OCEANIC INSTITUTE
MAKAPUU OCEANIC CENTER · WAIMANALO, HAWAII 96795

A FEASIBILITY PILOT PROJECT FOR A METHOD OF OPEN WATER FISH FARMING

FINAL REPORT

Report No. OI-72-78-1

A FEASIBILITY PILOT PROJECT FOR A METHOD OF OPEN WATER FISH FARMING

Final Report

by

OCEANIC INSTITUTE
Waimanalo, Hawaii 96795

for

National Sea Grant Program
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Rockville, Maryland 20852

Principal Investigator - Kenneth S. Norris, Ph.D.

June 1, 1972

This work is a result of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant GH-78. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISTRIBUTION LIST

Office of Sea Grant — 5
NOAA, U.S. Dept. Commerce
Rockville, Maryland 20852

Sea Grant Depository — 3
Pell Marine Science Library
University of Rhode Island
Kingston, Rhode Island 02881

Sea Grant 70's — 1
Center for Marine Resources
Texas A&M University
College Station, Texas 77843

Director, Environmental Science Information Center — 50
NOAA
Rockville, Maryland 20852

Mr. Taylor A. Pryor — 1
President, The Oceanic Foundation

Dr. Kenneth S. Norris — 1
Oceanic Institute

Dr. Colin E. Nash — 1
Oceanic Institute

Dr. Ziad H. Shehadeh — 1
Oceanic Institute

GH-78 Project File — 1

Publications — 5
Oceanic Institute

Oceanic Institute Library — 1

Mr. Arden L. Pratt — 1
American Assoc. of Junior Colleges
One Dupont Circle
Washington, D.C. 20036

Dr. Willard J. Pierson, Jr. — 1
Professor of Oceanography
School of Engineering and Science
New York University
University Heights
New York, New York 10453

Mr. Arthur Mathieson — 1
Assistant Professor of Botany
College of Agriculture
University of New Hampshire
Durham, New Hampshire 03824

Mr. J.E. Thomas, Director — 1
Gulf Coast Technical Institute
Mississippi State University
State College, Mississippi 39762

Dr. Tapan Banerjee — 1
Southern Maine Vocational Technical Institute
Fort Road
South Portland, Maine 04104

Mr. Gordon L. Chan — 1
College of Marine
Kentfield, California 94904

Mr. S.T. Hsu — 1
Professor of Mechanical Engineering
College of Engineering
University of Maryland
College Park, Maryland 20742

Mr. Ted Boaz 1
Division of Technical & Vocational Education
Del Mar College
Corpus Christi, Texas 78404

Dr. Donald L. Woodrow 1
Department of Geology
Hobart & William Smith College
Geneva, New York 14456

Dr. James M. Parks 1
Lehigh University
Bethlehem, Pennsylvania 18015

Dr. John Wood 1
Virginia Institute of Marine Science
Gloucester Point, Virginia

Dr. Harold J. Humm, Director 1
Marine Science Institute
University of South Florida
St. Petersburg, Florida 33701

Dr. John Noakes 1
Department of Geology
University of Georgia
Athens, Georgia 30601

Mr. James Andrews 1
Skidaway Institute of Oceanography
55 West Bluff Road
Savannah, Georgia 31406

Mr. Paul Venno 1
Dept. of Sea & Shore Fisheries
State House
Augusta, Maine 04330

Dr. George Fulton 1
Department of Biology
Boston University
Boston, Massachusetts 02215

Dr. Alva Harris & Curt Rose 1
Dept. of Biological Sciences
Nicholls State College
Box 2021
Thibodaux, Louisiana 70301

Dr. Robert Corell 1
Chairman, Mechanical Engineering Dept.
University of New Hampshire
Durham, New Hampshire 03824

Dr. Edward L. Beckman 1
University of Texas
School of Medicine
Galveston, Texas 77550

Dr. Warren R. Healey 1
Director, Marine Resource Division
New England Council
Statler Office Building
Boston, Massachusetts 02116

Dr. Frank Mather, III 1
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Dr. David Hickok 1
Director, Sea Grant Program
University of Alaska
108 East Third Avenue
Anchorage, Alaska 99501

Professor Charles Stephan 1
Chairman, Dept. of Ocean Engineering
Florida Atlantic University
Boca Raton, Florida 33432

Dr. Russell Riese 1
Chief, Higher Education Specialist
Coordinating Council for Higher Education
1020 12th Street
Sacramento, California 95814

Dr. William Herrnkind 1
Project Director
Caribbean Institute
College of the Virgin Islands
St. Thomas, Virgin Islands 00801

Dr. Oswald Roels 1
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

Dr. Alfred H. Keil 1
Head, Department of Naval Architecture & Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. Richard Tibby 1
Catalina Marine Science Center
University of Southern California
University Park
Los Angeles, California 90007

Dr. Rita Colwell 1
Department of Biology
Georgetown University
Washington, D.C. 20007

Dr. Wheeler North 1
California Institute of Technology
Pasadena, California 91109

Dr. Jack Davidson 1
Director, Sea Grant Program
University of Hawaii
2540 Maile Way
Honolulu, Hawaii 96822

Dr. Joh P. Harville 1
Director, Moss Landing Marine Laboratory
Moss Landing, California 90350

Dr. Robert W. Holmes 1
Associate Professor of Marine Biology
University of California
Santa Barbara, California 93106

Dr. Herbert Frolander 1
Director of Sea Grant Program
Oregon State University
Corvallis, Oregon 97331

Dr. Jack Armstrong 1
Sea Grant Director
University of Michigan
Ann Arbor, Michigan 48104

Dr. John Knauss 1
Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

Dr. Richard C. Bader 1
Associate Director
Institute of Marine Science
University of Miami
Miami, Florida 33149

Dr. John C. Calhoun, Jr. 1
Director
Sea Grant Program
Texas A&M University
College Station, Texas 77843

Dr. Robert Ragotzkie 1
Coordinator, Sea Grant Program
University of Wisconsin
1225 West Dayton Street
Madison, Wisconsin 53706

Dr. John Lyman 1
Sea Grant Program Coordinator
University of NorthCarolina
Chapel Hill, North Carolina 27514

Mr. Scott Daubin 1
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Dr. Ramsey Parks 1
Santa Barbara City College
Cliff Drive & Leadbetter Drive
Santa Barbara, California 93105

Mr. William H. Diment 1
Department of Geological Science
University of Rochester
Rochester, New York 14627

Dr. John P. Breslin 1
Director, Davidson Laboratory
Stevens Institute of Technology
Castle Point Station
Hoboken, New Jersey 07030

Dr. Richard Ridenhour 1
Sea Grant Program Coordinator
Humboldt State College
Aracata, California 95521

Dr. William S. Gaither 1
Dean, College of Marine Studies
University of Delaware
Newark, Delaware 19711

Dr. Jack Van Lopik 1
Sea Grant Coordinator
Louisiana State University
Baton Rouge, Louisiana 70803

Dr. George Shor, Jr. 1
Associate Director
Scripps Institution of Oceanography
La Jolla, California 92037

Captain Arthur Jordon 1
Sea Grant Coordinator
Cape Fear Technical Institute
Wilmington, North Carolina 28401

Dr. Donadl F. Mulvihill 1
Department of Marketing
Kent State University
Kent, Ohio 44240

Dr. Martin F. Stempien, Jr. 1
Osborn Laboratories of Marine Science
New York Zoological Society
Seaside Park, Coney Island
Brooklyn, New York 11224

Mr. Nelson Marshall 1
Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

Alfred J. Weinheimer 1
Professor of Chemistry
University of Oklahoma
660 Parrington Oval
Norman, Oklahoma 73069

Dr. Stanley Murphy 1
Director, Sea Grant Program
University of Washington
Seattle, Washington 98105

Mr. Glen Wade 1
Department of Electrical
Engineering
University of California,
Santa Barbara
Santa Barbara, California 93106

Mr. Ajay K. Bose 1
Dept. of Chemistry & Engineering
Stevens Institute of Technology
Hoboken, New Jersey 07030

