FOOD FOR A HUNGRY WORLD?

VOL. XIV, NO. 4, FEBRUARY 1969

OCEANUS

ON THE COVER—

Shall all of the fish of the Sea be gathered together for them . . .

Numbers 1:22

COVER PHOTO BY jl

Jan Hahn, *Editor*

Vol. XIV, No. 4, February 1969

OCEANUS™ THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

The Harvest of the Sea and the World Food Problem

PREDICTIONS of future famine in the poor countries of Asia, Africa, and Latin America have been made frequently and widely believed. It was never likely that they would come true, and the chances have now been greatly diminished by the development and widespread adoption of new high yielding varieties of rice and wheat in South Asia, and corn in Africa. But the fact that man cannot live by bread alone is true nutritionally as well as in other ways. The new cereals can provide sufficient calories and a good share of the protein requirements for the rapidly growing populations of the poor countries. However, they should be supplemented by high-quality protein from other sources. One possible source is the ocean.

We cannot expect that the ocean will supply a major part of the food energy needed by human beings, but the harvest of fish and shellfish could provide most of the required high-quality protein — protein having about the same relative amounts of essential amino acids as eggs or milk. In thinking about the future ocean harvest, we must consider the potentialities of both ocean farming and management of the open ocean range, the pastures of the sea.

In modern land agriculture, large quantities of chemical fertilizers are added to the soil as nutrients for plants. In marine farming, as Japanese experience shows, the highest yields will be obtained if we start with animals, such as filter feeding mussels and oysters, instead of plants, and let the ocean provide not only chemical fertilizers but the plankton and organic particles these animals feed upon. The areas most useful for aquaculture will not be those that can be enclosed or fenced in, but rather those where there is a continual supply of plankton carried by currents past sessile animals.

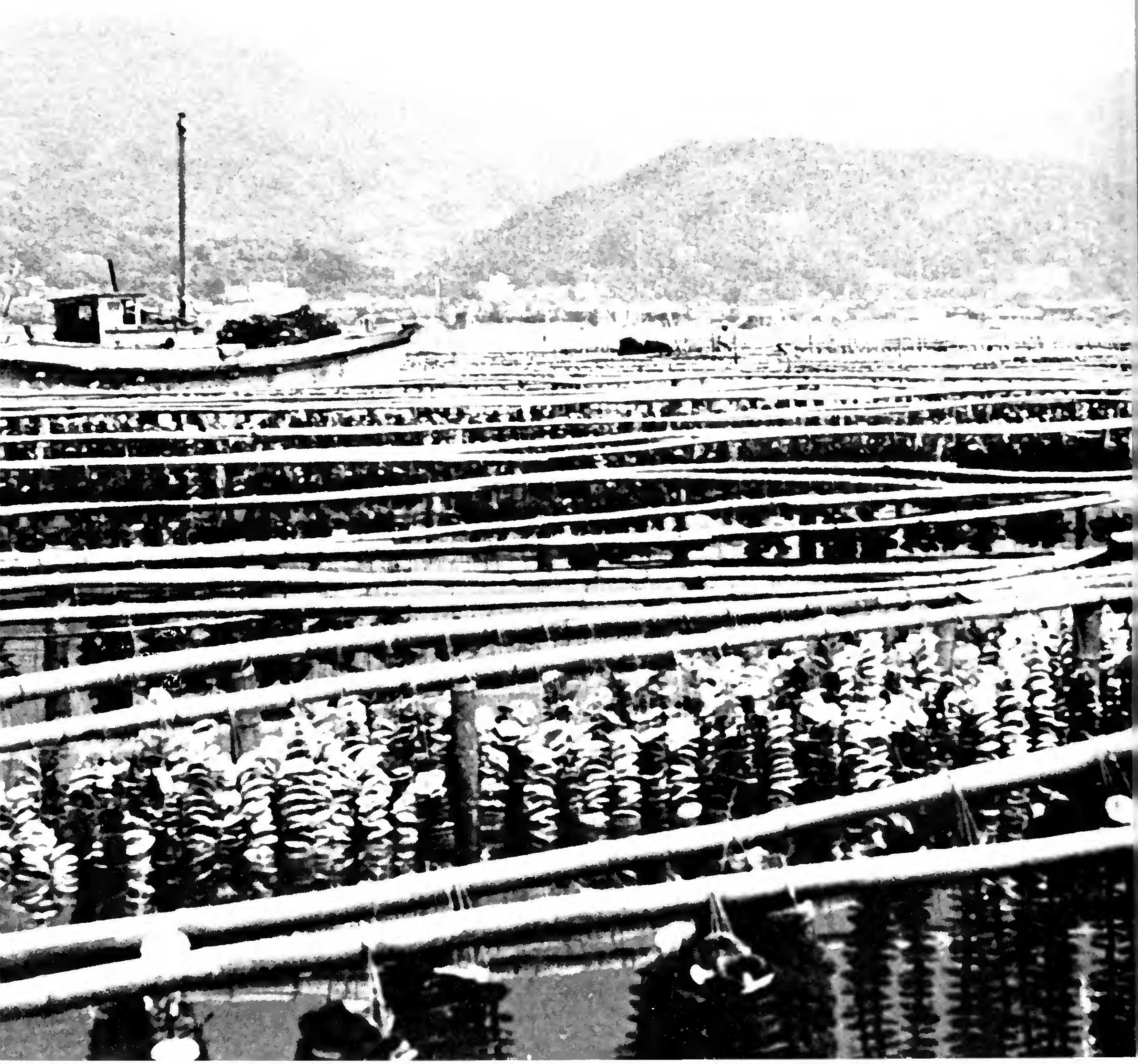
Cultivation of oysters or mussels on less than one percent of the area of the continental shelves could supply all the protein needed by the world's population in the year 2000 (about twice the present population), if average yields of 5 tons per acre could be attained — about equal to those of today's Japanese oyster farmers. The catch in this estimate is the proviso that Japanese yields could be matched. These depend on the ability of the oysters to filter out organic matter from sea water passing through the cultivated area. The oysters act as a sink for primary production from a large region, and it is by no means clear that enough organic matter would be available to sustain the assumed total shellfish crop.

For the foreseeable future the growth of more or less conventional fisheries will probably contribute most to increasing the marine harvest. To raise yields from the pastures of the sea which support these fisheries, we need to harvest and utilize a balanced catch of different species at the same ecological level, to control the populations of unusable and predatory species, to improve the breeds of such self-corralling fish as salmon, and to make the pastures more productive by adding relatively small quantities of minor nutrients, such as vitamin B_{12}, or by speeding up the vertical interchange of surface waters and deep nutrient-containing waters.

But if the potential of the ocean harvest is to be realized, radical changes in technology will also be needed, both to lower the cost of marine protein to the ultimate consumers and to increase its acceptability as a normal component of human diets. Mechanization of the Japanese aquacultural technology will be essential to reduce high labor costs. Equally important will be methods for processing or extraction of protein from many different kinds of marine animals to produce acceptable, easily used, and inexpensive high protein foods that can be preserved from spoilage under the conditions of tropical village life.

The unprecedented success of American agriculture has depended on research and development of an equally complex technology, in large part by the agricultural experiment stations of the land grant colleges. The challenge to the new sea-grant institutions is to build aquacultural experiment stations in which food technologists, marine engineers, biologists, physical and chemical oceanographers, and economists can work together to increase the production, lower the cost, improve the marketing, and ensure the use of the ocean harvest.

ROGER REVELLE



Strings of shells suspended from rafts for the collection of seed oysters shows the Japanese three-dimensional method in Hiroshima Harbor. The strings are pulled up on the tall mast of the ship and deposited on deck.

Aquaculture, its Status and

RYTHER

Potential

by J. H. RYTHER
and G. C. MATTHIESSEN

INCREASING public awareness of the discrepancy between projected world populations and world food supply has caused much speculation regarding the potential food sources of the sea. Some fishery experts feel that future seafood production cannot exceed greatly the current annual level of fifty to sixty million metric tons. Others, on theoretical grounds, envision a possible yield of two billion metric tons or more. Such diversity of opinion shows that it is dificult to estimate the seas' potential food resources with any certainty and weakens the assumption, held by some, that the solution to the world food problem lies in the open ocean.

THERE is more general agreement about the potential productivity of the inshore environment – the coastal waters – largely because their ability to produce significant quantities of protein foods in areas of limited size has been demonstrated clearly in many parts of the world. The yield in terms of kilograms (2.2 pounds) of edible animal protein per hectare (2.5 acres) per year from many bays and estuaries, with no assistance from man, far exceeds average levels of production from the off-shore fishing grounds and is comparable to yields obtained from first rate pasture land. Where man has deliberately intervened and applied certain principles of husbandry to the marine environment, difference in production between agricultural land, the off-shore fishing grounds, and inshore coastal waters is enormous, as the following figures show:

Annual Yield			
Area	Product	Pounds/Acre	Kilograms/ Hectare
Pastureland	Cattle	5-250	6-308
Continental Shelf	Groundfish	20-60	25-75
Humboldt Current	Anchovies	300	375
Japan	Oysters	46,000[1]	57,500
Spain	Mussels	240,000[1]	300,000

[1]Not including weight of shell

This table shows clearly that the culturing of shellfish provides an enormous yield, as compared to pastureland and offshore "hunting" methods of fishing.

