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Woods Hole Oceanographic Institution

MARINE RESOURCES DEVELOPMENT AND MANAGEMENT A REPORT ON THE WOODS HOLE OCEANOGRAPHIC INSTITUTION SEA GRANT PROGRAM JULY 1973 - JUNE 1974

By

Dean F. Bumpus

December 1974

TECHNICAL REPORT

Prepared for the Sea Grant Program under [illegible]

WOODS HOLE, MASSACHUSETTS 02543

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Approved for Distribution Ferris Webster

Ferris Webster
Associate Director for Research

MARINE RESOURCES DEVELOPMENT AND MANAGEMENT

1973-1974 ANNUAL SEA GRANT REPORT

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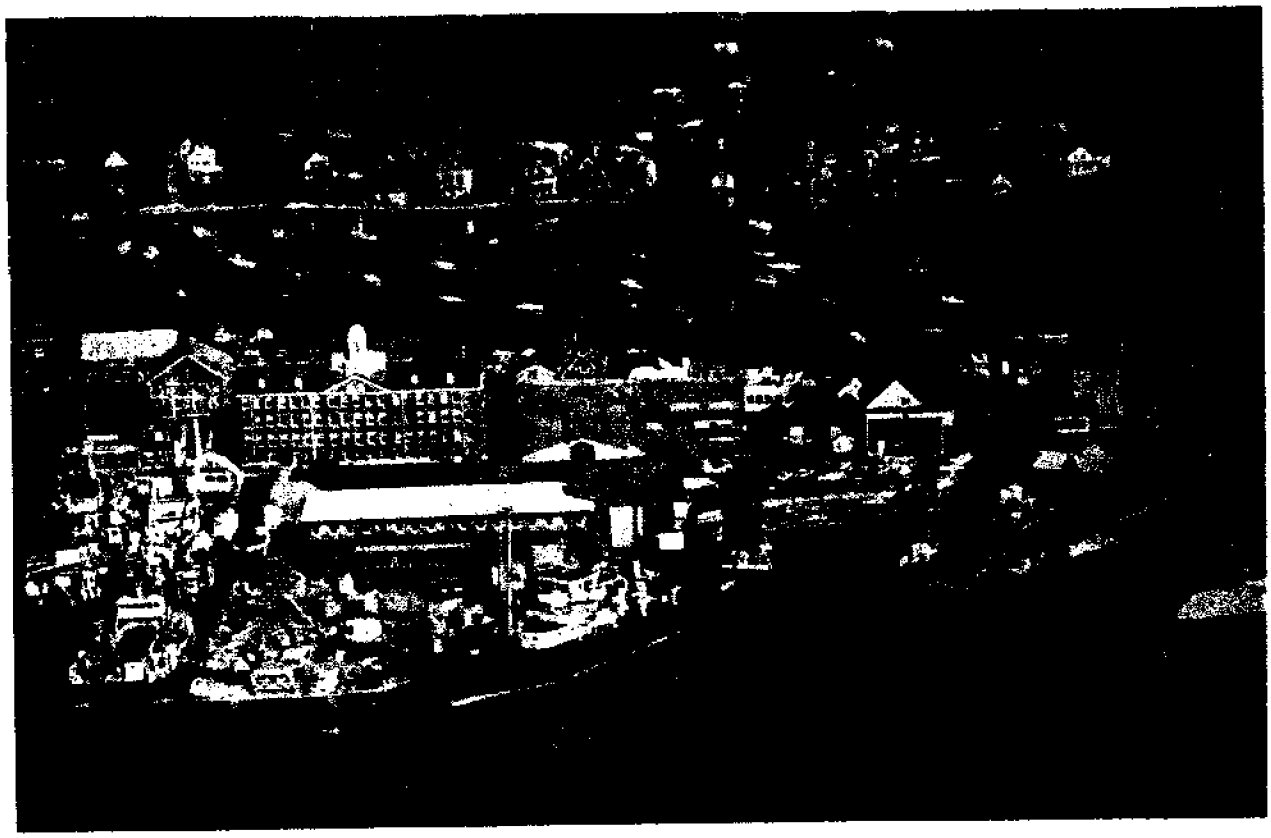


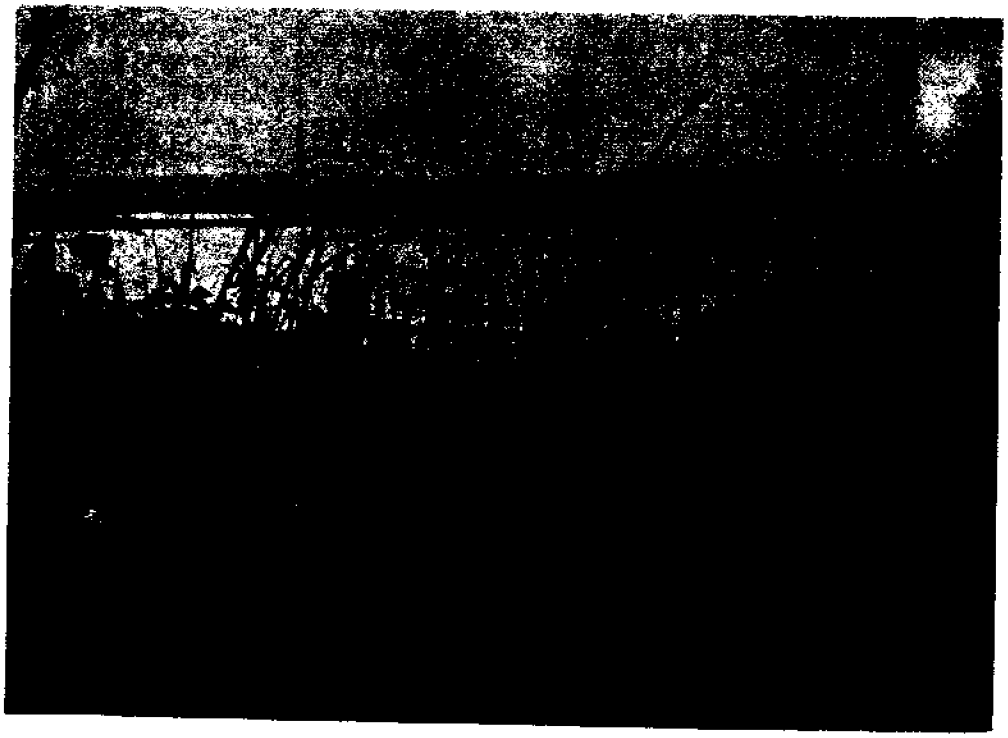
Introduction

The Woods Hole Oceanographic Institution has been devoted to a diversified research and educational program in oceanography since its founding in 1930. Through the efforts of many people it has become recognized as one of the world's leading centers of oceanography. With a research staff of 234 in a total of 809 employees, four ocean-going ships, a submersible and tender, and an annual budget of $18,000,000, the Institution carries out a world-wide program in all the Marine Sciences. The Institution is divided into five departments of similar size: Biology, Chemistry, Geology and Geophysics, Ocean Engineering, and Physical Oceanography. The departmental organization, however, does not dominate the scientific program in any respect since research programs originate and proceed from individuals and groups with common interests without regard to departmental structure. A detailed record of the Institution's work may be found in the Woods Hole Oceanographic Institution's Collected Reprints published annually since its founding.