Mr. Donald W. Melvin 1
Associate Professor of
Electrical Engineering
College of Technology
University of New Hampshire
Durham, New Hampshire 03824

Mr. John H. Lech 1
Department of Pharmacology
Medical College of Wisconsin
Milwaukee, Wisconsin 53233

Mr. Clarke Williams 1
Nassau-Suffolk Regional
Planning Board
Hauppauge, Long Island
New York 11787

Mr. Robert W. Brody 1
College of the Virgin Islands
Caribbean Research Institute
St. Thomas, Virgin Islands 00801

Mr. James F. Wright 1
Executive Director
Delaware River Basin Commission
25 Scotch Road
Trenton, New Jersey 08628

Mr. Clinton Dawes 1
University of South Florida
Tamp, Florida 33620

Dr. Sidney Upham, Director 1
Universities Marine Center
P.O. Drawer AG
Ocean Springs, Mississippi 39564

Miss Shirley Scott 1
Pell Marine Science Library
Sea Grant Depository
University of Rhode Island
Narragansett Bay Campus
Narragansett, Rhode Island 02882

134 copies

I. AN EXPERIMENT IN UNDERSEA MARICULTURE

Kenneth S. Norris, William D. Madden, and Phyllis S. Norris

AN EXPERIMENT IN UNDERSEA MARICULTURE

Abstract

1. The potentials of maricultural activity in moderate to deep ocean water below the turbulent zone are discussed. The major advantage is the presence of large unused areas of sea floor that are largely non-competitive with other human uses. Uses envisioned are for the development of habitat enhancement areas by use of "plastic grass beds" made of plastic strips, either enclosed by nets or not, the development of herbivore and carnivore trapping areas, algal rope or net culture, and for shellfish culture.
2. An experiment is described in which a 6 x 12.5 meter PVC pipe frame was anchored in 26 meters of water off Oahu, Hawaii, to which were attached 4500 2.5-meter long, 10-cm meter wide strips of two kinds of plastic (polyethylene and olefin) each with a buoyant bubble plastic border which floated the strips more or less vertically in the water. The course of microfloral and faunal establishment on this bed was followed for five months, as was invasion by local fishes. Algal growth quickly (3 weeks) reached maximum standing crop, though the composition of the biota fluctuated constantly throughout the test period. At maximum expression the biota was an incrustation of algal colonies, diatom films, some barely visible foliose and branching colonies, including hydroids, flagellates, minute worms and molluscs, and a large complement of sea hares (*Notarchus lineolatus*), the largest organisms actually living on the plastic constantly. Heavy grazing both by passing fish and the hares was evident for most of the test period. Fish of 15 species gathered around or in the beds, with the density of grazing scarids and acanthurids increasing throughout the test. Possible economic potentials are discussed.

INTRODUCTION

Mariculture faces one very difficult problem: it competes with many other activities and needs for space at the sea surface. These competing needs include such things as recreation, the movements of commercial vessels, aesthetic considerations, and fishing. This competition is made especially acute because maricultural activity generally requires the calmest water available, which is also prime area for other activities. An attractive alternative is to use the sea bottom for mariculture while the surface is left wholly or largely free for other activity. Even though storms may whip surface waters or swells may course across the surface, not far down one can expect to find relatively calm water. In most areas such water will be found 20-25 meters below the surface.

It is obvious from the start that sea bottom mariculture will have its own special set of problems. Our approach here is to come to grips with these problems by means of a pilot project on the sea bottom. We were aware at the start of a number of problems we would face. First, where water clarity is low due to turbidity in the water column, primary productivity would be reduced. The same can be said of any very deep placement where simple light attenuation would have the same effect. Sea bottom mariculture under such situations might not profitably depend upon natural productivity, but would have to turn to filter feeding organisms utilizing ambient particulate food material, or to local nutrient enhancement, or actual importation of food materials. Second, if enclosures are contemplated one must face the problems of water currents induced by tidal change. Fixed structures on the sea bottom encounter great forces from such currents; with water about 800 times as dense as air a two-knot current on the bottom means more than a 20-knot wind above the sea. The necessity of diving to reach a sea bottom farm adds an additional dimension of expense, effort and time. Yet the idea remains attractive, and we feel the great competition for sea space that has hardly yet been realized will force the developing mariculture industry, both in the United States and elsewhere around the world, to consider seriously the alternative of sea bottom use.

This paper will present first a brief account of some possible methods and opportunities for sea bottom use, and then describe a short experiment designed to test certain of these ideas. The possible uses we envision are: (1) sea bottom habitat enhancement, (2) shellfish culture, (3) production and trapping of detrital feeders, carnivores or herbivores.

1. Sea Bottom Habitat Enhancement

Most work on sea bottom enhancement has been directed at sport fishing, and has used large items of solid waste such as old car bodies, railroad cars, and the like (Carlisle, Turner and Ebert, 1964; Klima and Wickham, 1971; Randall, 1963; Turner, Ebert, and Given, 1969). When such materials are placed on a flat sea bottom they rather quickly assemble a biota which eventually includes fishes of suitable size and species for sport fishing. The enhancement is, of course, local and is relatively expensive. Furthermore, it is probably unharvestable by any other means than sport fishing. Other alternatives exist. It should be relatively simple, instead, to design enhancement systems that could be easily harvested by mechanical means, or which could be designed as traps to capture and concentrate the vagrant fauna.

A number of experiment have been carried out using "plastic sea grass" in which thin flexible strips of buoyant plastic are arranged in closely adjacent parallel rows usually by being attached to a net or a line stretched over the sea bottom (Richards, in Odum, 1968). If rope is used, it is payed off a vessel and stretched back and forth over a rectangular grid until a "grass bed" is formed. Strip length varies with the application desired. Very long strips tend to tangle, and in any case, currents tend to flatten such beds periodically, thus varying their thickness. Such beds have been used in ponds at Oceanic Institute and over shallow flats for shrimp culture, but so far as we know their possible use in deeper, more open sea has not previously been tested. If successful, the areas available for grass bed or other construction are very large.

Conceivably, source organisms can come either from species indigenous to the area, or by planting of desirable species. Thus, grass beds established near rocky or coral habitats quickly assemble a fauna drawn from residents or their reproductive products. Anyone attempting this economically has only minor choice of the kinds of organisms that will colonize, and productivity will inevitably be spread over many species of little economic worth. In fact, such unwanted organisms are likely to be preponderant, at least early in the establishment of such beds.

Planting specific valuable fish species in such beds faces severe difficulties such as wandering, predation and competition, unless beds are enclosed by netting. Our experience suggests that even completely enclosed beds cannot exclude competitors. Many competitors are simply too small to be excluded by nets. For instance, in the test we report here the major competitor, and a very efficient one, was the sea hare (*Netarchus lineolatus*) which swarmed in the plankton at sizes so small as to be scarcely visible.

Our test showed that a vagrant mass of detrital algae continuously moved over the bottom of the test area, in our case primarily composed of masses of *Enteromorpha*, presumably broken loose nearer the surface by wave action.

From other diving experience we know such masses to be common phenomena. Such algal masses typically serve both as food and as shelter for a variety of organisms, some of which (shrimps, young spiny lobsters, young of valuable fish species) have commercial value. It could prove valuable to trap such material in the region of a sea bottom farm, both to provide brood stock for the farm and to provide food. Such trapping should be easily accomplished with some efficiency since without our help it tended to gather on guy ropes, anchors, and amidst the grass itself. In this way, productivity in the turbulent zone might be imported and concentrated for farming in calmer, deeper water, which hence would not be dependent solely upon direct light penetration.

Harvest of sea bottom grass beds might be relatively simple since it is uniform and can be bent down to the sea bottom, causing fish and other organisms to flee. One can envision a harvest device on skids that is drawn over a grassbed causing organisms to flee upward into the water where they are swept up by a net attached to the skids.