Such figures are used to illustrate the potential role of aquaculture in alleviating the world's nutritional problem, particularly in the developing countries. To put this subject in proper perspective, we shall discuss the reasons for the extraordinary yields cited above; the various constraints upon the development of aquaculture; and the possible developments that may result in more effective methods of seafood culture.

Production in Aquatic Areas

The figures shown for mussel and oyster production apply to relatively small areas, supplied by the action of the tides with large volumes of water. In addition, the shellfish are suspended vertically in the water column, sometimes to a depth of 30 meters, from surface rafts or other devices. Consequently, even though the actual surface area under culture is rather small, the volume of water continually available to the species being cultured is enormous, and the areal yield is deceptively large.

The sedentary, bivalve mollusks such as oysters and mussels expend comparatively little energy to obtain food, which is brought to them by tidal currents. Therefore, a higher percentage of food consumed is converted into flesh than might be the case for animals that must actively pursue their food. Also, no energy need be expended to maintain a constant body temperature, an advantage not enjoyed by terrestrial livestock. Fish have a further advantage over livestock since, due to the buoyant effect of water, they do not require heavy skeletal structures. Therefore, a higher percentage of total weight is in flesh rather than in bone.

The amount of particulate matter — in the form of micro-organisms and detritus — is far greater in the inshore environment than in the open ocean. This material constitutes an important source of food for many species that are being cultured. In fact, the great majority of aquatic animals selected for intensive culture are herbivorous during part or all of their life cycle. Therefore, if a food conversion efficiency of 10 per cent is assumed, 100 kilograms of microscopic plants (phytoplankton) might produce 10 kilograms of mussels — the herbivore — but only one kilogram of cod — the primary carnivore — and perhaps only one-tenth of a kilogram of swordfish, the secondary carnivore.

Aquaculture by definition implies a certain degree of control over, or manipulation of, the organisms and/or its environment. The cultured species is not fugitive and hunted at random, but is in fact thoroughly and efficiently harvested. Usually certain techniques are employed to improve chances of survival of the young, reduce natural predation, avoid disease, in short, to increase the likelihood of survival from fertilized egg to maturity.

A modern mussel culture raft near Vigo, Spain. One thousand ropes, each ten meters long, are suspended from the raft. Annual production is 60 tons of mussel meat.

These are perhaps the major reasons why levels of food production by aquaculture are impressive. Figures as those shown on page 4, inevitably are applied to much larger areas, with dramatic—albeit unrealistic—results. It has been calculated, for example, that the total annual seafood production of the United States could be doubled, if one-third the total of Puget Sound was devoted to oyster culture by Japanese, e.g., three-dimensional, methods. Such extrapolations are sufficiently valid on a theoretical basis to arouse the curiosity, if not excitement, of those concerned with world food needs. But such estimates cannot be accepted as realistic because there are various constraints upon aquaculture.

Constraints upon Aquaculture

Food production by aquaculture requires both technical proficiency and incentive. Japan, combining technical skills with an awareness that a great percentage of her protein foods must come from the sea, has made unquestionably the most significant advances in this field. The sociological and legal climate is, of necessity, favorable, and Japan regards food production as the primary function of her coastal waters.

The United States, despite her technical competence, has not placed much emphasis upon aquaculture, largely due to lack of incentive. With abundant sources of protein foods available from the land, and with lethargic public demand for seafoods other than luxury items, such as oysters, shrimp, lobsters, etc., interest in aquaculture from either the nutritional or economic standpoints is limited. Quite recently, and because of increasing public demand for luxury seafoods, certain private interests have started aquacultural enterprises with anticipation of eventual profit. Others have done so because traditional methods of production have failed and certain culture practices have become necessary. By and large, however, the incentive to farm, rather than hunt, seafood has been lacking.

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Lack of economic incentive is not the only reason why aquaculture has been slow in developing. Fishery resources have long been regarded as common property, and the coastal waters as public domain. Private efforts to assert exclusive rights to coastal waters for aquacultural purposes are frequently thwarted by local statutes reinforced by public resentment. (It might be noted that conflict between public rights and private interests with regard to seafood culture is no less real in Ireland or the Hawaiian Islands, for example, than it is in New England). Ironically, where private ownership and responsibility is practiced —as on certain oyster beds in the Chesapeake Bay—the yield is incomparably greater than that derived from public grounds, for obvious reasons.

In Kessenuma Harbor, Japan, more than 5,000 oyster rafts cover some thirty square kilometers. It is obvious that such use of U.S. coastal waters would be objectionable to watersports' interests.

Projects involving use of coastal areas for aquaculture, if not prevented by statute, may be frustrated by competitive interests. At best, such interests may involve recreational activities—boating, water skiing, etc.—that exert ever-increasing demand upon water space. At worst, they involve the transforming of bays and estuaries into convenient receptacles for industrial and domestic wastes. The potential value of such areas for food production is subsidiary to other, more immediate, economic considerations.

Such constraints are economic, social or legal in nature. In areas of the world where the need for protein foods is critical, the equipment necessary to implement aquaculture—capital and trained personnel—may be the limiting factor. In these situations, culture is limited to species that produce the maximum amount of food with minimum expense and sophistication of method. Through technical assistance, it should be possible to reach much higher levels of production, not only for species that are being cultured now, but possibly for exotic species as well. However, certain of the technical problems are formidable.

Problems in Culturing

In the case of bivalve mollusks of commercial importance, much has been learned about methods of culture. These animals are attractive for intensive culture since they are herbivorous, sedentary, highly prolific, of considerable nutritional value, and frequently command a high market price. Largely as a counter-measure to failure in natural reproduction, oyster and clam "hatcheries" have in fact been established in Europe, Japan, and the United States for purposes of producing large quantities of seed shellfish. In oyster hatcheries, adults are sexually matured by appropriate temperature manipulation, and then induced to spawn by chemical or thermal excitation. The larvae are reared on a diet of cultured phytoplankton, in tanks in which the water is pre-warmed, pre-filtered and changed daily. After the larvae metamorphose, the tiny juveniles, now attached to shell, are conditioned to the natural environment by exposure to appropriate water temperatures and eventually transferred to the oyster beds, where, it is hoped, they will mature to marketable size. Some of the hatcheries in New England may produce several hundred million juvenile oysters each year.

Commercial hatcheries have not been in operation long enough to allow a realistic evaluation of their economic merits. The available evidence indicates a high mortality rate among the juveniles on the natural beds. In Long Island Sound, off New York, where most of the hatchery produced oysters are set out, the loss is primarily due to natural predation—by starfish and oyster drills—and smothering of the oysters by siltation. The important point is that once the oysters are exposed to the natural environment, the oyster culturist has lost a large degree of control.

The loss from bottom-crawling predators and siltation might well be avoided by adopting Japanese methods. Raft culture has not been considered practical in Long Island Sound, because of boat traffic and pollution in the sheltered coves, and because of adverse weather conditions in exposed areas. Labor costs for assembling oyster strings and constructing and maintaining rafts must also be considered. (In Japan, the value of the eventual harvest outweighs the comparatively low labor costs).

A superficially attractive alternative would be to culture oysters in ponds or excavated pools protected from the sea, in which a maximum amount of biological control might be applied. Unfortunately, to grow well an oyster needs either huge volumes of water, continuously replaced to keep up the supply of natural planktonic food, or else large amounts of algae must be cultured as supplementary food. So far, neither alternative is economically justified.

In the case, then, of oysters and other shellfish, the problem is not one of providing enough off-spring, but rather that of rearing the juveniles to marketable size with minimum loss and at reasonable cost. Precisely the opposite problem exists in the case of the milkfish, a species cultured in brackish-water ponds in many parts of Southeast Asia. In certain areas, over one thousand kilograms of milkfish may be harvested from a single hectare of pond each year, and large tracts of mangrove swamp have been developed for this purpose.

Milkfish

The milkfish spawns at sea, and the fry are gathered by nets when they move inshore. They are stocked in shallow ponds, to which fertilizer may have been added to stimulate growth of algae, bacteria and various protozoa. The milkfish thrives in these enclosed areas, feeds readily upon the algal mats—known as "lab-lab"—and may exceed 0.5 kg. in weight in less than one year. Because it is herbivorous, a rapid grower, fleshy, and tolerant of the crowded conditions in shallow, stagnant ponds, it is in many respects an ideal species for intensive culture.

