 1974. "The American Lobster as a Model for the Continuous Production of Quality Food through Aquaculture." MTS Journal, Vol 8, #8, pp. 4-8.

Shleser, R. and M. Gallagher. (MS) Formulations of Rations for the American Lobster, *Homarus americanus*.

Squires, H.O. 1970. Lobster (*Homarus americanus*) fishery and ecology in Port Au Port, Newfoundland. Proc. Natl. Shellfish. Assoc. 60: 22-35.

Tenore, K.R., M.G. Browne, and E.J. CHesney, Jr. 1974. Polyspecies aquaculture systems: the detrital trophic level. J. Mar. Res., 32(3): 425-432.

Tenore, K.R. and U.K. Goplan. 1974. Feeding efficiencies of the polychaete *Nereis virens* cultured on hard-clam tissue and lyster detritus. J. Fish. Res. Bd. Can. 31: 1675-1678.

Templeman, W. 1948. Growth per molt in the American lobster. Bull. Newfoundland Govt. Lab., 18: 26-48.

Van Olst, J.C. (MS in prep. for Aquaculture (a)). "Effects of Substrate Type on the Survival and Cannibalism of Juvenile *Homarus americanus* in Mass Rearing Systems".

Van Olst, J.C. (MS in prep. for Aquaculture (b)). "Survival, Aggression, and Cannibalism of Juvenile *Homarus americanus* in Mass-Rearing Systems at Three Food Levels".

Van Olst, J.C. (MS in prep. (c)). "Effects of Stocking Density on Survival and Cannibalism in *Homarus americanus*".

Van Olst, J. C., and David Sommerville. (MS in prep. for Fish. Bull. Nat. Mar. Fish. Serv.) "A Comparative Study of the Activity Rhythms in Three Decapod Crustaceans, *Homarus americanus*, *Panulirus interruptus*, and *Cancer anthonyi*.

Von Westernhagen, H. 1974. Food preferences in cultured rabbitfishes (Siganidae). Aquaculture 3: 109-117.

Walne, P. R. 1970. Studies on the food value of nineteen genera of algae to juvenile bivalves of the genera Ostrea, Crasmostrea, Mercenaria, and Mytilus. Fishery Investigation, Series II, Vol. 26 No. 5.

Weiss, H. M. 1970. The diet and feeding behavior of the lobster, *Homarus americanus* in Long Island. Ph.D. Thesis, University of Connecticut, Storrs, Conn. 80 pp.

Wilder, D. G. 1953. The growth rate of the American lobster (*Homarus americanus*). J. Fish. Res. Bd. Can. 10(7): 371-405.

Woods Hole Oceanographic Institution
WHOI-76-44

PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER (*HOMARUS AMERICANUS*) AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS by Dr. John H. Ryther, Joseph S. Levine, Fredrick M. Mencher, David J. O'Neill, Barbara Plasman, Jeffrey L. Star, Jeffrey L. Thielker, Karen Irving and Greg Redmann. 102 pages. April 1976. Prepared under NSF Grant GY-11544.

Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems Laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus.

The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

1. Lobster
2. Aquaculture
3. Advanced Sewage Treatment

I. Ryther, Dr. John H.
II. Levine, Joseph S.
III. Mencher, Fredrick M.
IV. O'Neill, David J.
V. Plasman, Barbara
VI. Star, Jeffrey L.
VII. Thielker, Jeffrey L.
VIII. Irving, Karen
IX. Redmann, Greg
X. GY-11544

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-76-44

PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER (*HOMARUS AMERICANUS*) AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS by Dr. John H. Ryther, Joseph S. Levine, Fredrick M. Mencher, David J. O'Neill, Barbara Plasman, Jeffrey L. Star, Jeffrey L. Thielker, Karen Irving and Greg Redmann. 102 pages. April 1976. Prepared under NSF Grant GY-11544.

Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems Laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus.