The biota that collects on grass beds includes a large variety of species of plants and animals. Those accumulated will be enumerated later, but in our test, the most common forms included many algal diatom and dinoflagellate species, a protist fauna, hydrozoans, worms, molluscs, and crustaceans. Such a biota is subject to increase in biomass through proper fertilization. Though we did not attempt this in our tests because we wished to observe natural colonization, growth, and competition, we see no serious obstacle to local fertilization of the ambient water in and around a sea bottom farm. The major consideration we feel will be efficiency. Fertilizers released into the water mass will quickly disperse beyond the limits of any farm, even in areas of very calm water. The usual currents of half a knot or so will move such nutrients across a farm in minutes. Strategies such as placement of fertilizers in dispersal containers which leach slowly into the surrounding water can keep a continual supply of nutrients available, but cannot contain them within the farm. Placement of such dispersal containers deep in the grass bed may take advantage of the reduced currents found there.

Currents, in our test, did not always move in the same direction, but changed with the tides. This, too, will affect the placement of any such dispersal containers.

Such containers can be perforated drums or bags filled with nutrient materials whose availability for solution is kept low enough to leach slowly into the passing water.

Perhaps the most promising solution would be the development of special plastics for the strips of the grass beds, which themselves contain nutrients that very slowly leach into the surrounding water, perhaps being available only to settling organisms. If properly designed, such strips might be renewable. A grass bed hauled to the surface for cleaning might be immersed in a nutrient bath allowing recharging of its fertilization capability.

Because some of our settling organisms seemed to actually penetrate into the plastic strips one can envision a nutrient plastic in which the exterior surface is designed to allow attachment, with a nutrient-rich core available only after penetration.

Not only the sea bottom may be usable, but also the water column itself. It is well known that flotsam and floating kelp rafts are highly attractive to a variety of pelagic fishes, many of which have commercial value (Gooding and Magnuson, 1967). Every fisherman in Hawaii knows that if he trolls his lures around floating logs, boxes or other debris he is very likely to catch the mahimahi (Coryphaena hippurus). Fishermen in the southern California area know that considerable tonnages of certain fish (principally the genera Medialuna, Chromis, Girella, Anisotremus and Sebastodes) congregate under kelp rafts primarily composed of the algal genera Macrocystis and Pelagophycus. Therefore in designing the test reported here we built the gear so the grass bed could be suspended at different heights from the bottom on an anchored frame. However, our experiment told us little beyond giving us a graphic demonstration of the complicated seamanship and marine design involved in reliable anchoring of such a bed in a moving water mass.

2. Shellfish Culture

We feel that the potential for subsurface shellfish string culture is considerable. Mussels and oysters are amenable to string culture (Ryther and Bardach, 1968), in which growing shellfish are allowed to set on ropes or kept from setting by use of "setless cultch" and held in baskets, which may then be arranged in strings. In sea bottom application such strings can be suspended up from the bottom, to a floating frame above.

In the Lummi Indian Aquaculture project, such frames have been designed to have adjustable buoyancy through regulation of air volume within floats, thus allowing the entire shellfish farm to be brought to the surface for harvest or treatment as desired, simply by use of compressed air (W. Heath, personally communication 1972). The potential of this sort of shellfish culture is great because the organisms do not depend upon sunlight, but, indeed, may sometimes grow in total darkness, as when mussels grow inside salt water pipes. Further, detrital drift is greatest near the bottom and may provide greater nutrition than is found in surface waters. Proper design should avoid benthic predators and parasites that tend to plague simple bottom culture.

3. Production and Trapping of Detrital Feeders, Carnivores or Herbivores

Our test showed us that a sea-bottom grassbed is attractive to both predatory fish and to herbivores. The predators presumably came to seek out the variety of smaller fish that come to live on the plastic strips, and to feed upon the growing consumer organisms feeding on the grassbed--in our case, primarily sea hares. The herbivores fed constantly upon the grass bed, leaving the marks of their teeth everywhere on the plastic strips. Many of such fish were of commercially useful species, especially scarids and acanthurids, while numbers of labrids and other species from other groups also gathered.

The point is that the attraction of such grassbeds allows design of limiting nets so that they could be made to draw in and capture wild fish from the local region. These could either represent a direct harvest or food for captive predators.

Production of herbivores will depend for its success upon the feeding efficiency of the herbivore used, in relation to unsolicited competitors for the food which is raised, the degree to which such competitors can be controlled by exclusion or by selective use of predators within the enclosure.

MATERIALS AND METHODS

A "plastic grass bed" was established in 28 meters of water, 2 kilometers off the coast of Oahu Island, Hawaii, and 800 meters northwest of Manana Island. It was located over an irregular coral sand patch, which sloped gently toward the northeast. Twenty meters to the south and the north were located outcroppings of coral and rock which supported a moderately rich resident biota. The water in this area is generally quite clear, the bottom often being visible from the surface. However, turbid inshore water frequently obscures the bottom when tidal currents are forced seaward during heavy seas.

The grass bed itself was designed to be stationed at various depths in the water. It consisted of a 6 x 12.5 meter polyvinyl chloride pipe frame with the lines holding the plastic strips laced back and forth across it (Fig. 1). In this way 19 rows of plastic strips (6 mil clear polyethylene) were produced; or about 4500 individual strips in all, each placed directly adjacent to the next. The strips were formed by slicing a large sheet which had been heat-sealed on the bottom rope into 10-cm wide strips, 2.5 meters long. Each strip had a 5-cm wide border of bubble plastic heat-sealed to its top edge, providing flotation to the entire strip.

The entire frame with its plastic strips rolled and held in place with rubber bands was towed by small boat to the chosen area, sunk and attached to three 550-kg cement weights. A bridle from each extended to the side pipes of the frame. Directly above these attachments were drums filled with syntactic foam which provided approximately 55 kg buoyancy per float. These six drums were sufficient to suspend the frame about 3 meters off the bottom