The major limitation upon milkfish culture is that it is difficult to catch fry consistently, due to unpredictable fluctuations in abundance. To date, efforts to stimulate reproduction in captivity have failed. It might be noted that certain species of mullet—also a brackish-water fish that normally spawns at sea—have been induced to spawn by injecting the adult with pituitary hormones. This technique might be applied successfully to milkfish, but it should be remembered also that as is true of mullet, it may be difficult to supply appropriate food for the larval fish.

A somewhat different problem occurs in the rearing of plaice and sole in hatcheries on the Isle of Man. Adults of these species are held in special spawning tanks, and the fertilized eggs are readily obtained. The resulting larvae are reared through metamorphosis, eventually settle to the bottom, and may mature to market size in densely stocked pools. It has been estimated that the entire annual catch in Great Britain could be cultured in shallow ponds covering an area of only one and a quarter square miles.

Unfortunately, these fish are carnivorous. Before the larvae metamorphose and settle to the bottom, they consume large quantities of small crustaceans which, for hatchery purposes, must be carefully cultured. To be economically profitable, a hatchery must produce fish in large volume, which in turn implies an abundant, readily available supply of food. If the cost of food, plus the expenses involved in maintaining a clean and healthy environment in the rearing tanks, approaches the eventual market value of the fish—as it does in this case—then the economic justification of the operation is questionable. It might be proposed that attempts to culture carnivorous species are unrealistic, and that emphasis should be placed upon herbivorous species. However, the herbivorous mollusks appear to be so selective as to the type of algae they will assimilate that providing large volumes of suitable food involves a considerable investment.

Lobsters

Because of its high market value, and because it feeds readily in captivity upon fish scraps, shellfish and other types of food that need not be cultured, the lobster has excited the interest of prospective sea-farmers. Adult lobsters have been successfully mated at the Massachusetts State Lobster Hatchery on Martha's Vineyard, and the resulting larvae reared through metamorphosis. Juvenile lobsters have been reared to marketable size in this hatchery.

However, even if it were economically feasible to feed large quantities of lobsters on such foods, the culturist would be faced with a possibly more serious problem: cannibalism. Lobster are particularly vulnerable to other lobsters immediately after molting before their shell has hardened. Therefore, they should be held in isolation as much as possible. In view of the extensive period of time required for a newly-hatched lobster to attain marketable size—under normal New England water temperature conditions, this is estimated to be five years—the idea of feeding and maintaining large numbers of lobsters in separate compartments, in a manner somewhat similar to modern poultry farming, appears somewhat impractical at present.

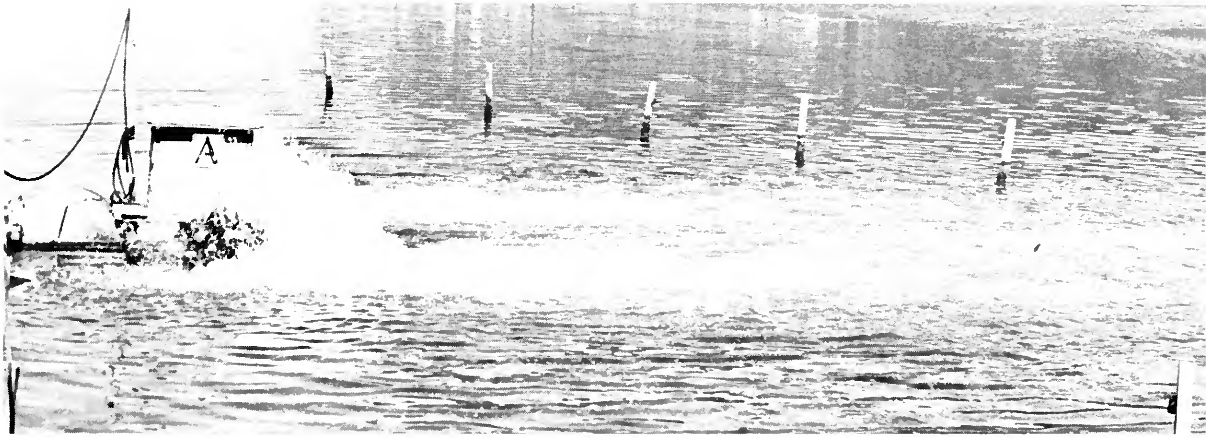
The problem of cannibalism also occurs in the culture of certain species of shrimp and prawns. However, the major difficulty, and one that appears so frequently in various aquacultural endeavors, is that of providing sufficient amounts of suitable food at realistic cost. In Japan, where shrimp culture is most advanced, larval shrimp are obtained from egg-bearing females captured in the sea. These larvae initially are fed cultured algae and, at subsequent stages of development, small crustaceans (which also must be cultured). After a period of twelve days or so, the larvae metamorphose into the adult form, and a diet of fish scraps or ground clams is provided.

The cost of rearing shrimp in such fashion—not to mention the expense of maintaining the culture pools free of parasites and disease—would seem prohibitive. It is profitable in Japan because labor costs are relatively low and because there is such a high demand for shrimp, that the price is high, even by U.S. standards.

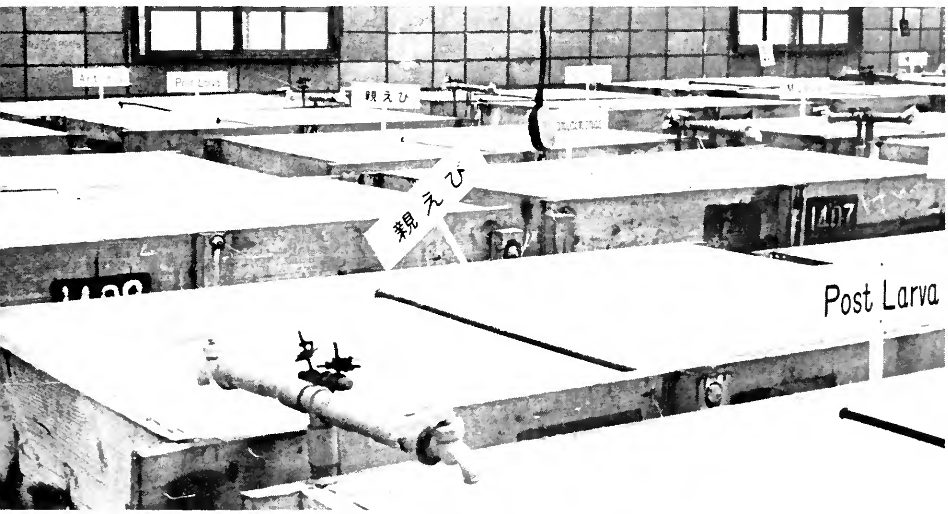
An interesting variation on the problems of shrimp culture involves the giant prawn, common in brackish and fresh water ponds throughout Southeast Asia. One particular species may exceed 0.15 kg. in weight, and the market value makes it desirable for culture. Investigators in Hawaii have cultured this species through its larval and post-larval stages, despite its complex feeding habits, and have released the juveniles in ponds from which it was intended they would eventually be harvested. At this point, however, the elusive prawn has refused to cooperate and has successfully defied all efforts — by trap, seine, or other device—to effect its capture.

Synthetic Food

With few exceptions, the major technical problems associated with aquaculture appear to be resolvable if sufficient time, scientific talent and capital are invested. Although it is a highly diversified enterprise with respect to the species cultured, geographic location, methodology, and even motivation, the major problems—reproduction and nutrition—appear to be common throughout. At this point, it would seem likely that development of an appropriate, possibly synthesized, food for shrimp might have immediate and beneficial application to, for example, plaice culture on the Isle of Man, or lobster culture in Massachusetts.