Prior to 1968, our educational program was conducted on a semi-formal basis in the form of a summer fellowship program, courses offered to visiting students in the summer, Ph.D.

candidates from other institutions performing their thesis work at the Institution, participation by staff members in nearby universities, joint appointments for faculty members from other universities, and summer research opportunities. In 1968 the education program was formalized when the Institution was empowered by the Commonwealth of Massachusetts to grant graduate degrees in Oceanography. A joint degree now is offered by M.I.T. and the Institution in a strong program, while cooperation with other universities, particularly Harvard and Brown, continues at a level equal to or somewhat higher than before the formalization.

An examination of the Collected Reprints of the Institution will show that while the major portion of the papers relate to basic studies of the oceans, a substantial number are concerned with the practical programs of man's use of the sea. Interestingly, until the Sea Grant Program was originated, Federal support for applied research in the sea was minimal except for the Navy's obvious needs. In 1971 the National Sea Grant Program awarded the Institution support for two "projects"; one dealt with the study of pelagic fish, to determine their life history so that a better level of husbandry can be sought, and the other has supported a growing engineering education curricula which is part of our formal program with M.I.T. In 1972 in addition to these two projects, proposals in chemotaxis, aquaculture, and marine policy were funded in part by Sea Grant. In 1973 a Sea Grant coherent program was commenced in which we dealt primarily with Aquaculture and Living Resources research, Ocean Engineering education and Marine Policy.



AQUACULTURE

- Operation of a pilot plant for a combined sewage treatment and aquaculture system - J. H. Ryther.
- A new technique for the culture of midges - W. O. McLarney.
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- Study of chemical communication by marine animals - J. Atema, R. B. Gagosian, and J. Mitchell.

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EDUCATION

- Ocean engineering and academic development - J. W. Mavor, Jr.

The development and management of marine resources requires a joint effort on the part of many people from different specialties of oceanography. Recognizing that at Woods Hole there exist specialists from all the marine sciences, that our Marine Policy program includes specialists in law, anthropology, and economics, and that the proximity of large universities means that other specialists can be available early and often, it seems appropriate to direct some of our efforts toward Marine Resources Development and Management. We welcome the opportunity to become partners with the National Sea Grant Program in this endeavor. The location of Woods Hole means that much of our work concerns the Northeastern seaboard; some is of world-wide interest; and some relates only to specific areas or resources. We maintain good liaison with our neighbors in the National Marine Fisheries Service. We are seeking ways to develop working relationships with those citizens and industries who gain their livelihood from coastal resources.

This our first annual Sea Grant report conveys a summary of our endeavors under Sea Grant funding and asserts a commitment to become more involved in the solution of problems of the coastal zone.

December 1974

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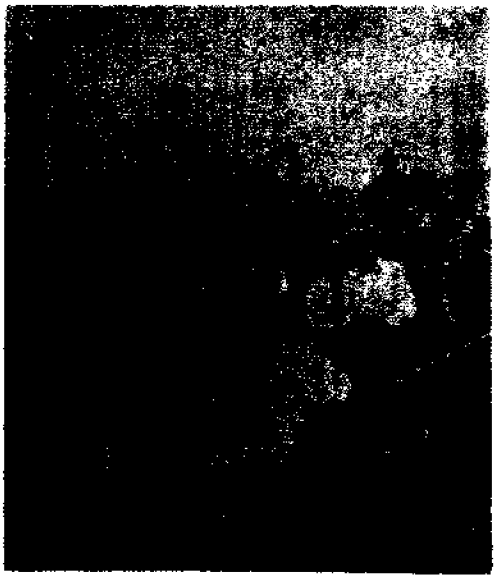
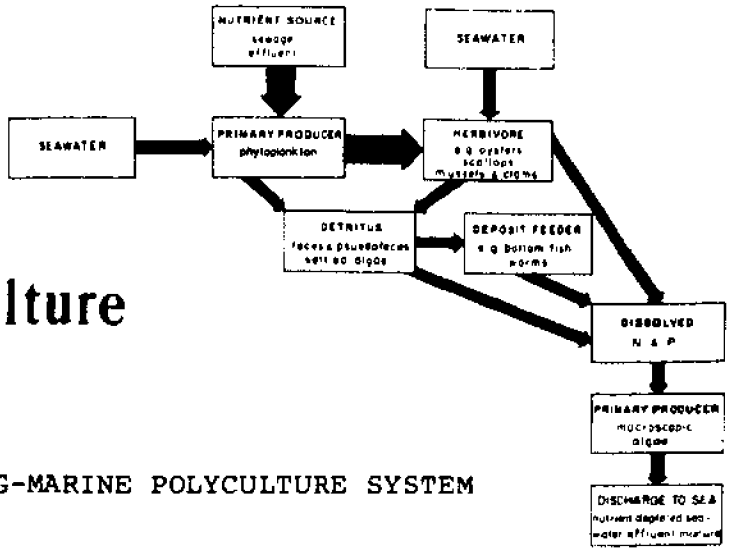


Aquaculture



A WASTE RECYCLING-MARINE POLYCULTURE SYSTEM

Current methods of "intensive" aquaculture practiced in the United States and other developed parts of the world involve, for the most part, the cultivation of predators or omnivores high on the food chain and usually rely on heavy feeding with specially-prepared, artificial feeds. Such practices have several disadvantages and, as a result, have seldom been economically successful or sociologically attractive. The major problems are:

1) Organisms grown in this way consume several times their own weight in high quality and high protein-content food and hence cannot alleviate the world's protein deficiency.

2) The most costly single operating expense is that of food, often 50% or more of total costs, which alone frequently spells the difference between economic success and failure.

3) Heavy application of artificial feeds results in the production of large quantities of organic wastes in the form of uneaten food, feces, and excreted nutrients. Removal of these wastes, prevention of toxicity, anaerobiosis, disease, and fouling associated with them, and treatment of the wastes to meet present discharge standards all add significantly to both capital and operating costs and, together with escalating food costs, have made this approach to aquaculture generally impractical.

In contrast, "extensive" aquaculture systems, such as are operated in Southeast Asia and the Orient, involve the culture of herbivores or omnivores low in the food chain that depend on natural foods that are produced within the culture system, eliminating the cost and associated problems of artificial feeding. Yields of as much

as one metric ton per acre may be obtained by these methods, which have proved to be economically successful and have contributed significantly to the protein requirements of the countries where they are practiced.

By increasing the level of primary organic productivity of such "extensive" aquaculture systems by fertilization and other manipulation, it is anticipated that yields may be increased by as much as tenfold. Also, by adding the concept of polyculture, using all trophic levels and niches of the ecosystem including the wastes produced by the cultured organisms themselves, total yields may be further enhanced through the production of valuable secondary crops.

A source of nutrients presently not only being wasted but contributing to environmental deterioration, are the organic wastes of our society including sewage effluent as well as food processing, aquacultural, animal, and certain industrial wastes. The recycling of the nutrients in these wastes through their uptake and utilization in a mariculture system not only makes use of a valuable resource that may be available at little or no cost, but also the practice represents a form of tertiary sewage treatment in which the nutrients are removed from the wastes before the latter are discharged to the environment.