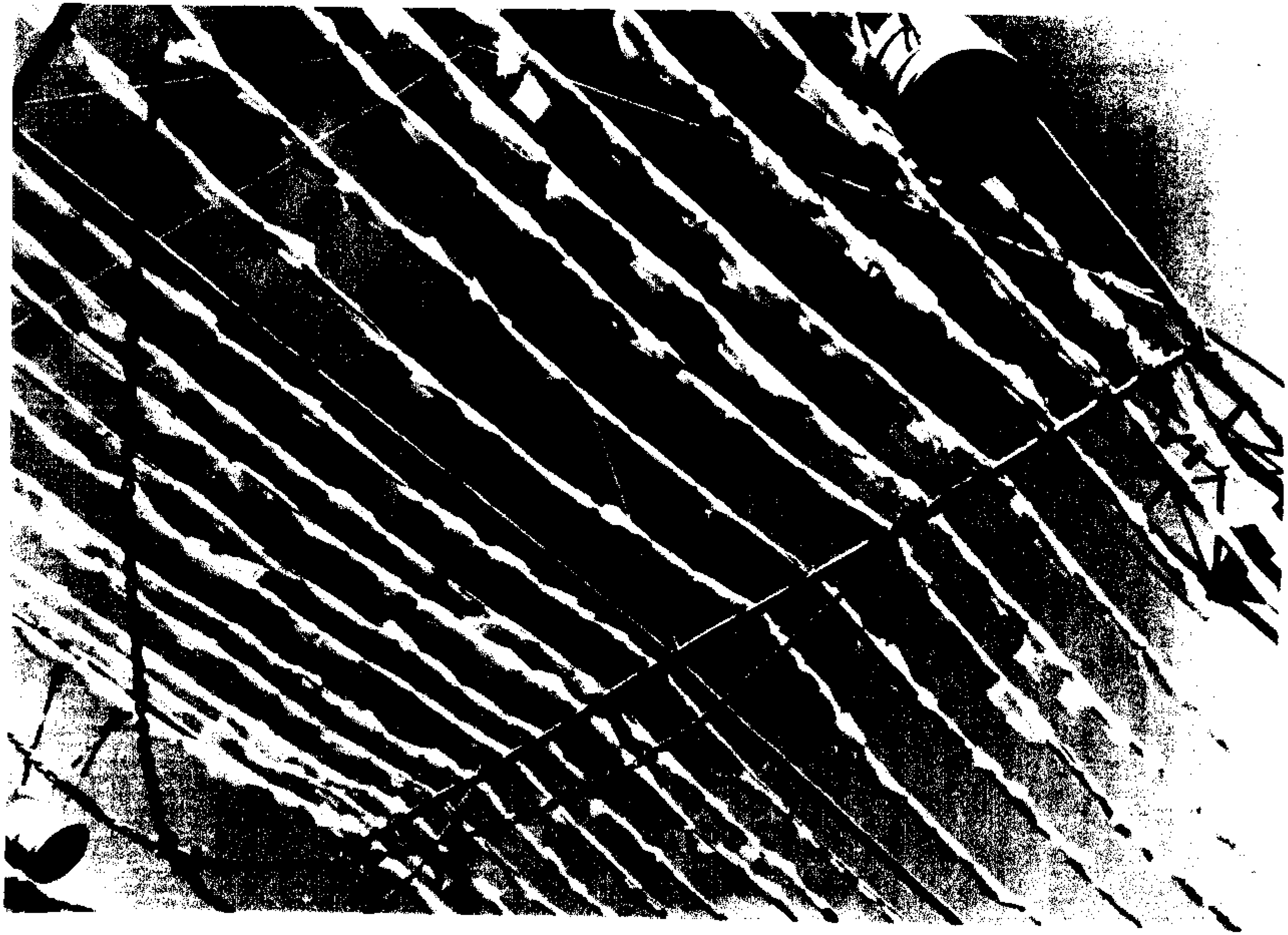

Fig. 1 Grass bed frame readied for towing to sea. The individual plastic fronds are still wound around the frame.

and to maintain it in that position during the tests. Thirteen-mm, braided polypropylene line was used for bridles.

The temperature regime in the area of the bed was one of a minor fluctuating thermocline which horizontally transected the bed at about the middle of the plastic strips. At ebb tide, when an eastward drift of 1.0-1.5 knots developed, a thermal boundary could be detected at about 20 meters depth, with turbid inshore water above at 25.5-26.0° C, and clearer offshore water below which was 1.5-2.0° C cooler.

The status of the grass bed was checked approximately weekly by a diver, and three strips of plastic cut--one from each of the NW and SE corner areas, and one from the center. In addition to the smooth polyethylene strips of the main bed a group of 500 strands of a more texture-surfaced olefin plastic (DuPont Tyvek No. 1079-D) were tested. A strip of Tyvek was also taken weekly for examination. Each such strand was carefully rolled and placed in a small plastic bag and sealed closed. Care was taken to dislodge neither algae nor associated animals from the plastic. Many of the latter were found swimming free in the bag when it reached the laboratory. These strips were examined along their lengths and identification of species made. Estimates of percentage composition were made.

At first, weights of accumulated organic material per unit area of each strip were taken but it soon became evident that natural grazing was so efficient that such films were not increasing, but being kept constant at a very low standing crop. Count and species compositions of the fish and invertebrate faunal elements of the area were kept throughout the test. Observations of behavior allowed identification of fishes and other organisms involved in grazing on the plastic and those that proved destructive to it.

RESULTS

1. Colonization of Plastic Strips

After one week of immersion, to the eye the plastic appeared clean. Microscopic inspection, however, showed a growing colonization of widely separated brown clusters of Ectocarpus and diatoms, especially near the edges of the strips. A few unidentified green patches could also be seen.

By two weeks few macroscopic organisms were evident but a thin brown film could be seen over much of the strips, especially within a meter of the top. This was found to be composed of approximately 70 percent Ectocarpus sp. and 30 percent unidentified diatoms. Some flagellates were found, and on the strip taken from the center of the bed the film was present, but also filamentous Ectocarpus up to 3 cm long, and smaller filamentous red algae, (Ceramium sp.) plus several colonies of encrusting red algae. By this time some of the colonies had penetrated slightly into the surface of the plastic. Growth was greatest wherever the plastic provided unusual protection, for example in folds or seams where the plastic had been heat sealed to the bottom rope.

Samples taken after three weeks of submersion showed that the biota had diversified in species composition and that grazing had begun in earnest. Filamentous red and brown algae were common, though filaments were short (generally less than 1 cm) and interspersed with diatom scums, mixed with hydroids, dinoflagellates, flagellates and much evidence of grazing from the sea hare, Notarchus lineolatus. Much broken or digested material could be seen, presumably derived from these animals, especially materials from encrusting red algae.

By the fourth week, N. lineolatus had become exceedingly common and was swarming over plastic surfaces in some areas. Algae had become patchy; in some places spotty green patches were interspersed with clear patches. In others, especially on the central sample strip, mostly diatoms were found, with occasional patches of a filamentous red alga (Jania sp.). In general, standing crop was somewhat less than the previous week, while grazing by N. lineolatus was markedly increased.

The fifth week sample showed very light growth in the peripheral strips, with heavier growth in the central sample. Notarchus lineolatus were extremely common, mostly very small (less than 1 cm), and the detrital remains of their grazing were very evident,especially on red algae such as Jania and Porolithon. One could see red algae in the intestinal tracts of the N. lineolatus, through their body walls. The algae Codium, Centroceras sp. and Ceramium sp. had made their appearance, and some long (several centimeters) Ectocarpus filaments were found. Both diatoms and flagellates were very common over most parts of the central strip.

The sample from the sixth week showed that the N. lineolatus were generally larger, approximately twice the size of last week's sample, but still very abundant, and the effects of their grazing continued to be very clear. The strips showed somewhat more overall growth, but visible filaments remain sparse. Flagellates, small worms, and groups of a globose microscopic alga (Colpomenia sp.) were found. Some of the worms had ingested red algae as could be told by the color of their gut contents, and the fact that some were colorless. Strands of a red alga Polysiphonia were found.

Masses of Enteromorpha, a green alga, presumably from inshore, had washed along the bottom and accumulated on guy wires around the anchors (Fig. 2). This alga could be seen in small patches away from the frame, creeping over the sandy bottom in the current.

The seventh week sample showed a reduction in the numbers of N. lineolatus but egg masses were present, a continued grazing of algae, especially the

Fig. 2 Enteromorpha on frame bridle

reds, and a diversification of the biota. For the first time very small gastropod molluscs were noted. An encrusting red alga (Peysonnelia sp.) became quite widespread over the plastic strips. Some of the algae, even though they were essentially only films on the surface, showed well developed fruiting bodies.

The eighth week sample showed an increase in growth, especially on the central strip, but almost wholly as a mat without significant filamentous algae standing up above it. Much grazing was evident, and a number of N. lineolatus were taken from the bag, some as long as 1 cm. Predominant algae were the same as before: Peysonnelia, Ectocarpus, Jania, Porolithon, and a newly reported green matted algae was very common the attachment ropes, Microdictyon. Diatom populations seemed to be smaller, and more spotty.

The ninth week sample showed a regression in the mat over outer strips. Hydriods had become common, and N. lineolatus was still in evidence, including egg masses of a variety of sizes up to those 1 cm in length. In many areas the clear plastic could be seen, and often the microscopic inspection showed scraping marks, probably from the radulae of sea hares. Much debris of grazing was evident. Macroscopic filaments were rare.

No samples were taken for 29 days (Sept. 1, 1971) and when the bed was sampled, growth was found to be sparse, and grazing very evident, both by N. lineolatus and fish. The sea hares, as always, seem selective in their grazing, preferring red algae while the fish leave raking tooth marks that cut across all the algae and other organisms present. Notarchus lineolatus was very common and mostly quite large, approximately 1.5 cm in length. Many were found free floating in the plastic sample bags. Egg masses of the sea hare were common.

For the first time the plastic sheets were perforated in one place, along a fold, and tooth marks were evident nearby. One tear along a fold was found, as if the plastic had become somewhat brittle. On an outer strip four ovoid holes approximately 2 cm long were found. These are thought to have been produced by Diodon holocanthus, the spiny pufferfish, which had taken up residence in the bed (Fig. 3).

The September 9th sample showed no significant change from the patterns noted above.