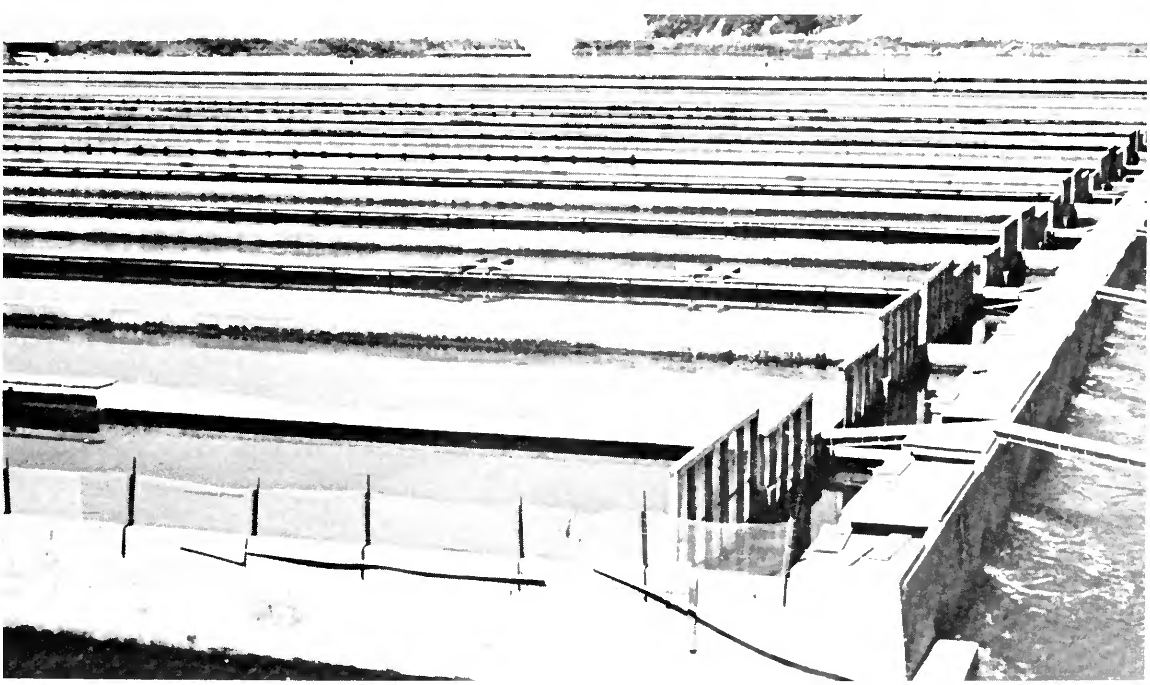


An artificial pond used for shrimp culture in Japan is aerated by an electrically driven paddle wheel. The heavy feeding of the shrimp and the high organic content of the water makes aeration necessary.



Six million juvenile shrimp can be raised each month in these heated ceramic tanks at Takamatsu, Japan.

Shrimps are raised to adult size in these oudoor tanks at Takamatsu. The tanks are 100 x 10 meters. Some 80,000 liters of water per hour is pumped through the tanks.



The Future of Aquaculture

The ultimate usefulness of aquaculture will depend to a large extent upon our ability to reduce cost of production, an achievement so clearly demonstrated by the poultry industry. Modern poultry production has been the result of the combined efforts of nutritionists, geneticists, pathologists, engineers, and representatives of other scientific disciplines, and the development of aquaculture as an efficient method of producing food will require an equivalent combination of talents.

Perhaps the most significant accomplishment would be the development of artificial, as opposed to natural, foods for various species. Just as chickens, and even trout and catfish, are fed pellets containing the necessary biochemical ingredients—amino acids, minerals, vitamins, etc.—it should be possible eventually to synthesize nutritious diets for shrimp, bivalve mollusks and other forms. Some progress in this regard has been reported, but in general the marine aquaculturist must accept the fact that, in order to raise one species, he must also culture one or several more species as food.

Eventually it may be possible to raise large quantities of algae, of a suitable variety, at costs that are not prohibitive. Certain green algae, such as *Chlorella* and *Scenedesmus*, are being cultured in sewage treatment processes in considerable volume—40,000 to 60,000 kg. of algae (dry weight) per hectare of pond surface area per year—and with a high protein and vitamin yield. The dried algae has been incorporated in livestock food with beneficial results. Similar techniques might be employed to culture forms more useful for aquaculture, and simultaneously, help relieve the increasing problem of sewage treatment and disposal.

Genetics

Genetics already has played a prominent role in fresh water fish culture, notably in the hatchery production of salmon and trout. In the Pacific Northwest, salmon and trout parent stock are bred selectively to produce offspring with superior qualities, e.g., rate of growth, hardiness, fecundity, etc. There would seem to be little reason why selective breeding might not be applied profitably to a wide variety of species, including lobsters, oysters, and various fin fish.

The rapid development of electric generating plants along the coastlines may also be of benefit to aquaculture, at least in temperature latitudes and if properly managed. For many species occurring in temperate waters, growth is possible only during the warmer months of the year. It might, therefore, be economically advantageous to establish culture operations in the vicinity of generating plants, where seawater used for cooling condensers is continually discharged at higher temperatures. Use of cooling water would seem to be particularly appropriate for shellfish hatcheries, which require large volumes of warm seawater daily for the rearing of larvae and juveniles.

Hunger Problem

Despite such developments, it is unrealistic at present to assume that the world's nutritional problems will be resolved by aquaculture. Today, only 3 per cent of the world's food production is derived from the sea. If, as seems unlikely, this amount was doubled during the next decade as a result of intensive aquaculture, the overall impact upon total food supply would not be impressive. Already more than 60 per cent of the people in underdeveloped areas, which comprise two-thirds of the world's population, suffer from undernutrition, malnutrition, or both; yet, as certain social scientists point out, the technical competence for fully exploiting aquatic food resources in these areas cannot be developed fast enough to avoid famine.

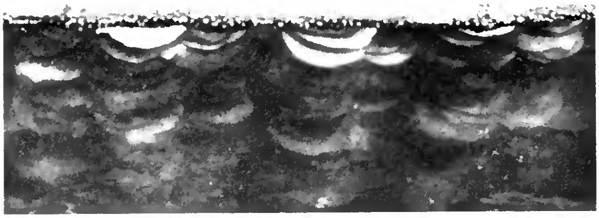
On the other hand, famine might at least be alleviated through aquaculture, even by applying techniques currently in use. The Food and Agricultural Organization of the United Nations has estimated that there are now 37 million hectares (92 million acres) of swamp and aquatic areas available for fish culture in South and East Asia. If this entire area was developed for the culture of milkfish at

(continued on page 14)

Mussel culture on poles (bouchots) near St. Malo, Brittany. The method was discovered accidently in A.D. 1235 by a shipwrecked Irishman, Walton, who tried to snare seabirds on crude nets set between poles on the mud flats. Young mussels settled on the woven nets.

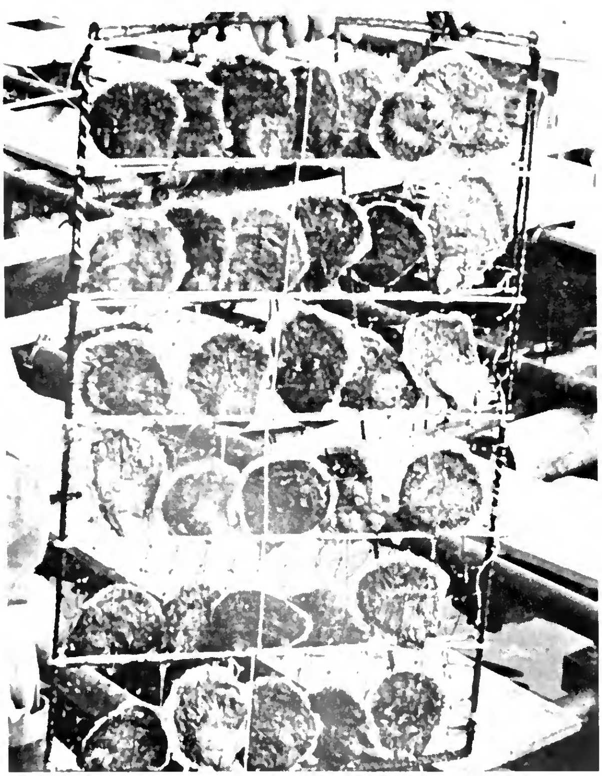
Today, ropes on which young mussels have set, are wound spirally around the poles. ▶

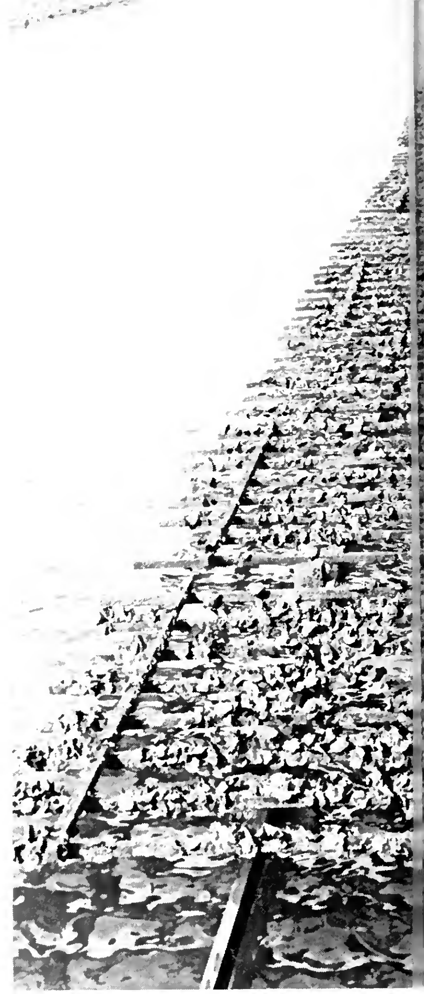
Adult mussels ready for harvesting on the poles of Britanny. The extreme ranges in tide in the area ease the harvesting problem.