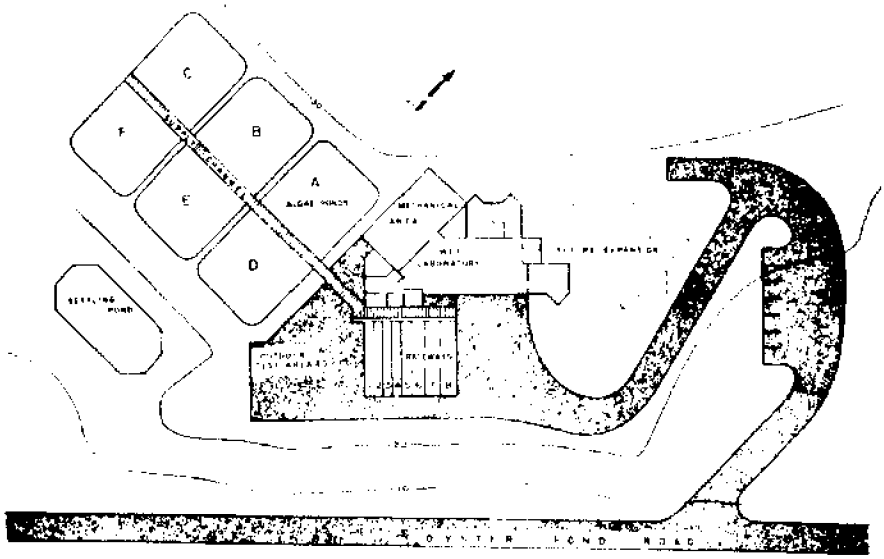
Beginning in 1972, small-scale experiments were conducted both in the laboratory and outdoors, providing the basis for the design and operation of a pilot-plant facility to test and evaluate the waste recycling-aquaculutre system described above. On the basis of that experience, the WHOI Environmental Systems Laboratory was constructed and commenced operation in the autumn of 1973.

The ESL facility, in addition to a modest laboratory building, consists of:

(6) 50' × 50' × 3' (deep) 35,000 gallon algae ponds,

(5) 40' × 4' × 5' (deep) cement raceways, and

(3) 40' × 8' × 5' (deep) cement raceways.



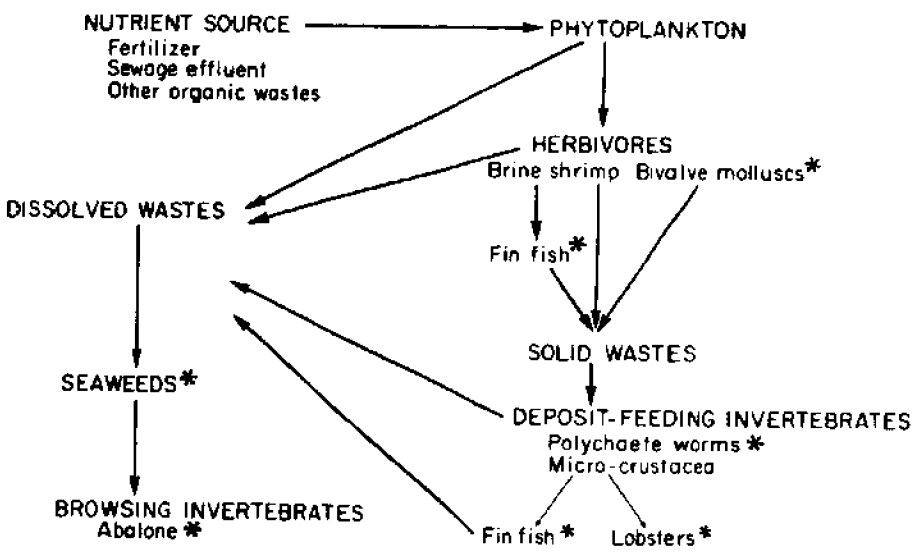
The seawater system is capable of delivering in excess of 650 gallons per minute to the laboratory, the algae ponds, and the raceways. The contents of two of the algae ponds and the seawater feeding the laboratory and all raceways may be heated to 20° above ambient, 200 gallons per minute of the incoming seawater may be filtered through 20μ sand filters, and all of the aquatic systems may be aerated. Three 8,000-gallon fiberglass tanks, buried behind the laboratory, serve as reservoirs for sewage effluent or other nutrients that may be pumped to headboxes in the laboratory and thence distributed to the ponds or raceways.

Starting in November, 1973, the two heated algae ponds, operating at about 15°C, were fed filtered seawater initially enriched with chemical nutrients (ammonium chloride and sodium phosphate) and later mixed 50:50 with secondary sewage effluent from the Town of Wareham, Mass. These ponds developed dense cultures of the diatom *Phaeodactylum tricornutum* (10^6-10^7 cells/ml, 15-20 mg organic carbon/liter) which persisted at approximately the same level until August, 1974. These large, continuous-flow cultures were exchanged at the rate of 25% of their volume per day throughout the winter and increased to 50% of their volume per day in April, when artificial heating was discontinued. At that time, cultures enriched with chemical nutrients were started in the four unheated algae ponds and were operated in the same mode. All pond cultures consisted of *Phaeodactylum*. Repeated attempts to inoculate with or select for other species of algae (by varying nutrients, temperature, exchange rate, circulation, aeration, etc.) proved unsuccessful. Species control remains a major problem that will receive top priority in the coming year.

Three hundred thousand seed oysters (*Crassostrea virginica*) were stocked in trays in two of the raceways in November, 1973 and 150,000 seed hard clams (*Mercenaria mercenaria*) were stocked in another raceway in January, 1974. These have been fed the 9,000 - 18,000 gallon/day harvest from each of the algae ponds mixed with varying amounts of filtered and (in winter) heated seawater. Growth of the shellfish has been relatively slow and some mortality of the oysters was experienced, due it is believed, to the exclusive diet of *Phaeodactylum*.

Other animals including the deposit feeding polychaete worms, *Capitella capitata* and *Nereis virens* and various amphipods and isopods were added to the raceways to feed on the shellfish deposits, and juvenile winter flounder (*Pseudopleuronectes americanus*) and lobsters (*Homarus americanus*) were added separately to the raceways to feed upon the smaller invertebrates. These animals will be sampled and measured for growth late in 1974.

The net flow from the animal raceways passes through adjacent raceways in which commercially valuable species of seaweeds are grown in suspended culture, by rotary circulation provided by aeration. The seaweeds provide a final polishing step in the polyculture system, removing nutrients not initially assimilated by the unicellular algae and the nutrients regenerated by the shellfish. Initially the red algae *Rhodymenia palmata* (Dulse) and *Chondrum crispus* (Irish moss) were stocked. As the temperature increased above



*COMMERCIAL CROPS

15°C in Spring, the cold-water species *Rhodymenia* was replaced with warmer-water species (*Gracilara foliifera*, *Hypnea musciformis*, and *Agardhiella tenera*). All of the seaweeds have done well in the system, but by far the most effective has been *Gracilaria*, which doubled its bio-mass every 5-7 days during the summer. All species of seaweeds have remained healthy and in good condition, with virtually no fouling from filimentous algae or from invertebrates.

The initial success with the seaweed culture and the fact that a world-wide shortage exists of all these commercial species from which agar and carrageenin are extracted (i.e., all of those we now have in culture) has led to some preliminary experiments, initiated in the spring of 1974, in which these algae are being grown directly in a sewage effluent-seawater medium.