The olefin plastic seemed to be a considerable improvement over smooth polyethylene. Its textured surface tends to hold a reservoir of algae (Fig. 4). partially protected from grazing, even from the very selective grazing of the sea hares. Its opaque quality did not seem to inhibit growth though our sample was small enough that ambient light from the sides might have induced growth were a full dense bed might inhibit growth deep in the bed. It seemed somewhat less brittle than the polyethylene after exposure to seawater, and it is extremely light and tough. One can conclude that texture is an important feature of grassbed plastics, and that further checking of available types of

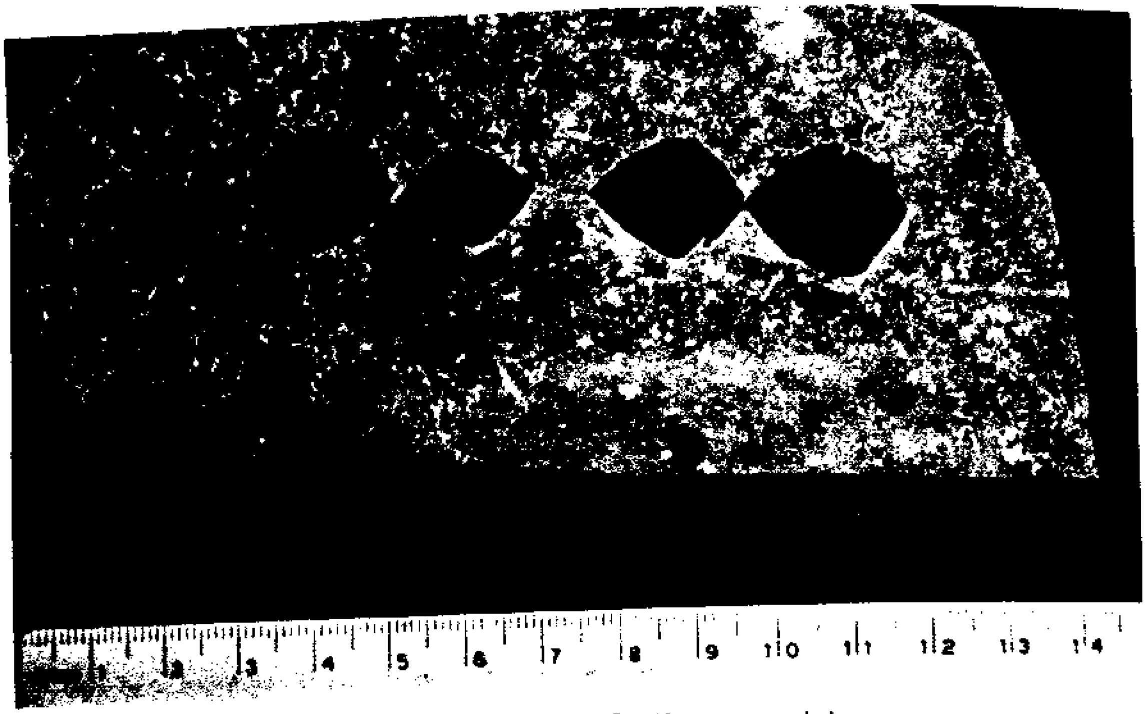

Fig. 3 Perforations in plastic grass strip.

Fig. 4 Tyvek fronds showing algal accumulation.

plastics is in order, as is the attempt to develop new ones specifically designed for this application.

Thus, in the uncontrolled environment of the subtropical open sea one can expect grazing to be so efficient that only a matting of algae and associated organisms is produced. Filaments are quickly cropped off. Sea hares, in this test at least, were in continual supply and were able to reproduce on the plastic, and probably provided food for carnivorous fish in the area. No obvious way to control them is apparent.

2. Fish Populations

A fairly representative fish fauna of species typical to moderate depth, nearshore coral and rocky reef areas was present at the time the bed was put in place. These fish, naturally enough, were concentrated over the adjacent rocky refuges and only occasionally strayed as far as the grass bed. The composition of this fauna is shown in Table 1.

Schools of adult acanthurids and scarids were frequently seen in the area but fled as soon as the diver appeared. These fish are thought to be responsible for the grazing marks attributed to fish. Small schools (5-20 individuals) of juvenile acanthurids, principally the Achilles Tang (Acanthurus achilles), were common around the bed.

The spiny puffer, Diodon holocanthus, was typically found at the bottom of the frame or amongst the lower ends of the plastic fronds. In the plastic it tended to match the motion of the strips as they swept in the tidal current. It was felt that this fish was feeding in part on the population of sea hares, and that it was responsible for the large ovoid perforations of the plastic occasionally found.

The Trumpet fish, Aulostomus, was common throughout the bed, taking up the alignment of plastic strips or ground tackle to which they oriented. They, too, are likely to have been feeders on sea hares.

3. Light Regime

The light regime was generally rather bright at the level of the plastic strips, though storms did cause a layer of murky surface water to enter the area from time to time. A series of light readings were made during October and November at the grassbed site. These are listed in Table 2. They were performed using a Kahl Scientific Instrument Corporation submarine photometer Model 268WA310. This instrument has a wide spectral range with 50 percent of its sensitivity in the visible wavelengths between 4000 and 6400 Å. Water clarity during the period of light readings was approximately the same as during the grassbed tests, though later in the year. Hence we expect that actual light levels at the time of growth tests would have been somewhat higher than indicated in Table 2.

Table 1. Fish species found in the area of the submerged plastic grassbed

Species	Present in adjacent area	Present near Frame	Resident in Grassbed
Chaetodontidea			
Holocanthus arcuatus	X		
Centropyge potteri	X		
Forcipiger longirostris	X		
Chaetodon corallicola	X		
Chaetodon fremblii	X	X	
Chaetodon miliaris	X	X	
Chaetodon ornatissimus	X		
Chaetodon multicinctus	X		
Heniochus acuminatus	X		
Zanclidae			
Zanclus canescens	X		
Pomacentridae			
Dascyllus albisella	X		
Chromis leucurus	X		
Balistidae			
Balistes bursa	X	X	
Canthigasteridae			
Canthigaster cinctus	X	X	
Aulostomidae			
Aulostomus chinensis	X	X	X
Monocanthidae			
Alutera scripta	X	X	
Cirrhitidae			
Paracirrhites forsteri	X		
Labridae			
Bodianus bilunulatus	X	X	
Coris ballieui	X	X	(feeding)
Thalassoma duperreyi	X		
Novaculichthys bifer	X	X	
Labroides phthirophagus	X		
Mullidae			
Parupeneus pleurostigma	X	X	
Parupeneus multifasciatus	X	X	
Parupeneus chryserydros	X		
Scaridae			
Scarus sp.			(young of two species feeding on plastic)

(Table 1 - continued)

Species	Present in adjacent area	Present near Frame	Resident in Grassbed
Acanthuridae			
Acanthurus sandvicensis	X		
Acanthurus olivaceus	X	X	(feeding)
Acanthurus achilles	X	X	(feeding)
Acanthurus nigrofascus	X	X	(feeding)
Acanthurus nigroris	X	X	(feeding)
Naso lituratus	X		
Diodontidae			
Diodon holacanthus	X	X	X
Sphyraenidae			
Sphyraena barracuda	X		
Lutjanidae			
Aprion virescens	X		
Malachanthidae			
Malacanthus hoedetii	X		

Table 2. Illumination measurements at 80' test site. (Readings in foot-candles)