A string of scallop shells separated by bamboo spreaders for the collection of seed oysters at Hiroshima Bay.

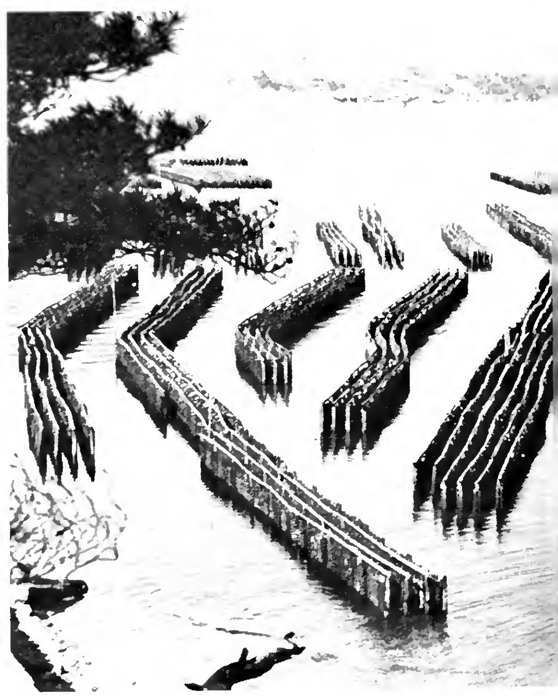
Arranged neatly in a rack these European flat oyster are grown suspended from bamboo rafts in Kessenuma Bay.





Low tide in Georges River, New Sou attached to tarred wooden sticks.

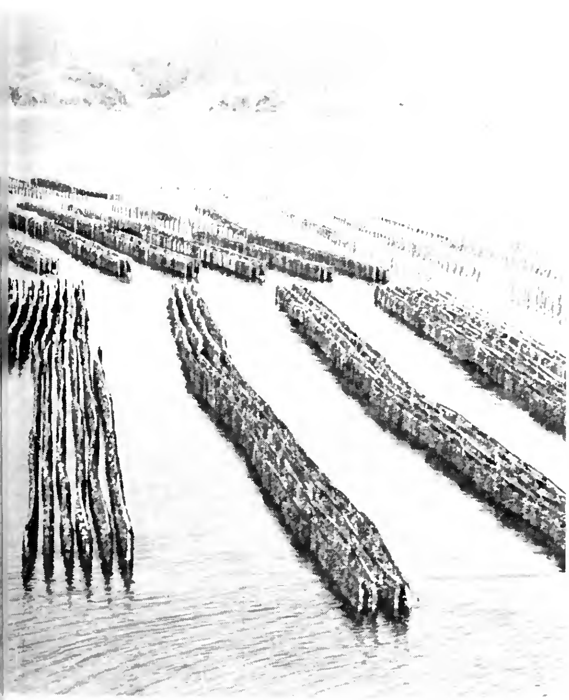
A red algae (Porphyra) culture in the Inland Sea



WOLF

ales, Australia, shows young oysters

ɔan. Japanese consider *Porphyra* cakes a delicacy.



An impressive pile of shells represents one month of oyster shucking at a Hiroshima Bay establishment with thirty rafts.

Abalone also are cultured in the Japanese raft system. They are suspended from the poles in plastic containers.

levels of intensity approximating those achieved routinely in Taiwan, i.e., 1000 - 1500 kilograms of fish produced per hectare per year, the resulting yield would exceed 30 million metric tons of high quality protein food per year, or more than half the total world production of seafood. Clearly such a contribution would not erase world hunger, but it could avert famine for many in a part of the world where, as is also true of Africa and Latin America, malnutrition is chronic.

Aquaculture should also be considered from the point of view of efficient resource use and future resource management. It has been estimated, for example, that algae may be cultured, on sewage, so intensively as to yield 20,000 kg. (10 tons, dry weight) of digestibe protein per hectare of pond per year, or roughly ten to fifteen times as much protein as a hectare of land planted with soybeans, and 25 to 50 times as much as one planted with corn. Similarly, while an average hectare of pastureland produces 150 kg. of beef (on the hoof) each year, production of trout, reared in flowing water, has exceed 1.5 million kg. per hectare per year. Clearly aquaculture, as a means of producing food, makes comparatively small demands upon space.

Possibly more relevant with respect to resource use are the comparative demands upon fresh water by terrestrial agriculture and aquaculture. Soybeans and wheat reportedly yield only 230 and 46 kg. (500 and 100 lbs.) of protein respectively, for every acre-foot of fresh water consumed, whereas, 2,300 kg. of algal protein are produced per acre-foot. It has been estimated that one kg. of beef has required 66,000 to 132,000 kg. of water in its production, if the amount of water necessary for producing the food consumed and the amount taken directly by the animal are included. This is in striking contrast with seafood production, which is essentially non-competitive for our fresh water resources.

Within the next twenty years, the world's population may double. This implies that, in order to maintain present living conditions and yet satisfy demands for habitation, industry, recreation, agriculture, and refuse disposal, twice the amount of space and fresh water will soon be required. Aquaculture will not resolve this problem any more than it will resolve the problem of human nutrition, but it suggests an approach to resource use that is efficient, beneficial, and possibly necessary.

New Program

At Woods Hole we are developing a program in aquaculture with a dual approach: to study the basic environmental requirements of some marine animals of existing or potential importance to mankind, and to apply the obtained results of the basic biological principles involved to the intensive and controlled culture of such animals. In a sense, such a program will merely be an extension of current research on the biology of marine organisms. Still, it represents a departure from purely basic research in that emphasis will be placed upon species of economic importance, and upon culture techniques which may lead to economically viable, and socially desirable methods of producing food.

This program will include basic biological research related directly to aquaculture; investigations of the possible application of environmental modifications to aquaculture, such as domestic pollution, thermal pollution, etc. and technical and economic studies on the production of commercially desirable species on a pilot scale. The ultimate objective is to establish basic principles of aquaculture that may be applied to a wide range of species in diversified areas and environments. When we obtain useful information regarding the culture of specific organisms, this will be made available to others involved in aquaculture in any part of the world.

We have suggested earlier that to assume that aquaculture is an obvious answer to the world food problem is unrealistic. A noted U.S. expert on fisheries has stated: "As a panacea for relieving protein shortage in latitudes and societies such as ours, mariculture is nonsense!" Possibly this is true. On the other hand, there is now sufficient factual evidence to encourage, if not demand, a concerted exploration of aquaculture's potential and to apply these findings as rapidly as possible in "latitudes and societies" not necessarily ours.

ALL PHOTOS IN THIS ARTICLE WERE BY DR. RYTHER, UNLESS OTHERWISE NOTED.

- - Let them have dominion over fish of the Sea

Genesis 1:26

Cape Horn

LOOK! LOOK! The clouds break; See! there is Cape Horn! — that great dark looking object that does not move! Cape Horn! Everybody on deck is shouting "Cape Horn."

There it stands and there it has stood for unknown ages. The sun never shines upon the side we are looking at and it seldom shines upon the north side. The storms of the ages have beat upon it, the mighty waves of three seas rush upon it incessantly as if they would tear it from its foundation, only to beat themselves into a sea of hissing foam. There it stands — the great southern sentinel of a continent — the great symbol of storms and turbulent waters — the great guide post — the great beacon of those who go down to the sea in ships. It saw the first white sail of the explorer struggling westward to see what was on the other side of the world — it saw the first white sail of commerce pass by — it saw those white sails grow to a mighty fleet — it saw the migration of many people going westward in search of gold — it saw the first whaleship pass from the Atlantic to the Pacific in search of greater profit — it saw those ships grow to a mighty fleet, and there it will stand when all those white sails shall have disappeared from the sea, when the steam ship which will replace them will seek more congenial passages back and forth, and there it will stand, when man has ceased to pass this way, as it has stood for ages, the great lonely sentinel in a still more lonely region, the eternal beacon at the end of the world.

The Murdock Whaling Voyages
Reynolds Printing
New Bedford, Mass.