CULTURE OF THE LARVAE OF THE MIDGE *CHIRONOMUS TENTANS* AND FEEDING TRIALS WITH TILAPIA, CARP, AND LOBSTERS

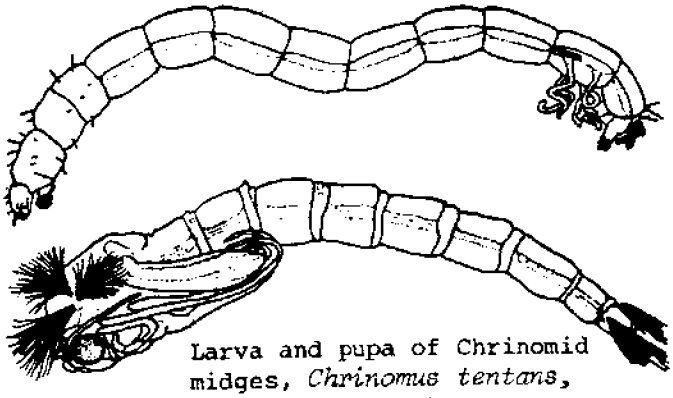
The first two years of this study were devoted to perfecting a new system of culturing *Chironomus tentans* larvae which makes their use as fish food much easier and more efficient, and to studying the results of various environmental variables within the culture system.

The objectives of the 1974 work were two: (1) To incorporate all that we had learned about environment and techniques in *C. tentans* culture into a production level culture system, and determine the rate of production that could be sustained. (2) To measure the effectiveness of midge larvae added to the diets of young cultured fishes in small quantities as a growth-promoting supplement.

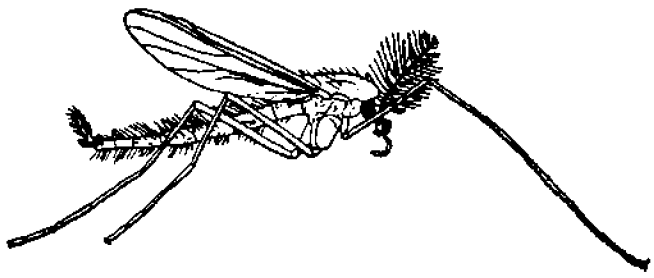
Four 15 m × 2 m × 1 m plastic-lined ponds were constructed and provided with substrates, fertilized, etc. in accordance with findings in the 1972 and 1973 studies. Further improvements were made and the most effective culture system to date operates as follows:

A series of separate 2 m × 1 m × 1 m pools are maintained as nursery areas. These are set up by suspending a 2 m × 1 m sheet of burlap horizontally in the water, then fertilizing the pool with 500 grams of a dampened mixture of 70% Milorganite^{R}, 20% fine sand, and 10% mud. The pools are stocked naturally by wild adult *C. tentans*, but we augment the population by stocking the pools with *C. tentans* egg masses taken from the production ponds. After a week, the burlaps, by this time covered with midge larvae in their tubes, are transferred to the production pools, where they are suspended vertically for two or more weeks to allow the midge larvae to reach maximum size for harvest.

Preliminary calculations indicate that we can harvest about 200 g/m^2/week without depleting the population. This rate is a little lower than that achieved by Israeli and Russian culturists, but our new system is far less



Larva and pupa of Chrinomid midges, *Chrinomus tentans*, (after Johannsen).



labor and energy-intensive, thus much more attractive for use in practical fish culture.

In addition to the harvests necessary to arrive at population estimates, larvae were harvested to be fed to fish being cultured at New Alchemy East, for use in the feeding trials described below, and to supply the needs of a cancer research laboratory in Boston.

The feeding trials involved tilapia and carp fed a standard diet of rolled oats and roasted soy meal, with *C. tentans* larvae added at the rates of 2% or 10% of the total diet. A control group received no larvae. No significant difference in rate of weight gain was found for tilapia over five grams in weight, but smaller tilapia fed the 2% to 10% supplement grew 1.53 and 1.77 times as much, respectively, as the controls. Growth rates for young carp fed in the same way were 1.35 and 1.39 times those of controls. These figures become more impressive when one considers that if we allow for the moisture content of the larvae, the actual weights of *C. tentans* larvae fed to the experimental fish amounted to about 0.28% and 1.40% of the total diet.

At present similar experiments are being carried out at the Environmental Systems Laboratory with larval lobsters fed on a standard diet of frozen brine shrimp supplemented with *C. tentans* larvae. Observations indicate differences in the increments of weight and carapace length which are significant.

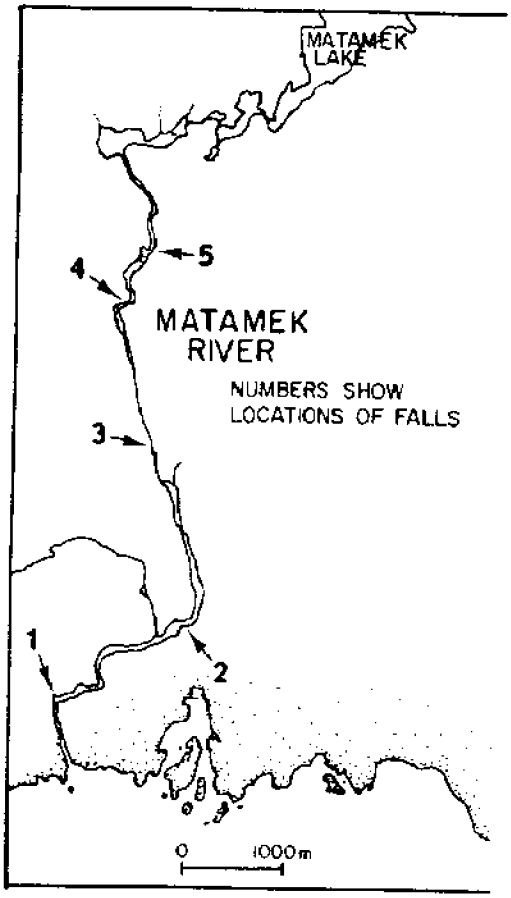
There thus appears to be some foundation for the belief of some aquaculturists that chironomid larvae act as a growth-stimulator. We have demonstrated that they can be cultured cheaply and efficiently in quantities sufficient to make a significant impact in a practical aquaculture operation. We estimate that our present system, comprising less than 500 square feet of water surface, could be used to provide a 2% dietary supplement continuously for 25,000 young fish at an installation cost of $900, with two hours/day of labor.

FINFISH RESEARCH AT MATAMEK, QUEBEC

In the lower Matamek River ecological studies were made on brook trout, juvenile Atlantic salmon, eels, and longnose suckers. These are the dominant species in the river. Biomass, age structure, growth, diet, and movements were investigated in differing habitats, mainly with a view to understanding interrelationships and relative production of these species.

An estimate was made of the total production of smolts (about 8000) and 283 smolts were tagged with Carlin tags. Adult salmon were sampled for size, age, and skeletal changes through the season. Scales and opercula of smolts and adults were collected for micro-analysis by electron microscopy. A fishway at the first falls from the sea has been completed, and will allow counts of the adults in 1975.

Behavior studies were made of brook trout and juvenile salmon in stream tanks. Interactions, and habitat preferences were studied. Preferences in cover, depth, and water velocities through the season have been studied. This information will be useful in habitat improvement work, and in predicting the effects of changes in rivers on salmonid production.



Trout populations were compared in an area where there are salmon, and in a section upstream from the fourth waterfall impassable at present to salmon. Differences were found in distribution, biomass, growth, and age at maturity. Next year a fishway will open up this area to salmon. Changes in fish production will be followed.