Date & time	Reading at	Depth (feet) 0	10	20	30	40	50	60	70	Comments
10-25 1615	Depth	33.3	33.3	33.3	29.1	27.0	25.8	25.0	22.5	Partly cloudy, moderate seas-some cresting, water clear.
	Surface	33.0	33.0	41.6	31.2	29.1	29.1	29.1	29.1	
10-26 0930	Depth	96.0	62.9	60.4	59.5	57.0	54.5	55.0	54.1	Clear, moderate seas-little cresting, water clear.
	Surface	95.8	108.3	112.5	112.5	108.3	116.6	112.5	100.0	
10-27 1330	Depth	120.8	70.8	65.0	60.8	55.4	50.0	43.7	41.6	Clear, calm seas-slight swell, water clear.
	Surface	120.8	114.5	110.4	112.5	112.5	110.4	112.5	108.3	
11-3 1100	Depth	54.0	52.0	51.2	47.5	45.0	44.5	41.2	40.0	Overcast, moderate seas-some cresting, water clear.
	Surface	58.3	79.1	95.8	91.6	79.1	87.5	75.0	70.8	
11-5 1200	Depth	108.3	54.1	54.1	52.0	47.9	43.7	34.1	30.8	Clear, calm seas-heavy swells, water clear.
	Surface	120.8	120.8	---------(meter not reading)------------------						
11-15 1000	Depth	108.3	90.4	89.5	88.3	83.3	80.0	72.5	63.7	Overcast and rainy, moderate seas-some cresting.
	Surface	------------------------- (meter not reading) ----------------								
11-18 1030	Depth	66.6	57.5	55.4	53.3	48.3	43.7	41.6	36.6	Partly cloudy, seas moderate-no cresting.
	Surface	91.6	104.1	100.0	104.1	104.1	100.0	91.6	83.3	
11-19 1100	Depth	37.5	36.2	35.4	34.1	32.9	31.6	30.8	30.0	Clear, seas very rough-6-8' swells and cresting.
	Surface	116.6	116.6	112.5	116.6	120.8	116.6	116.6	116.6	

DISCUSSION

The experiment reported here points to some of the difficulties anyone faces in attempting sea bottom or water column mariculture. Grazing proves to be extremely efficient in the subtropical waters of the test, with species specific grazing being carried on by small molluscs, and less specific grazing by herbivorous fishes. Little filamentous algae appeared during the tests because of this extensive grazing, even though some forms became reproductively mature. A simple ecosystem developed in which predators, primarily on the mollusc population, took up residence in the plastic; and various herbivorous schooling species fed from the beds at varying intervals. There seems no way to exclude the molluscan grazers from such beds, and the only obvious solutions are to trap vagrant herbivores, using the beds as a lure, and the netting enclosures as traps, and to utilize the molluscs as food for desirable predators, none of which took up residence in the bed spontaneously.

Even the modest tidal currents encountered gave serious problems of anchoring and drag upon the bed as a whole, especially since it was suspended in midwater. Stresses upon the ground tackle and the frame required important maintenance within six months of submersion, including repair to ropes, the pipe frame upon which the plastic strips were mounted, and other minor repairs.

The plastic itself, both for polyethylene and Tyvek, showed signs of degradation by the end of the test. Brittleness seemed to have increased, causing cracks to appear at folds, and minor damage from fish was also apparent. This sort of problem would be expected to reach important levels in approximately a year of submersion. Whether the plastics could be expected to remain usable over two or more seasons is uncertain.

It is concluded that while a variety of problems have appeared for undersea mariculture in this simple test, that certain problem areas can now be pinpointed for further work. Specifically these are: the development of new and more rugged plastics, and especially those that might incorporate slow leaching nutrients from a central core, the study of proper anchoring and grass deployment, the development of net barriers that could trap vagrant herbivores and carnivores, and experiments with the planting of beds with desirable species for mariculture.

SUMMARY

1. Undersea mariculture deserves intensive study because it will provide large areas of calm water relatively free from the intense human competition one encounters at the sea surface. Open sea areas can be used because surface turbulence becomes unimportant at modest depths beneath the surface.

2. Plastic grassbeds are attractive to both carnivores and herbivores, and this feature may allow their capture by properly designed net barriers.

3. Detrital algae typically creeps along the sea bottom in masses, and might be collected to enhance food supply in sea bottom farms.

4. Plastic grassbeds quickly grow a matting of plants and animals, principally diatoms, hydroids, red and green algae, worms and molluscs, that is very efficiently grazed from its initial appearance both by fish and by smaller organisms. The smaller organisms, chiefly the sea hare Notarchus lineolatus, are selective feeders, primarily upon red algae.

5. Presently used plastics are not expected to be long lived in the sea, primarily because of their tendency to grow brittle and because certain fish species perforate them during grazing.

REFERENCES

Carlisle, J.G., Jr., C.H. Turner, and E.E. Ebert. 1964. Artificial Habitat in the Marine Environment. Calif. Dept. of Fish and Game, Fish Bull. 124: 1-93.

Gooding, R.M. and J.J. Magnuson. 1967. Ecological significance of a drifting object to pelagic fishes. Pac. Sci. 21, no. 4:486-497.

Heath, W.G. 1972. Scientific Advisor, Lummi Aquaculture Project, Bellingham, Washington.

Klima, E.F. and D.A. Wickham. 1971. Attraction of coastal pelagic fishes with artificial structures. Trans. Amer. Fish Soc. 100(1):86-99.

Randall, J.E. 1963. An analysis of the fish populations of artifical and natural reefs in the Virgin Islands. Caribbean Jour. Sci. 3(1):31-47.

Richards, W.L. (reported in Odum) 1968. Utilization of the direct grazing and plant detritus food chains by the striped mullet Mugil cephalus. Symp. on Marine Food Chains, University of Miami, Contribution no. 19.

Ryther, J.H. and J.E. Bardach. 1968. The Status and Potential of Aquaculture, Vol. I: Particularly Invertebrates and Algae Cuture. Amer. Inst. of Biological Sciences, Washington, D.C.

Turner, C.H., E.E. Ebert, and R.R. Given. 1969. Manmade reef ecology. The Resources Agency, Calif. Dept. of Fish and Game. Fish Bull. no. 146, 221 p.

Yokote, M. 1969. Observation on eggs spawned upon the artifical weeds set in the Sagami reservoir. Bull. Freshwater Fish. Res. Lab., Tokyo, 19(2):113-119.

II. REFURBISHING AN HAWAIIAN FISHPOND

Kenneth S. Norris and John J. Crouch

REFURBISHING AN HAWAIIAN FISHPOND

Abstract

Approximately two hundred stone-walled fishponds were built by early Hawaiians along the shores of the islands, chiefly on shallow reef flats. The majority of these ponds have fallen into decay from tidal wave damage, siltation and clogging with mangroves. But some are in a fair state of preservation and are still used for low level production of mullet and milkfish.

The ancient ponds are of much historic interest, and efforts have been made repeatedly to preserve the best as historical monuments. Most plans to refurbish the ponds and to reinstitute mullet and other mariculture have failed before repair has been completed. Still, the popularity of "restoration" remains as a way to (1) assure the continued existence of the ponds in the face of land development, hotel and marina plans; and (2) provide a profitable commercial venture, especially considering the increasing cost of mullet.

To test the economic feasibility of restoration, the Oceanic Institute undertook the refurbishment of a moderate-sized pond on Molokai Island for experimental culture of mullet and other pond organisms. Total refurbishment of half the pond has required 18 months for completion and cost a total of $50,799. The details of refurbishment are described and costs are listed, with an idealized projection for the refurbishment and long-term operation of other ponds.

INTRODUCTION

Rather frequently one sees in the public press comments about the fate of the aboriginal Hawaiian fishponds. They dot the shores of the islands, and many are very old, some perhaps having been built in the 13th century (Summers, 1964). They are, indeed, antiquities of great value. Yet their existence is constantly threatened by the various pressures of modern society. Shorelines are at a premium everywhere, and in Hawaii such pressures are especially great because of the strong marine orientation of Hawaii's people and its tourist industry. It is at once apparent that such ponds can be filled to produce prime hotel sites, or dredged to provide marinas. Those who would preserve them often speak of refurbishing them and operating them as fish, shrimp or oyster farms, or as areas for controlled sports fishing.

This study details the refurbishment of Ali'i Pond on Molokai Island, a 25.8 acre enclosure located three miles to the east of Kaunakakai (Evans, 1937) for a research pond for fish culture studies. Ali'i Pond is one of fifty along the Molokai shoreline (Summers, 1964) and is of a class called *loko kuapa*. This means that its wall was a solid barrier of lava boulders and coral, pierced only by a gate or *makaha* which, when in operation, was blocked by a solidly fixed weir made of wood and slim branches set close together to form a barrier to large fish (McAllister, 1933). Ali'i Pond apparently originally had only a single such gate in its 2700-ft long wall, though there are now two. The second was doubtless built in recent years. Other ponds of the *loko umeiki* type had walls pierced in many places, each equipped with a station for net fishermen, who stood on one corner of each gate and dipped fish that passed in or out with the tide. There are several *loko umeiki* on the Molokai shore, though the preponderance of ponds are of the *loko kuapa* type, which were used for fish culture, or fish holding, by ancient Hawaiians. Culture fish were primarily mullet (*Ama ama*--*Mugil cephalus*) or milkfish (*Awa*--*Chanos chanos*).