A flat calm

by W. A. WATKINS

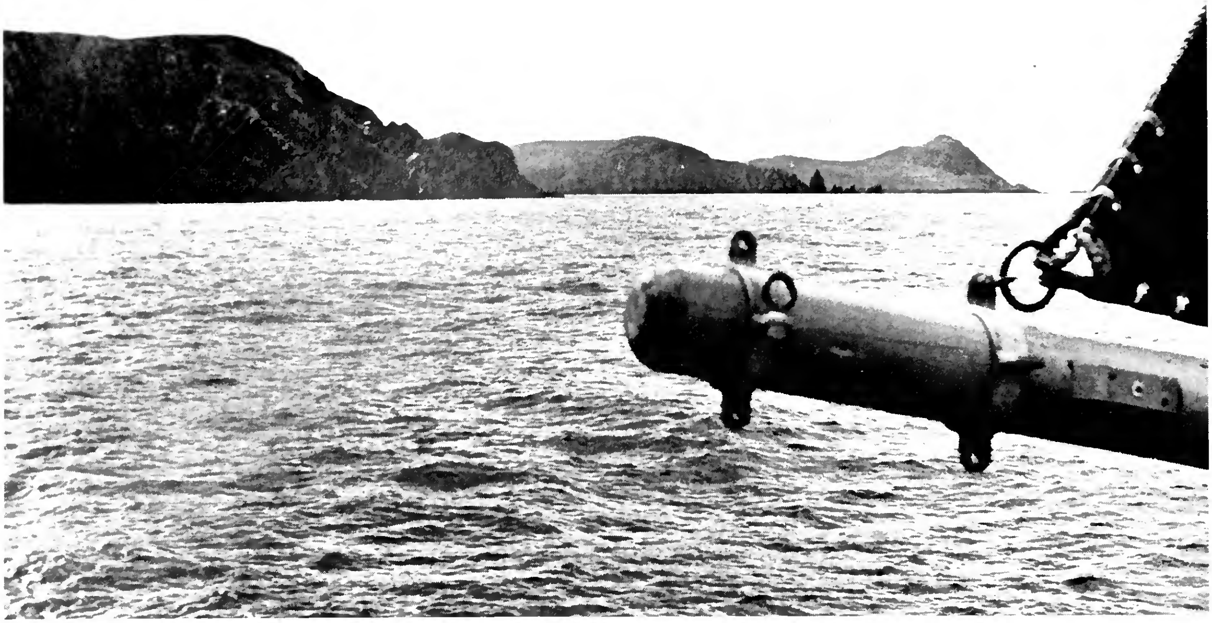
TO have it said: "He rounded Cape Horn" is the final accolade that can be bestowed upon a true sailor. Charged with history and tales of incredible hardships, the Horn has the worst reputation of any landfall on earth.

Not so on December 3, 1968, when the little R.V. 'Hero', the new wooden vessel of the National Science Foundation, rounded the Cape on her maiden voyage. Captain S. G. Hartshorne felt it would be downright disrespectful to round "the Horn" without sail, so in spite of a flat calm the sails were set. I felt the sense of history so deeply that my skin was prickling.

Few vessels pass within sight of this famous landmark — most ships prefer to stand well out to sea. Those that have come closer report mostly high seas and poor visibility. In fact, some sailors insist that no one ever sees Cape Horn. Close-to, it has a decided unfriendly look. The barometer aboard 'Hero', however, was a steady 1020.2 millibars (30.125 inches) during the entire day of the passage.

(From: *Atlas de la Navigation*. L. Renard. Amsterdam 1715. In the collection of jan hahn)

CAPE HORN, as depicted on an old Dutch chart, was discovered on January 24, 1616 by Willem Cornelisz Schouten in the small ship 'Eendracht'. Named for the town of Hoorn in North Holland which had equipped the expedition, the Cape was discovered in an attempt to find "Terra Australis Incognita". Another purpose of the voyage was to attempt to circumvent the monopoly of the Dutch East India Company (VOC) which forbade other ships to reach the Indies by the only known routes, around the Cape of Good Hope or through the Strait of Magellan.



THE small wooden vessel 'Hero' of the National Science Foundation rounded Cape Horn in a flat calm, 152 years after Schouten's discovery. The Cape bears 140° T. (SE 1/2 South). The headlands are Hall Island, and the two prominences of Horn Island: Cloven Cliff and Cape Horn.

Rounding

AT one mile, bearing 000° (North) the 406 meter high rock is an awesome sight. The traditional drift-bottle with signatures and cruise plan was tossed onto the swell. A school of Magellanic penguins promptly came over to inspect it.

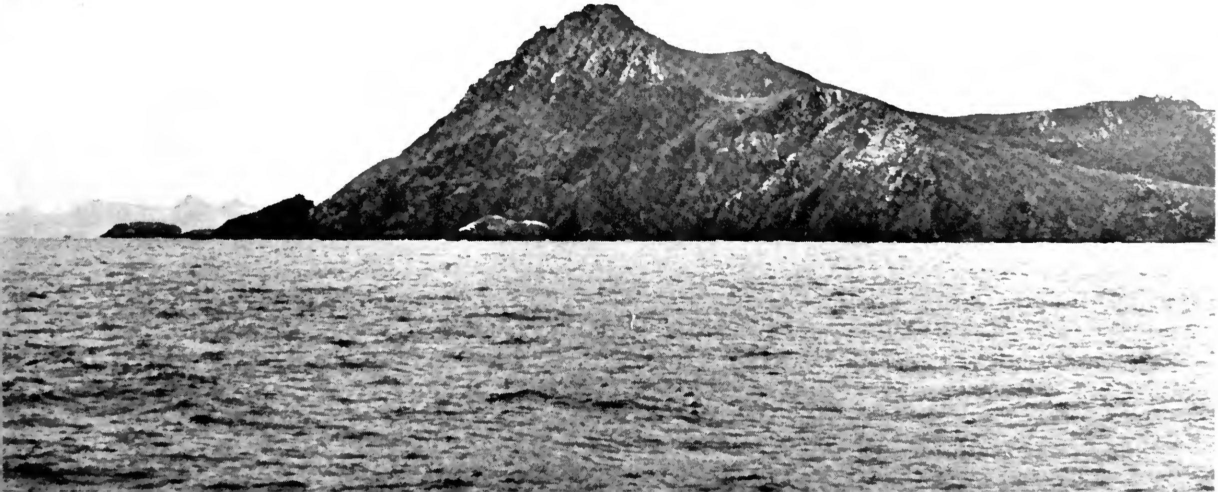
A lone porpoise was sighted about eight miles northwest of the Cape — during the passage I saw a single albatross, two skuas, two shearwaters, and one giant fulmar.

NOW bearing 040° (NE 1/2 North), the jagged eastern slope of Cape Horn begins to show. The positions given to the famous rock vary. The charts warn that "positions . . . should be . . . by bearings and distances from natural features." 55°59'S-67°16'W is the position given by Sailing Directions.

the Horn!

PHOTOGRAPHS BY W. A. WATKINS

LOOKING back now and bearing 320° (NW 1/2 North), the long gentle sweep of grassland behind Cape Horn can be seen. The Cabo de Hornos light is at an elevation of only 38 meters and is just off the picture to the right, at a little less than one-tenth of the elevation of the Cape itself.



Satellite Cloud Pictures

by R. M. ALEXANDER

ALTHOUGH the general public seems to be aware only of manned space flights, the space program has provided great benefits to meteorology through weather satellites which supply the forecaster and research meteorologist with an instantaneous day to day look at the earth and its weather.

Only about ten years ago, film packs and motion pictures recovered from sounding rockets and missiles, showed the value of high altitude photography to meteorology. By 1960 the Tiros I satellite carried a television camera aloft which transmitted the signals to earth. But million dollar command and data receiving stations were needed to receive the pictures. Sending the received data over landlines or by radio to local stations delayed and often degraded the quality of the pictures.

More recently an Automatic Picture Transmission System (ATP) has been installed on satellites. Fairly inexpensive and easy to operate the ATP system has made it possible to provide cheap and clear pictures to local weather forecasters. At this time there are five meteorological satellites in operation. ESSA has spacecrafts II, VI and VIII in polar circular orbits with average heights of 1100 to 1300 kilometers above the earth. A 2700 km wide area is covered by each picture. These satellites take about 114 minutes to complete one revolution of the earth. They fly in a sun-synchronous orbit, which means that they keep an unchanging illumination of the earth beneath them, from day to day. At Woods Hole we receive three passes per day.