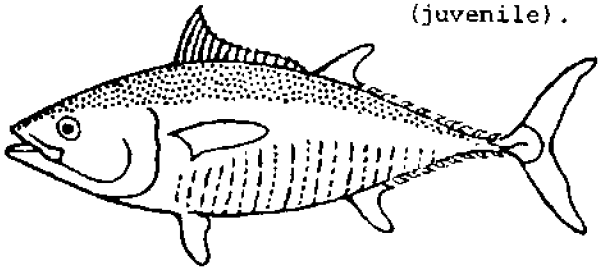
Invertebrates were compared below a falls near Matamek Lake, and below a falls 4 km downstream, and their abundance compared with fish production. A taxonomic study was made of the Caddis fly *Trichoptera* which is the principal food of salmonids in the river.

In the upper part of the watershed estimates of trout production in four tributory streams of Matamek Lake were c pleted. These were related to habitat and available food.

A survey has been made of tl lower river by engineering students, and a geological survey of Matamek Lake and part of the river system was made. Lin nological work on Matamek Lake and Gallienne Lake (a fishless lake) was broader in scope this year, with studies on primary production, water chemistry, th organic budget, lake sediments, and *Chaoborus* in the zooplankto Physiological studies were made on planted fry.

The standard hatchery practices of rearing and stocking salmon can be considerably improved, and important recommenda tions can now be made regarding feeding, water velocities, temperature, oxygen, and shock from transport. Invertebrate predators were shown to be important predators of salmon stocked in fishless waters. Work continued on stocking salmon fry in fishless streams and lakes, and much greater growth of salmon was found there than in areas having other species of fish. Greatest growth was in lakes, where some salmon were 40 cm long at two years old. The primary food in the lake was the Phantom Midge *Chaoborus* larvae. There are many fishless areas on the Labrador plateau, and this work will provide useful knowledge for their future management.

Living Resources



Bluefin tuna (juvenile).

MIGRATIONS AND POPULATIONS OF CERTAIN LARGE PELAGIC FISHES

The objectives of this program were to continue obtaining the basic biological knowledge of the life history of the Atlantic tunas, billfishes, and the greater amberjack, and to analyze the extensive data collected on distribution, migration, and population parameters of these species and publish the observed results. This work has been carried on at the Woods Hole Oceanographic Institution since 1950 under various grants and contributions. During our Sea Grant support, when fishing pressures on several of these species was reaching dangerous levels, this information had become crucial to the survival of these species and was presented to the proper authorities for their use.

The information on bluefin tuna was and is of prime importance as the International Commission for the Conservation of Atlantic Tunas (ICCAT) has been considering the management measures needed for optimum sustainable yield. Two other species also in danger of depletion throughout this time have been the blue and white marlins. We wanted to intensify tagging of these three species and continue tagging the other species of interest; skipjack tuna, broadbill swordfish, sailfish, and greater amberjack, so that the effects of fishing pressure could be continuously monitored. In addition to tagging, catch and effort, size composition and stock size data were desired.

This tagging program has been active since June, 1954, and has obtained more information on these fishes than all other Atlantic programs combined. The Principal Investigator is a member of the Expert Panel for the Facilitation of Tuna Research (EPFTR) of the Food and Agriculture Organization of the United Nations, and was the Convenor of its Working Party on Tuna Tagging in the Atlantic and Adjacent Seas (WPTTAAS), and a member of the Sub-committee on Stock Identification (SCSI) under the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) until both were disbanded.

The information obtained by this program is being used on a continuing basis by ICCAT for the management of the Atlantic tuna and billfish resources, some of which are already endangered. Reports on Atlantic tuna and billfish tagging have been prepared and have been used as Working Documents at meetings of EPFTR and SCSI of ICCAT. A Final Report of WPTTAAS, covering all Atlantic tuna and billfish tagging to date, was completed for use as a Working Document at the meetings of EPFTR and ICCAT in November and December, 1971. Tagging, catch and effort, and age composition data were supplied to the Meeting of a Group of Experts on Tuna Stock Assessment (under EPFTR) at Miami, in August, 1968, and are being supplied on a continuing basis to SCRS of ICCAT.

During this two and one-half year period of support over 6,000 tunas, billfishes, and greater amberjack were tagged and released; and more than 500 tag returns were reported from fishes of these groups. We continued to supply ~8,000 tags annually to interested sport fishermen cooperating in our program. The collection of size composition and catch and effort data for the local tuna fisheries was also carried on concurrently.

An important service begun in the summer of 1971 and continued in each of the following summers was our participation and help in coordinating a tag testing experiment recommended by SCSI of ICCAT with the St. Andrews Biological Station, Environment Canada and the National Marine Fisheries Service, Southeast Center, Miami.

LOBSTER BEHAVIOR IN A 1500 GALLON AQUARIUM

In January, 1974 two semi-natural laboratory environments (10' diameter, octagonal aquaria) were established and stocked with five lobsters of both sexes, mature and immature, along with other invertebrates and fishes characteristic of the Cape Cod subtidal habitat. The object was to combine the advantages of a field study with those of the laboratory to permit a greater degree of control over the lobsters. Both aquaria were arranged identically with oyster shell substrate, cement blocks, rocks, and ceramic pipes to provide surplus shelters for the lobsters and other species.

Observations were made during the day, following feeding, and at night (using a red light) when lobsters are active under natural conditions. The types of behavior quantified included the occupation of specific shelters, feeding activity, and social behavior.

The lobsters appeared to be much less aggressive than has been generally reported, aggressiveness being shown most frequently during feeding with few aggressive encounters during the nighttime observations. The aggressive encounters appeared to be ritualized (i.e., threat displays) rather than of a damaging nature. Dominance hierarchies in lobsters may lead to less aggressive encounters and the animal's size (regardless of sex) seemed to determine its relative dominance. Complicating the dominance observations was the territorial defense behavior of the larger individuals. During winter and early spring, large animals of both sexes maintained territories, however, later (with one exception) apparent defense of a particular shelter for a period longer than a week was rarely seen.

A lobster's position in the hierarchy appeared to weaken just prior to and for a month or more following the molt. At this time individuals were often observed in exposed locations where they did not appear to be harassed excessively. There was only one loss, a small female molt. The three other females that had molted were protected during their most vulnerable period by the males with whom they mated.

After six months of observations at ambient sea water temperature the water temperature was slowly raised in the summer to 28 °C. The lobster activity, feeding, and social behavior changed little over the wide range of temperatures. The eels in the aquarium, however, became noticeably aggressive at temperatures of 26 to 28 °C.

Another interesting discovery was made during the observations of social behavior in the aquaria. It had been suspected previously that lobsters might display premating behavior similar to that of crabs, where the male protects the mature female prior to and during her molt.

Separate experiments were also conducted to determine if lobsters could learn to discriminate between two different odors. It was first necessary to establish whether lobsters could learn and remember. Five

of the six lobsters tested in the experiment learned to come out of their shelter and pull a target when a specific food odor, mussel juice, was introduced. Four of the five learned to pull a different target when herring juice was introduced to the aquarium. None of the lobsters would perform correctly when both targets were simultaneously presented and the odors randomly introduced. The observations indicate that lobsters can learn a simple test. In addition, it was shown that two of the animals were able to perform the task when, after a lapse of five weeks, the experiments were repeated.