Hawaiians kept the ponds in repair in a variety of ways. Walls, of course, were continually repaired when waves rolled rocks from them. Excess algal mattings were rolled up and removed. Phelps (1937) reports that a bamboo rake was used to clean ponds by towing it behind a canoe. Mud from mountain runoff sluices into the sea in large amounts, and if stream courses are included within the walls of a pond, much siltation can occur. Even in ponds built with streams running outside the walls, general storm siltation over the reef flat causes the entry of much sediment into the ponds, and very violent storms may move much mud into ponds without regard for normal drainage channels. At any rate, siltation was, and is, a major problem for pond operators. Communal effort, using coconut

Fig. 1. Ali'i Pond and field station.

shells as scoops, is reported as an ancient method for silt removal. Today when labor costs are high, silt removal is the major deterrent to pond refurbishment, and in many cases a hundred years or more have elapsed since silt was removed from the ponds. It is now common to encounter silt layers, varying in depth from a few inches to five or more feet, covering the old coral flat surface. In Ali'i Pond the mud accumulation reduced water depth from zero at low tide in the eastern side, which is also heavily invaded with mangroves, to about 18 inches on the western and outer edges of the pond.

REFURBISHMENT

Refurbishing Ali'i Pond (Fig. 1) to provide experimental facilities for field studies of pond production of a variety of fish, shellfish and mollusc species included the following major items:

1. Dredging

   The first stage of refurbishment included dredging of half the pond to accommodate a minimum of one foot of water at low tide, with an ultimate capacity to hold water at a minimum of 2.5 feet regardless of tide fluctuations outside the pond. A deeper channel, 20 feet wide and five feet deep at low tide, extends from the outer makaha to shore for a thousand feet, and provides a siltation trap to protect the newly dredged areas from silt invasion from the undredged half of the pond.

2. Wall widening

   The western wall was widened to allow passage of vehicles (Figs. 2 and 3) from the research station ashore. The original plan was to build the inner wall from rocks obtained on nearby island slopes, with dredge spoils as the inner fill. However, a cheaper method proved more satisfactory: the inner wall was built of 1/2 in., form-lumber plywood sheets (obtained as waste from a local construction company) supported by mangrove poles. Dredge spoil was used to fill the 12-foot space between the plywood barrier and the outer rock wall. The double wall extends approximately 85 yards, and is 20 feet wide--ample length and width for vehicles.

Fig. 2. Dredge spoils being used as fill for service dock area.

Fig. 3. Nearly completed service dock area.

3. Installation of tidal gates

The ancient Hawaiians relied upon the porosity of their rock walls to allow movement of sea water during tidal change. However, our impervious west wall requires gates, each blocked by a one-way, 8-foot weir. These retain desired water depth in the pond as the tides fall.

4. Nursery pond and experimental enclosures

Inshore along the beach that abuts the west base of the wall, seepage of fresh water constantly enters the pond. Ultimately dredged material is planned to enclose a pond, which could be expected to be nearly fresh, for shrimp culture.

Experimental enclosures within the pond are to be constructed of netting according to experimental requirements. Further, fill from the siltation-trap channel will provide a 200' x 60' mid-pond island to support other experimental gear.

The initial refurbishment does not include complete removal of the mangroves along the eastern and northeastern borders of the pond. Removal would expose much otherwise stabilized mud and make more dredging necessary. Nor was this phase designed to improve the eastern half of the wall, or to dredge an east-west tidal flow channel.

REBUILDING THE POND

A project grant (NSF GH-78, Sea Grant Program) of $104,735 allowed us to begin repair operations on March 15, 1970. The other portion of the grant was used concurrently for other open ocean mariculture experiments at the Makapuu laboratory. Ultimate expenditures at Ali'i Pond totalled $50,799.

1. Special equipment

Subcontracts were let for engineering design and construction of two major pieces of equipment:

(a) A two-pontoon, 20' x 12' barge, (Fig. 4(a)) capable of being disassembled and placed on a two-ton truck for movement to various work sites.

The barge was equipped with a 6-in. Midwhirl Trash Pump, driven by a 50-hp Ford diesel engine, and 500 feet of demountable, 6-in. Ringtight Blue Bell PVC discharge pipe, (Fig. 4(b)), plus a movable suction head equipped with a screen deflector that rejected all particles bigger than 3 inches in diameter. In addition, a 3-1/2 hp gas engine for operation of the hydraulic spud and winch sweep system was purchased.

(b) A lightweight pile-driver capable of driving heavy mangrove poles for dike construction. The pile-driver was equipped with a 200-lb weight and a 2-hp gasoline motor to run a winch for hoisting the driver.

The total cost of these two critical items was $16,000, including design, construction and delivery. Both are in excellent working order at completion of the first phase of refurbishment, and will continue to serve without major overhaul.

2. Wall and gate construction

The double-walled dyke supporting the road extends 250 feet from shore. The original pond wall was retained as the outer wall, and a new parallel inner wall was constructed of lava boulders from nearby slopes. The boulders were placed manually to form a dyke 10 ft wide, five ft high, and 250 ft long. At high tide, the wall is 1-1/2 feet above water line, as is the ancient outer wall. The space between was filled with approximately 500 cu. yds of dredged fill, and forms the main service dock. At the end of the broad wall, a bridge was built to cross one of the two existing makahas. The remaining wall is 12 ft wide, and extends 1000 feet to the dense mangroves on the eastern side of the pond

In the middle of the new dock-road area of the wall, a cement awai and makaha were constructed. Instead of using the ancient method of binding straight saplings vertically on the makaha to keep out predators and competitors, sheets of a special heavy duty plastic screen (Filter X, Cartage Mills, Inc.) for hydraulic filtration were used. This plastic proved to be self cleaning in the tide and is expected to be much more efficient than the sapling barrier in keeping the pond free of unwanted fish. The awai (Fig. 4(c)) (4' h x 8'w x 4'l) is constructed of cast cement, and provided with three slots for plastic screen frames, rubbish grates, and

(a) Dredging barge in Ali'i Pond

(b) Close-up of dredging barge pump

(d) Filtration gate, awai

(d) Detail of wall filling, showing plastic lining

Fig. 4. Dredging barge, filtration gate, detail of wall construction.

weir boards. A mangrove pole bridge was built over the awai to the other half of the service dock area.

3. Dredging Procedure

The pond was dredged in a series of arcs. A manually operated system allows a spud to be set in the pond bottom off a rear corner of the barge. The barge, with its dredge head, pivots around the spud. Then the spud is re-set on the opposite rear corner, advancing about 1-1/2 feet with each sweep. The dredging barge, in effect, "walks" across the pond. Dredge spoil is carried by 6000 g/hr to the fill area between the walls. At times excess spoil was available and sold as fill. Manual operation of the spud was later replaced by a motor-driven hydraulic cylinder system.

The pond bottom is silty mud, of variable depth, resting upon a calcareous crust three to four inches thick. The crust is composed of coral and shell fragments cemented firmly together, but can be penetrated with effort by a steel bar. The crust covers only part of the pond bottom; a central, pie-shaped area approximately 500 feet wide by 1000 feet long, coming to a point at the makaha, is clear of crust. It is presumed that the ancient Hawaiian operators of the pond kept this area free of encrustation and had a deeper spot here. The maintenance of such deep spots in mullet ponds has been described to us by Molokai residents familiar with pond operation. Fish were supposed to have retreated to them to find cool water and shelter during low tide.

Interspersed in the muddy silt were shells and stones of various sizes, mostly less than 1-1/2 inches in diameter. In dreding the bottom down to the crust, only stones larger than three inches had to be removed by hand.