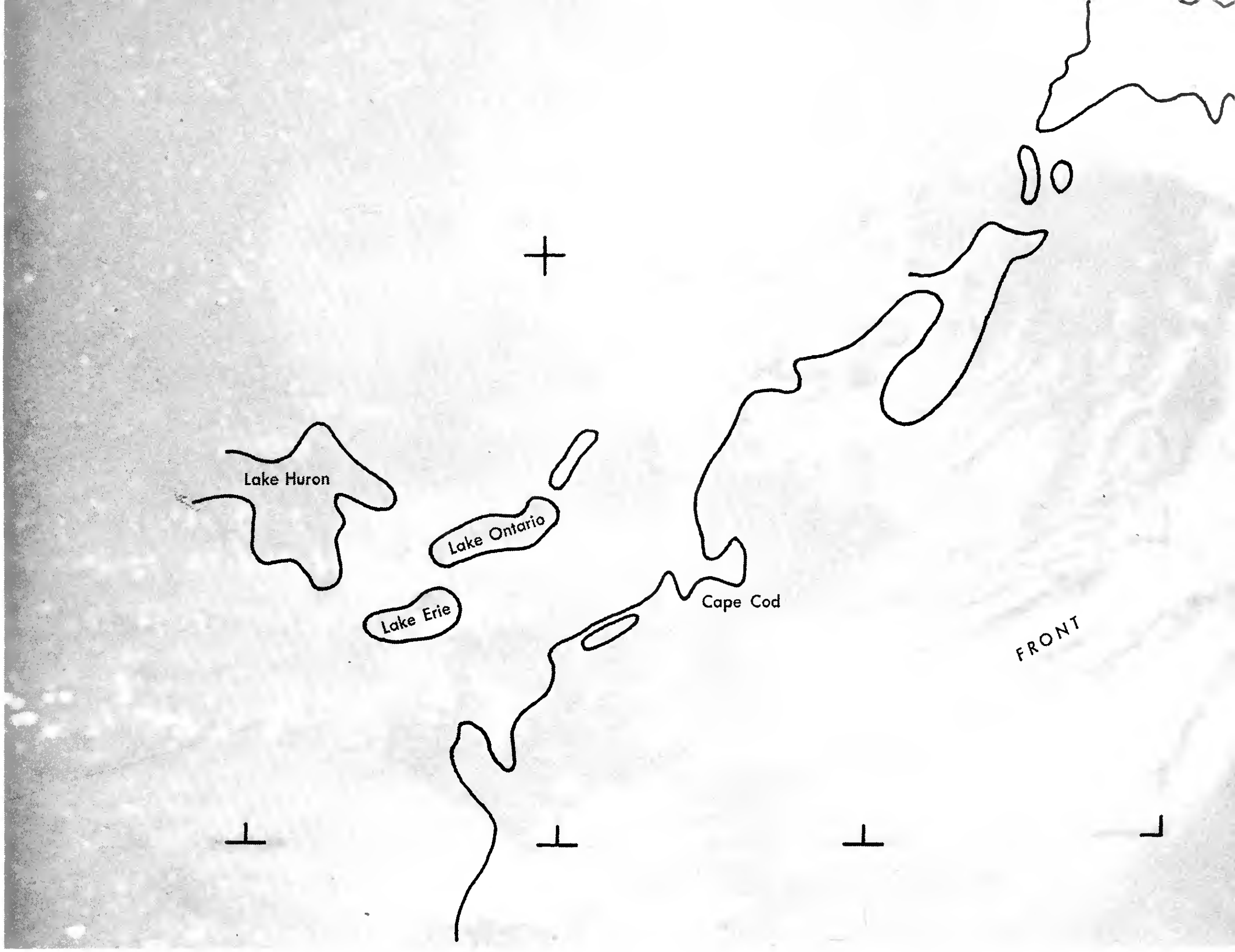
In addition there are two Application Technology Satellites (ATS) in orbit which provide a limited number of cloud pictures, since they also cover other observations. The ATS I and ATS II are in synchronous earth orbit, some 35,000 km above the equator. In such an orbit the spacecraft rotates with the earth and remains right above the same location. Only AST III is within range of our antenna at Woods Hole, where we receive its pictures twice a day. The ATS III camera is aimed at 47° West and 0.5° South.

To locate the received pictures geographically, it is necessary to make a grid over the prints*. Since the time the picture was taken is known, the satellite subpoint (the point at the earth center at which the camera was aimed) can be determined from predict messages received daily by teletype. A good number of pictures also show recognizable land and water masses so that it is not too difficult to fit the grid. When such features are not visible the task is more difficult but this is not a serious problem as long as the time is noted instantly when the camera shutter opens. The next step is to interpolate the time and distance on the tracking diagram of the satellite.

Further improvements no doubt will occur (one difficulty is that one cannot estimate the heights of the clouds shown). Nevertheless, the advantages of seeing cloud cover several times a day and from day to day, already has added immeasurably to the study of the weather. In the words of F. W. Reichelderfer, former Chief of the U.S. Weather Bureau: "Perhaps most promising for future weather analysis and forecasting is the increasing study of clouds and their arrays as symptoms, and thus diagnostic means for identifying atmospheric dynamic systems which make the weather.†

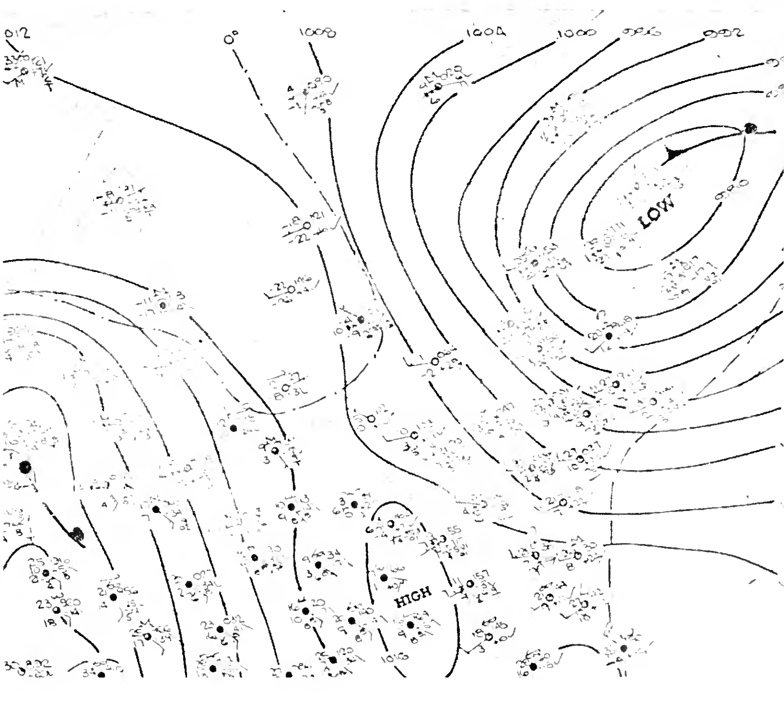
*See also: "The Gulf Stream from Space", by J. C. Wilkerson. Oceanus, Vol. XIII, Nos. 2 and 3, June 1967.

†See also: "Exploring Space with a Camera". NASA. Sp-168. U.S. Government Printing Office. $4.25.



Received at Woods Hole at 0950 EST on January 8, 1969 by Automatic Picture Transmission. A crude coastal line has been superimposed for geographic identification.

A good fit with the synoptic surface chart is shown. The cloud formations show a vortex over southeastern Canada and an occlusion to the east. Over northern Maine the clouds spiral into a vortex, indicating an intense storm. A series of distinctive cloud types appear along the front of the storm. Since height cannot be estimated the individual cloud formations cannot be resolved



MR. ALEXANDER is a Research Assistant in our Department of Physical Oceanography. Formerly he was a major in the U.S. Air Force Weather Service.

The Line Islands Experiment

by M. A. CHAFFEE

A NEW window was opened to the meteorologist in December 1966, when NASA placed Advanced Technology Satellite I into orbit, some 35,000 km above the central Pacific Ocean. For the first time we had a clear look at cloud amounts and patterns covering half the globe. The Suomi "camera"—actually photocell readings relayed by radio—aboard the satellite took "pictures" of the earth every 20 minutes and recorded daytime cloud changes.

Of great interest to the tropical meteorologist was the view he now had of the Intertropical Convergence Zone (ITCZ), an area which has not been thoroughly described and understood even less.

It became quickly evident that the large areas of clouds and especially the giant cumulonimbus towers which function as the "heat pump" of the atmosphere* were at best vagrant within the Convergence Zone and on some days barely evident. While providing a clear look at the ITCZ, the pictures did not suggest any easy answers to some of the problems confronting the meteorologist.

A large scale program was planned to obtain basic meteorological observations within the Trough Zone and thus provide the first comprehensive true oceanic sampling of the area, combined with the satellite observations.

The Line Islands were chosen as bases for the ground stations and aircraft. Located some 1600 km south of Hawaii and straddling the Equator between 6° N. and 11° S., the Line Islands are insignificant dots in a vast ocean. Of the eleven islands in the group, only three: Christmas, Fanning and Palmyra were chosen as suitable sites.

The initial planning of the experiment was carried out by meteorologists from several institutions and universities and co-ordinated by the National Center for Atmospheric Research (NCAR), in Boulder, Colorado. Plans were begun in earnest in August 1966; a survey trip to the Islands was made in November and the final operational and financial arrangements were completed in January 1967. Considering the drastically short planning time and the severe logistic problems, the field operations, carried out during February-April, 1967, were successful beyond the original expectations.

*See: "The Ocean as the Atmosphere's Fuel Supply", by Joanne S. Malkus. Oceanus, Vol. VI, No. 4, June 1960.

Our specially instrumented C-54Q aircraft and meteorological observers of our staff, under Mr. A. F. Bunker, joined the field program in April. The airplane is equipped to measure air turbulence and vertical velocities, as well as temperatures (wet and dry), and incoming radiation. Time-lapse 16mm motion pictures of the cloud formations also were made from our aircraft. Dropsonde measurements were made from heights of 4,000 to 5,000 meters during high altitude legs of the flights, while winds could be determined from the Doppler radar.