Mud Snail Alarm Substance

The common mud snail *(Nassarius obsoletus)* of salt marsh mud flats exhibits a burial alarm response when exposed to the juices of another *N. obsoletus*. This may be viewed as an evolutionary response to predation, as those animals which do not burrow into the substrate when specific juices are released by predation are less likely to survive. The *N. obsoletus* alarm response has been quantified in the field as well as in the laboratory test tray. A reliable laboratory bioarray has enabled the examination of other species of gastropods to determine if they possess an alarm substance which elicits the alarm responses in *N. obsoletus*, possibly indicating an ecological or taxonomic relationship between these species. Other aspects, such as the location of the alarm substance in the live snail, threshold concentration for response, and logevity of the alarm substance have also been examined. The isolation and chemical properties of the *N. obsoletus* alarm substance are being examined.

CHEMICAL STRUCTURE AND INFLUENCE OF THE LOBSTER MOLTING HORMONE

Previous work in our group on the lobster has shown that a female sex pheromone exists which suppresses aggression in mature males, and induces courtship and copulation. Because this chemical attractant is released upon molting, it was thought that the molting hormones of the female could be related to the sex pheromone.

It was subsequently reported that in the crabs *Pachygrapsus crassipes*, *Cancer antennarius*, and *C. anthonyi* the molting hormone, ecdysterone (20-hydroxyecdysone), serves a dual function and is directly involved as the sex pheromone of these three species of crabs. Essentially based on this work, it was further proposed that ecdysterone might serve not only as a general sex pheromone for crustacea, but also that it would provide the evolutionary basis for all arthropod sex pheromones.

When, however, ecdysterone as well as three other structurally related ecdysones were presented in a carefully designed bioassay to mature male lobsters, *Homarus americanus*, no sexual responses were noted. None of the four seemed to serve as sex pheromones for lobsters and hence cannot be called a general crustacean sex pheromone. In addition, these compounds did not elicit any particular type of behavior such as feeding, aggressive or defensive behavior. Only ecdysterone elicited a low key alerting response, indicating that only this compound was perceived, but in a non-specific way.

Although these experiments showed that the molting hormone itself did not cause sex attraction in the lobster, the possibility remained that a metabolic product of this hormone is involved. Fortunately, the structural chemistry of the metabolic

products of ecdysterone in insects and plants has already been studied by several investigators.

Thus, it appeared useful to test molting hormone metabolites and structurally similar compounds for sex pheromone activity in *Homarus americanus*. We have tested the natural metabolite 4,4-dimethylbutyrolactone, and six structurally similar molecules for their sex pheromone activity in the lobster. In the aquatic environment, solubility is an important factor, therefore this was also taken into consideration in choosing the test compounds relative to the basic structure.

It was found that none of the seven metabolites evoked sexual or feeding behavior. Aggressive behavior was observed only twice at low intensity. All other tests elicited either no response, or defensive and alerting behavior.

In view of the results of this study on ecdysone metabolites and the previous study on ecdysones, it must be concluded that none of these compounds show sexual attractiveness to the lobster under the test conditions used. Therefore, the hypothesis that a correlation exists between molting hormone and sex attraction becomes less convincing. It does, however, remain possible that specific ecdysone-related compounds, which were not synthesized or have not yet been isolated and identified, are involved as sex pheromones.

Another related problem is the structure determination of the lobster molting hormone. Crustacea in general have distinct molting glands (Y organs) comparable to those of insects. However, in the lobster, *Homarus americanus*, no structure comparable to the Y organ or any molting gland has yet been identified. We felt that this physiological difference between lobsters and the other members of their class might also be reflected in the chemistry of the lobster molting hormone, both in its structure and biosynthesis.

Although ecdysterone has been extracted and identified as the molting hormone of many species of insects, it has been found in only a few selected crustacea.

Our work on this problem for the last year involved the development of sophisticated organic analytical techniques and structure determination of a lobster molting hormone, ecdysterone, and the first definitive study of the uptake and biosynthetic conversion of cholesterol to ecdysterone in crustacea.

Recently it has been reported that injection of ecdysterone into both normal and destalked intermolt lobsters induced early molting. This work supports our results that ecdysterone, by itself, or in combination with other ecdysones, is playing a major role in the molting process of the lobster.

Injection of ecdysterone into other arthropods such as horseshoe crabs, barnacles, scorpions, and spiders also initiates molting. These results and those of the extraction and identification of ecdysterone from both insects and crustaceans, strengthen the hypothesis that ecdysterone is a general arthropod molting hormone.

SOCIAL BEHAVIOR IN JUVENILE LOBSTERS

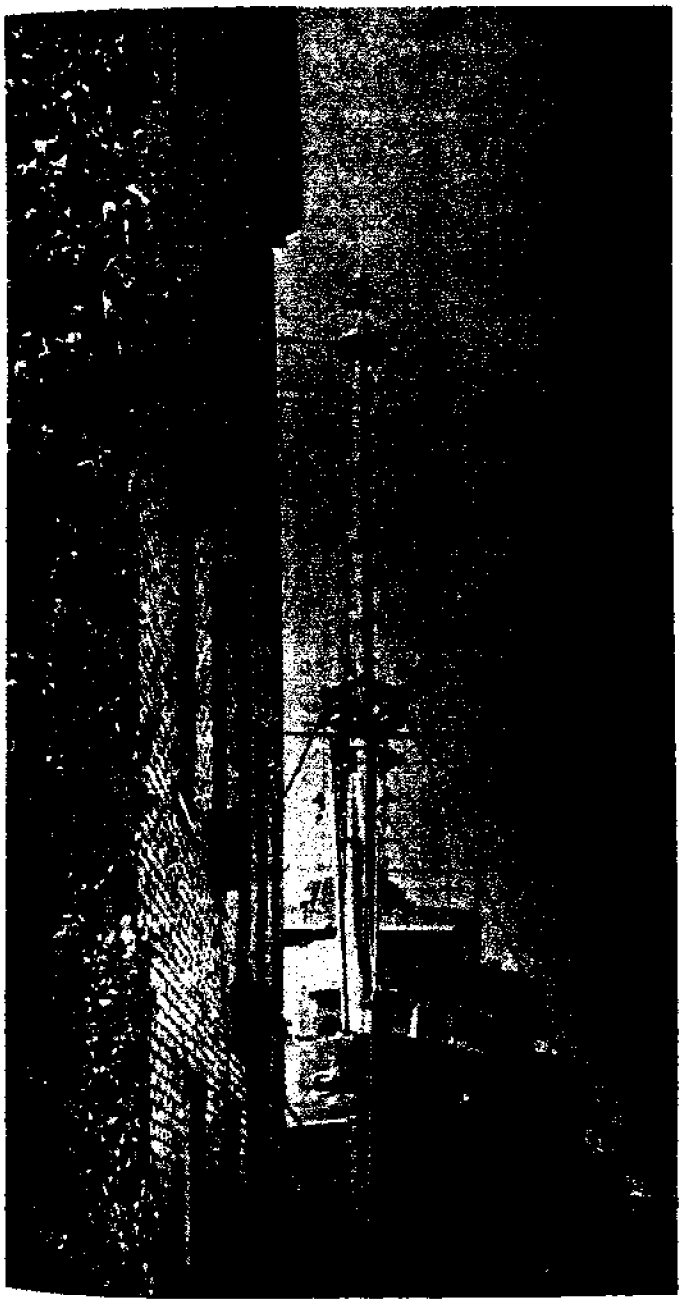
At present, cannibalism and aggression are two of the major problems preventing the mass culture of lobsters from larvae to marketable size. Therefore, information on density-related behavior of young lobsters would be beneficial in culture efforts beyond the larval stage.