4. Wall filling

Nine-foot mangrove posts, cut from cleared trees, were pile-driven three feet into the pond bottom leaving six feet above ground. They were placed 3-3/4 feet apart to provide support for used, half-inch plywood. The 4' x 8' plywood sections, narrow edge down, were nailed to the mangroves from the inside of the section to be filled. The section was then lined with 6 mil clear polyethylene plastic to keep water and small fines from leaking out through the overlapping joints, junctions of plyboard to pond bottom, and holes in the old wall (Fig. 4(d)).

4. Costs

The major overall expense, as would be expected for pond refurbishment, was for labor and supervisory personnel (Table 1). A project director was hired who supervised all aspects of the project. Other staff included a local resident hired as general foreman and pond manager, and a variable force of unskilled laborers, usually 2-3 young men from the local community of Kaunakakai.

The major equipment expenses were the specially designed and fabricated barge, dredging equipment and pile driver. During the course of refurbishment, a variety of other equipment was rented, including a truck used to haul rocks from the nearby quarry, and a skip loader to move excess spoil from the dredge discharge area. The difficult job of cutting and trimming mangrove poles proved more arduous and expensive than contemplated. The very hard wood took its toll of the lightweight chain saws. If further mangrove clearing is required, we would invest in heavy-duty equipment for this purpose.

The major construction expense was rebuilding the pond wall, and new inner wall which cost $928/100 linear feet, including cost of fill material. Dredging cost approximately $200/100 cubic yards of dredged material. We were able to recoup $500 of this cost by sale of excess fill. The materials in each gate cost $102, including concrete, aggregate, reinforcing wire, screens and frames, plus installation cost.

The adjusted amortized cost of refurbishing Ali'i Pond, is $474 per acre (Table 2). Because our staff at Ali'i Pond was performing functions concerned with work related to other scientific projects, we have prorated actual expenses on refurbishment during the time of repair to include only those items directly concerned with this aspect, and not total expenses during the period, which would inlfate the per acre figure to $944/acre. With a staff such as ours and with the sole job of refurbishing the pond, the lesser figure is correct.

Because our operations were being carried out by a nonprofit scientific organization, the costs listed above do not include usual fixed costs such as return on investment, general overhead, taxes and lease costs.

Table 1

EXPENDITURE SUMMARY (Two years)

	Total	Adjusted
Materials and Supplies		
Quarry rock	$ 487	$ 487
Plastic filter screen	563	563
Lumber and cement	759	759
Fuel	2,981	2,981
Oil	396	396
Tools, batteries, & parts	606	406
Miscellaneous hardware	409	309
Office supplies	10	10
Subtotal	$ 6,211	$ 5,911
Equipment		
Purchased	1,039	839
Fabricated	15,893	12,893
Subtotal	$ 16,932	$ 13,732
Expenses		
Shipping	531	531
Rental of equipment	1,005	505
Subtotal	$ 1,536	$ 1,036
Labor and Supervisory Personnel	$ 56,320	$ 30,120
TOTAL	$ 80,999	$ 50,799
Less research expenses not attributed to GH-78	30,200	
	$ 50,799	
Less depreciation (four years @ $2,635)		$ 10,540
Total Direct costs (for 17 acres)		40,259
Per acre amortized over 5 years		$ 474

Table 2

JOB COST BREAKDOWN

JOB	Adjusted Refurbishment Costs				
	Labor	Equip't	Mat'l	Total	Cost/Unit
Pond Wall Construction					
(2660 linear feet)					
Mangrove posts (cutting)	1,330	53	12	1,395	.52/linear ft
" " (driving)	1,596	72	16	1,684	.63 " "
Plastic liner	67	0	558	625	.24 " "
Bracing wire	67	0	53	120	.05 " "
Plywood	798	8	1,595	2,401	.90 " "
Totals	3,858	133	2,234	6,225	2.34 " "
Dredging (14,080 cu.yds.)	17,600	2,816	2,112	22,528	1.60/cu.yd.
Gate Construction (6 gates)					
Cement & aggregate	83	12	218	313	52.00/gate
Reinforcing wire	8	0	12	20	3.00/gate
Screens and frames	30	2	48	80	13.00/gate
Installation	120	84	0	204	34.00/gate
Totals	241	98	278	617	102.00/gate
Stone Wall Repair (400 cu.yds.)					
Field gathered stones	1,700	200	800	2,700	6.75/cu.yd.
Stone setting at pond	1,300	0	0	1,300	3.25/cu.yd.
Purchased quarry rock	0	0	487	487	
Totals	3,000	200	1,287	4,487	10.00/cu.yd. excluding quarry rock
Research Mgt. (portion of mgt salary not charged directly to labor)	5,421			5,421	
Equipment Rental & Shipping		505	531	1,036	
TOTALS	$ 30,120	3,752	6,442	40,314	

Total cost per acre	$	2,371
Cost/acre amortized 5 yrs	$	474

THE ECONOMICS OF HAWAIIAN POND OPERATION

Considering these costs for pond refurbishment and considering that the work was done by a nonprofit organization, can a private pond operator expect to refurbish such ponds elsewhere and realize a reasonable return on his investment? We have made a series of calculations relating to these questions. Our figures were based upon the following criteria:

1. The pond operation is a family or sole proprietorship operation.
2. The family provides 50% of the refurbishment work force and 100% of the annual operating work force.
3. Complete refurbishment of the pond is required.
4. Water depth is maintained at 2-1/2 feet, providing 4,000 cu yards of water per acre.
5. Sixty percent of required capital, including startup costs, will have to be borrowed.
6. A stable market exists in which fish can be sold at a price of $1.20/lb and rising to $1.53/lb on the retail market.
7. Two years are required to grow the first crop, and an annual crop is produced thereafter.
8. Family labor can be substituted with hired labor at a value of $3.50/hr.
9. Loss to poaching will be figured at 10% of the cash balance.
10. The pond contains 17 surface acres of productive water.

In order to achieve an 8%/yr return on investment, one has to project a yield of approximately 4,000 lbs/acre/yr, or 1 lb per cubic yard of water/yr. This figure is unrealistic for present mullet culture where expectable productivity is about 500 lbs/acre/yr. We concluded that for the refurbishment of Hawaiian ponds to be financially feasible at the present time mullet culture alone will not suffice, even with great technological improvement. Multiple culture of some sort must be considered, and even this is apt to be marginal. Costs and profits revealed by analysis of such culture would have to be matched against culture costs in other sorts of enclosures.

SUMMARY

Thus, in summary, the present cost of labor makes it expensive to refurbish aboriginal Hawaiian ponds for economically production. To succeed in such a venture an operator must follow of the suggested paths:

1. Find ways to significantly reduce the refurbishment costs we encountered in rebuilding Ali'i Pond. The most likely route is through methods to reduce labor costs significantl as for example, by community effort, by obtaining donated time from Community Action Programs, or by dedicated family effort. If large machinery, such as dragline equipment could be obtained cheaply, dredging costs might be significantly reduced.

2. Await or participate in field tests of existing laboratory data, to determine their validity in actual maricultural situations.

3. Await additional developments that will significantly increase yields from pond acreage. In any case, anyone who contemplates pond operation faces a rather long perio prior to debt-free operation, and must face a number of uncertainties, the greatest of which is nearshore pollution areas optimum for pond production.

REFERENCES

Bardach, J. F. and Ryther, J. H. (1968). The status and potential of aquaculture. Vol. II. Particularly fish culture. AIBS # PB 177 768, Washington, D. C.

Evans, T. J. K. (1937). Government fish ponds, Island of Molokai, Reg. Map 3010 (State of Hawaii Survey Office, Honolulu).

McAllister, J. G. (1933). Archaeology of Oahu. Bernice P. Bishop Museum Bulletin # 104.

Phelps, S. (1937). A regional study of Molokai. (ms. in Bernice P. Bishop Museum, Honolulu).

Summers, C. C. (1964). Hawaiian fishponds. Bernice P. Bishop Museum Special Publ. 52:1-26.