The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

1. Lobster
2. Aquaculture
3. Advanced Sewage Treatment

I. Ryther, Dr. John H.
II. Levine, Joseph S.
III. Mencher, Fredrick M.
IV. O'Neill, David J.
V. Plasman, Barbara
VI. Star, Jeffrey L.
VII. Thielker, Jeffrey L.
VIII. Irving, Karen
IX. Redmann, Greg
X. GY-11544

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-76-44

PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER (*HOMARUS AMERICANUS*) AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS by Dr. John H. Ryther, Joseph S. Lévine, Fredrick M. Mencher, David J. O'Neill, Barbara Plasman, Jeffrey L. Star, Jeffrey L. Thielker, Karen Irving and Greg Redmann. 102 pages. April 1976. Prepared under NSF Grant GY-11544.

Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems Laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus.

The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

1. Lobster
2. Aquaculture
3. Advanced Sewage Treatment

I. Ryther, Dr. John H.
II. Levine, Joseph S.
III. Mencher, Fredrick M.
IV. O'Neill, David J.
V. Plasman, Barbara
VI. Star, Jeffrey L.
VII. Thielker, Jeffrey L.
VIII. Irving, Karen
IX. Redmann, Greg
X. GY-11544

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-76-44

PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER (*HOMARUS AMERICANUS*) AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS by Dr. John H. Ryther, Joseph S. Levine, Fredrick M. Mencher, David J. O'Neill, Barbara Plasman, Jeffrey L. Star, Jeffrey L. Thielker, Karen Irving and Greg Redmann. 102 pages. April 1976. Prepared under NSF Grant GY-11544.

Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems Laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus.

The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

1. Lobster
2. Aquaculture
3. Advanced Sewage Treatment

I. Ryther, Dr. John H.
II. Levine, Joseph S.
III. Mencher, Fredrick M.
IV. O'Neill, David J.
V. Plasman, Barbara
VI. Star, Jeffrey L.
VII. Thielker, Jeffrey L.
VIII. Irving, Karen
IX. Redmann, Greg
X. GY-11544

This card is UNCLASSIFIED

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle PROJECT LOBSTAQ: INVESTIGATIONS ON LOBSTER (*HOMARUS AMERICANUS*) AQUACULTURE, ECOLOGY AND TERTIARY SEWAGE TREATMENT IN CONTROLLED ENVIRONMENTAL SYSTEMS

5. Report Date April 1976

6.

7. Author(s) Dr. John H. Ryther, Joseph S. Levine, Fredrick M. Mencher, David J. O'Neill, *

8. Performing Organization Rept. No. WHOI-76-44

9. Performing Organization Name and Address

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract/Grant No. NSF Grant GY-11544

12. Sponsoring Organization Name and Address

National Science Foundation

13. Type of Report & Period Covered TECHNICAL

14.

15. Supplementary Notes

16. Abstracts Research was based on different aspects of incorporating Homarus Americanus cultural into the multi-trophic level marine aquaculture-wastewater treatment system of the Environmental Systems Laboratory at Woods Hole. Experiments were directed toward optimizing food sources available within the system, developing designs to facilitate high density lobster growth, and elucidating the ecology of Homarus. The aquaculture-wastewater treatment system uses secondary sewage effluent or its equivalent as a nutrient source for marine phytoplankton ponds which in turn are fed into raceways containing racks of bivalves. The bivalves produce soluble nutrients used to raise macroalgae, and solid material (biodeposits) used to raise various deposit feeders. Almost all the N and over 50% of the P is removed from the wastewater by the artificial food chain.

17. Key Words and Document Analysis. 17a. Descriptors

1. Lobster
2. Aquaculture
3. Advanced Sewage Treatment

17b. Identifiers/Open-Ended Terms

* Barbara Plasman, Jeffrey L. Star, Jeffrey L. Thielker, Karen Irving, and Greg Redmann.

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 102
	20. Security Class (This Page UNCLASSIFIED	22. Price