Studies on the behavioral development of young lobsters showed increased aggressive behavior during their development from Stage 4 (4.0 to 5.5 mm carapace length) to Stage 8 (7.0 to 9.0 mm carapace length), with a peak occurring at Stage 7. Animals observed in community situations (four individuals per 55 gallon tank), also showed increased behavioral activity during development. However the observed behavior, including aggression, was significantly less in the community tanks than in paired encounters. One major difference between the two studies was that the animals in the community tanks showed differential growth, with at least one individual in each tank molting more frequently and growing larger than its tank mates. Hence, interactions usually were not between individuals of the same stage or size, and it is possible that the smaller individuals avoided interactions with larger animals whenever possible.

Following the descriptive studies on behavioral development of larval and juvenile lobsters, an investigation was completed on the relationship between population density, behavior, growth and survival in lobster communities. Communities of two, six, and ten Stage 4 individuals were established in six 55 gallon aquaria (twelve communities; four replicates of each density). The communities were observed on a daily basis over a period of three months, to determine the behavior of animals held at different densities, as they developed from Stage 4 to Stage 10 (up to 17 mm carapace length). In this study, the animals in each tank were color coded which made it possible to keep individual records of molting frequencies, growth rates, claw loss and mortality, as well as which shelters were occupied by each individual. The observations indicate that behavioral activity was even lower than in the first community study, and as before, showed differential growth in the tanks at all three densities. Excess food and shelter may have reduced the amount of cannibalism in these communities.

Socio-Economic and Legal Studies

MARINE POLICY AND OCEAN MANAGEMENT



The objective of the program in Marine Policy and Ocean Management is to promote interdisciplinary investigations of the problems generated by man's increasing uses of the sea. The program undertaken by postdoctoral fellows, predoctoral students, and professionals in the fields of economics, law, diplomacy, management, operations analysis, anthropology, geography, political science, engineering, etc., associated with members of the Institution's scientific staff have applied their disciplinary training to the examination of interactions, constraints, conflicts, accommodations, and cooperation in ocean use policy and management issues. These studies during the past year have dealt with:

- International cooperation in the marine sciences.
- The role of the scientist in the transfer of marine technology.
- Equity and equality in the law of the sea.
- The binding force of the conventional law of the sea upon third parties.
- The economic costs of pollution in the near-shore area.
- The economic impact of waste disposal in the New York Bight and the alternatives open to State and Federal authorities under the Marine Protection, Research and Sanctuaries Act of 1972.

- Prospects for the establishment of regional regulatory arrangements for the control of pollution of the seas.
- An international legal study of ocean dumping including an analysis and interpretation of the London Dumping Convention.
- Law, science, policy and management in relation to the Indian Ocean fisheries.
- Gear adaptability as a function of sociological factors of the crews of the New Bedford fishing fleet and economic factors of the market.
- Law and policy for marine minerals.
- The development of oil and gas resources, locally and off the Peoples Republic of China.

The impact of this program is evidenced by the positions the fellows have taken following their tenure in Woods Hole. More importantly in the long term are the perspectives gained by these investigators in the development of an awareness of the marine environment and a better understanding of the questions which must be asked and where the answers can be found. We all gain from this association a better understanding of the environment in which policy is made and the local, national, and international constraints under which policy makers operate.

Marine Education and Training

OCEAN ENGINEERING EDUCATION

The Sea Grant program in ocean engineering academic development at W.H.O.I. was initiated in 1968 and concluded this year. It has helped development of the Joint MIT/WHOI Graduate program in Oceanographic Engineering. Since 1971 seven participants have received graduate degrees given jointly by both institutions and are contributing their knowledge in various universities or research companies across the country. Two graduates, who have joined EXXON, are developing instrument systems to measure oceanographic parameters at the sites of oil and gas development.

This last year has seen increased MIT/WHOI activity in student support, faculty-student communication and in research, particularly acoustics.

Technological development in ocean science has been inhibited partly by the fact that natural scientists and ocean engineers have different goals and by the high cost of introducing new sophisticated ocean systems. The Sea Grant support, through research projects, publication and course initiation has helped to create a climate in the scientific communities in which engineers and natural scientists have been able to cooperate and improve the technology to their mutual benefit. Every project has contributed to this important part of ocean engineering either by a direct answer to a problem posed by a scientific program or by "spin-off" technology which has found unexpected application.

Four course offerings were given during the period of the grant:

Oceanographic Systems I & II
Given at WHOI

Marine Materials
Given at WHOI

Buoy Engineering
Given at MIT

Deep Submergence Oceanographic Engineering
Given at MIT

Texts for the last two subjects are nearing completion and negotiations are underway with a publisher.

Faculty and student joint research outside of formal courses have been an important part of the academic program and are as follows:

Deep Sea Oceanographic Systems Deployment:

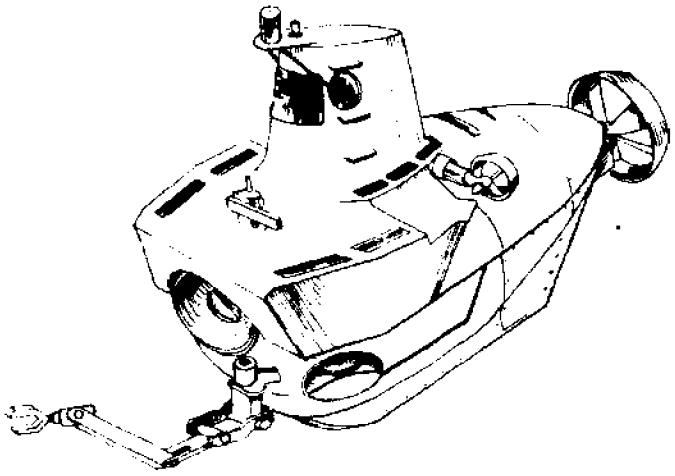
1. Deep Submersible Launch and Retrieval in Higher Sea States; measurements of statics and dynamics of the ALVIN cradle on LULU were made with the cradle submerged to a depth of 80 feet for proposed submerged retrieval. The results were hopeful but complex decoupling means were indicated. Improved surface launch and retrieval systems for deep manned submersible were studied with a promising scheme carried through preliminary design.
2. Revival of the Flettner Rotorship for Ocean Science; A feasibility study was started leading to a proposal to study the possible installation of rotors on existing oceanographic ships as an economy measure in the face of rising fuel costs.

Handbook of Oceanographic Engineering Materials; A handbook is being assembled to serve as an aid to oceanographic engineers and designers in materials selection. Part I, covering the properties of some eight metals and alloys was completed in 1972. Part II covering non-metallic materials is partially completed.

Other Research Projects; Projects with major contributions by students were as follows:

- Pneumatic Breakwater Study
- Wave Impact Force Measurement
- A Digital Recording System for Marine Experimentation
- Salt Finger Research
- Design Specifications for Semi-submerged Oceanographic Research Vessel
- Underwater Acoustics Research
- Swordfish Attack Experiments
- Deep Sea Capsule Design
- ALVIN Structural and Hydrodynamic Analysis
- TRIMOOR Wave Research
- Ocean Wave-Structure Interaction of Fixed Towers
- ALVIN Dynamic Stability
- Marine Science and International Law
- Role of the Oceanographic Engineer
- Monitoring Deep Ocean Circulation by the Use of Long Term Floats
- Engineering Analyses of the Giant Corer
- Maximizing Oceanographic Ship Use
- CURV and Other Unmanned Probes in Oceanography
- Instrumentation for Acoustic Measurement of Physical Oceanographic Parameters
- A New Technique for Non-destructive Examination of Offshore Structures

DSRV ALVIN



The joint program also offers opportunities to work at sea which can benefit even the ocean engineer without a natural science bent. It is consistent with the goals of research in both ocean science and ocean engineering that the two mix. Because of this, the breadth of ocean engineering for the direct service of man, is increasing at W.H.O.I. in such areas as aquaculture, ship maneuvering, and environmental monitoring.

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PROGRAM SUMMARY

Marine Resources Development and Management

Program Area	Project Support '71-'72	'72-'73	Coherent Program '73-'74
Marine Resources Development			
Aquaculture			
Combined sewage treatment and aquaculture system - Ryther		N	C
Finfish research at Matamek - Gibson			N-*
Culture of midges - McLarney		N	C
Living Resources			
Populations and migrations of certain large pelagic fish - Mather	N	C	*
Chemical communication of marine animals - Atema, Gagosian, Mitchell		N	C
Socio-Economic and Legal Studies			
Marine Policy and Ocean Engineering - Fye		N	C
Marine Education and Training			
Course Development in Ocean Engineering - Mavor	N	C	C
Program Management and Development - Bumpus			N

N - New Project C - Continued Project

* Continued with funds from sources other than Sea Grant

During FY '74 the Woods Hole Oceanographic Institution Sea Grant Program consisted of:

4 Research project
2 Education projects
Program management

Personnel associated with the Sea Grant Program were:

Scientific Staff - 15
Technical Staff - 9
Departmental Assistants - 26
Graduate Students - 10 (of which 7 awarded degree of Ocean Engineering)

Senior Fellows - 2
Post Doctoral Fellows - 6
Pre-doctoral Fellows - 4

BUDGET SUMMARY 1973-1974

	Sea Grant	Budget Matching*	Total
Marine Resources Development			
Aquaculture	$135,000	$ 30,000	$165,000
Living Resources	100,000	5,000	115,000
Socio-Economic & Legal Studies	10,000	60,240	70,240
Marine Education & Training	20,000	42,500	62,500
Total	$275,000	$137,740	$412,740

*Matching funds were provided by a number of benefactors of the Institution.

POSTSCRIPT

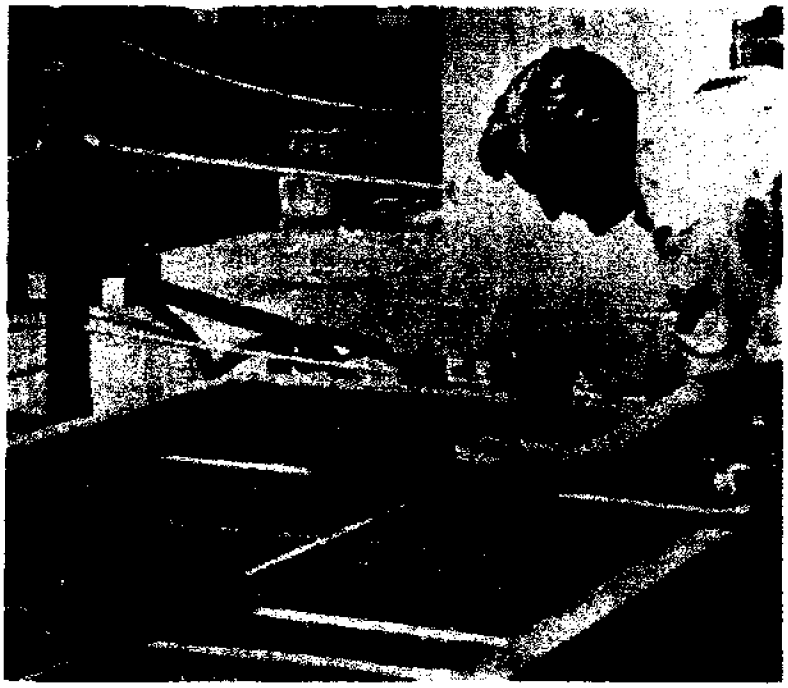
In looking ahead to another year of Sea Grant activity we find our program shaping up something like this:

John Ryther's program has been restructured to consider marine polyculture based upon natural food chains and recycled wastes. The products will be a tertiary treated effluent that will meet present and anticipated water quality discharge standards and crops of commercially valuable marine organisms.

Jelle Atema's Nutrition, Behavior, and Sensory Physiology of the lobster is being phased out and Wm. McLarney's Culture of Midges project is completed. John Gibson's Finfish research at Matamek is continuing with funds from other sources.

Robert Gagosian is continuing to isolate and determine the chemical structure of the sex pheromones that are used for chemical communication by the lobster, to isolate and identify the chemicals responsible for molting in the lobster as a function of the stage of growth and period in the molt cycle, to find the gland(s) responsible for the site of synthesis of the molting hormones, and to obtain a chemical background on the metabolites of the lobster by studying the chemistry of the blood and urine.

The Marine Policy Program will continue to promote interdisciplinary investigations by professionals (lawyers, economists, social and natural scientists) on problems generated by man's increasing uses of



the sea. In particular they will:

develop an interpretive document on the London Convention on Ocean Dumping;

undertake an interaction analysis of the commercial fishing and offshore petroleum industries in the Northeastern United States (sponsored by American Petroleum Institute);

structure several alternative limited effort programs for managing the New England fishery to deal with long-range trends of the industry;

make an assessment of the needs of the citizens and businesses of certain communities of Massachusetts deriving their livelihood in the coastal zone; and

assess the resources in Massachusetts to solve these needs.

Other new projects involve:

a study of the effects of low-level chronic exposure of mixed petroleum hydrocarbons in marine fishes;

the development of high resolution sub-bottom profiling gear for better resolution of thin, translucent or warped sedimentary layers in the sea bottom;

the redesign and reconstruction of an acoustic probe for precision ocean bottom and sub-bottom surveys; and

experiments to evaluate means of "looping" energy fluxes of natural processes in ways which produce resources rather than wastes. The power available in natural cycles supported by solar-terrestrial heat balance is more than sufficient for the needs of civilization but the techniques for conservation require study.

October 1973

DISTRIBUTION FOR SEA GRANT REPORTS

No. of Copies	Address
3	National Sea Grant Depository Pell Marine Science Laboratory University of Rhode Island Narragansett Bay Campus Narragansett, RI 02882
1	Sea Grant 70's Center for Marine Resources Texas A&M University College Station, TX 77843
5	Office of Sea Grant NOAA, U.S. Dept. of Commerce Rockville, MD 20852
50	Chief, Technical Information Div. D83 National Oceanic & Atmospheric Admin. Rockville, MD 20852
1	Charles W. Mason, Documents Librarian Morris Library University of Delaware Newark, DE 19711

Woods Hole Oceanographic Institution
WHOI-74-98

MARINE RESOURCES DEVELOPMENT AND MANAGEMENT
A REPORT ON THE WOODS HOLE OCEANOGRAPHIC INSTITUTION SEA GRANT PROGRAM JULY 1973 - JUNE 1974 by Dean F. Bumpus. 36 pages. December 1974. Sea Grant No. 04-4-158-5.

This report describes the progress of our first Sea Grant coherent program.

1. Aquaculture
2. Living Resources
3. Socio-Economic and Legal Studies
4. Marine Education and Training

I. Bumpus, Dean F.
II. Sea Grant 04-4-158-5

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4. Marine Education and Training

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