Observations

Each of the three islands had several observing stations to measure wind velocity and direction at various heights, temperature, cloud cover, rainfall and upper air observations at least every six hours, as well as hourly sky "panoramas" and 16mm time-lapse photography of the clouds. In addition to the routine observations which were performed basically by U.S. Army and Signal Corps personnel, the scientists made special measurements of rainfall, winds, radiation, tritium analysis, surface temperatures of Lagoon water and stereophotography of the clouds. The U.S.C.G.S. 'Surveyor' and 'Weather Ship II' made oceanographic and meteorological weather observations in the general area of the islands during the experiment, while the NCAR "Queen Air" Beechcraft flew 60 missions in 54 days in this "hostile environment" for a twin engine aircraft.

MISS CHAFFEE has participated in many field trips on board our aircraft.

Cloud vagaries

It had been hoped when flight plans were laid out that a maximum amount of the flight time on each mission would be within the cloudy areas of the Convergence Zone, however, the vagaries of the clouds and their inconsistency from day to day precluded these hopes. In fact, the day chosen to study the life cycle of a cumulonimbus cloud produced only cumulus congestus clouds to 5,000 meters in an area where on previous flights the Convergence Zone had been extremely active.

In viewing the time-lapse films for these flights one is struck by the fact that the unorganized clouds of the Zone are for the most part comprised of heavy middle and high cloudiness. The cumulonimbus while perhaps partly hidden from the view of the camera by these middle clouds were not as evident as one might expect. Most of those measured appeared to be on the outer edges of the cloud "globs" or in small groups or single units without the accompanying heavy middle cloud layers. A striking example of an isolated cumulonimbus build-up is shown in the photographs.

Clouds in the non-active convergence areas were for the most part small cumulus (some showering) and quite often spread by an inversion into stratus decks at 1500 to 2000 meters. Again the question arises how are these "preferred areas" for more active cloud growth determined? The small physical differences in air and sea temperatures, the convergence or divergence of the surface winds in the area, incoming radiation and upper air flow all must play a role in the maintenance of the tropical heat engine, which plays a vital part in the creation and maintenance of the world-wide wind system. Hopefully, the data from the Line Islands Experiment will provide some new insight into this complicated mechanism. The ground and aircraft observations will help to evaluate the cloud photography from the satellite. Finally this relatively small experiment was designed as a pilot program for a more extensive field program in the Marshall Islands sometime in the future.

NCAR

Palmyra Island, one of the observing sites.

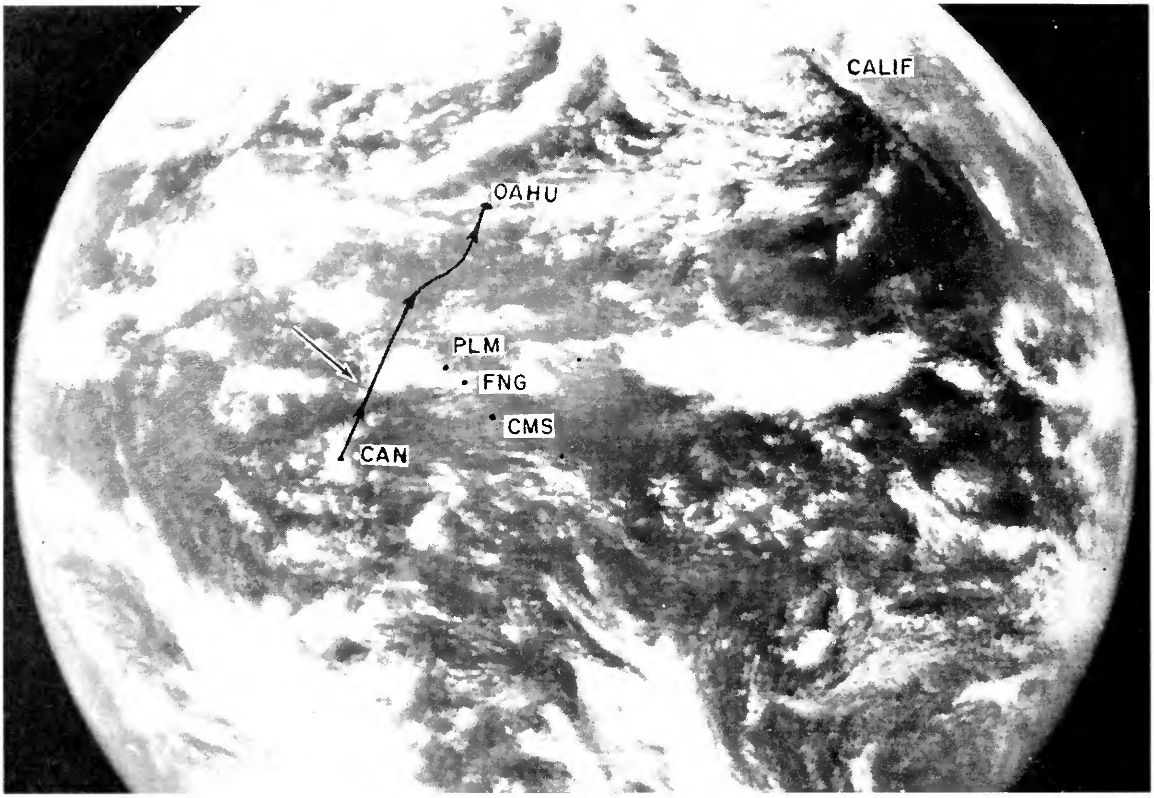
A single cumulonimbus cloud on the outer edge of a cloud "glob".

1777. December. when the clouds about the ſun diſperſed long enough to take its altitude, to rectify the time by the watch we made uſe of. After this, it was again obſcured, till about thirty minutes paſt nine; and then we found, that the eclipſe was begun. We now fixed the micrometers to the teleſcopes, and obſerved, or meaſured, the uneclipſed part of the ſun's diſk. At theſe obſervations I continued about three-quarters of an hour before the end, when I left off; being, in fact, unable to continue them longer, on account of the great heat of the ſun, increaſed by the reflection from the ſand.

The ſun was clouded at times; but it was clear when the eclipſe ended, the time of which was obſerved as follows:

		H. M. S.	
By Mr. Bayly	at	0 26 3	Apparent Time P. M.
Mr. King		0 26 1	
Myſelf		0 25 37	

Captain Cook discovered Christmas Island in 1777 and made the first scientific observation there.



NASA

The flight path of our aircraft from Canton Island to Honolulu is superimposed on a satellite photograph made at 21.59 GMT on 10 May, 1967. The arrow points to a striking example of an isolated cumulonimbus build-up, just south of a cloud "glob" in the Convergence Zone. At the time the ATS-I picture was taken our aircraft happened to be almost directly under the anvil of this cumulonimbus. The height of the cloud measured photogrammetrically was 15,000 meters.

BURKE

LINE ISLANDS EXPERIMENT
19 NCAR 67

A frame from 16mm time-lapse film shows our airplane flying under the cumulonimbus indicated by the arrow on the ATS I picture.

Aquaculture, Aquiculture, Mariculture, Sea Farming

By whatever name (We prefer aquaculture), there is an extensive literature on the subject.

The major article in this issue was based on a report: "The Status and Potential of Aquaculture," by Prof. E. Bardach and Dr. J. H. Ryther. Published in two volumes, the report is available at $3.00 each from the Clearing House for Federal Scientific and Technical Information, Springfield, Va. 22151. Vol. 1 (invertebrate and algae culture) is designated: PB 177-767. Vol. 2 (fish culture) is: PB 177-768.

Other recent references are: "Farming the Edge of the Sea", by E. S. Iversen, Fishing News (Books) Ltd, 1968. In the U.S. this book is available from National Fisherman/MCF, Camden, Maine. $10.00. The National Fisherman also publishes many articles on aquaculture. "The Farming of Fish", by C. F. Hickling, Pergamon Press, 1968, $3.00, is an excellent little book, providing also much insight in sociological and economic problems.

Many articles on fishery problems have appeared in *Oceanus*. See particularly: "Clams", by H. J. Turner, Jr. Volume VII, No. 1, Sept. 1960.

***

A forgotten namesake

DURING the voyage (of the Mayflower) there were several births. A son was delivered of Mistress Elizabeth Hopkins, wife of Master Stephen Hopkins. Because of the circumstances of his birth the child was named *Oceanus*.

From: "Medicine at Plymouth Plantation", by J. J. Byrne, M.D.
New England Journal of Medicine 259:1012-1017, 1958.

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Associates of The Woods Hole Oceanographic Institution

President	TOWNSEND HORNOR
Secretary	JOHN A. GIFFORD
Executive Assistant	L. HOYT WATSON

MEMBERSHIP inquiries are invited. They should be addressed to Mr. L. Hoyt Watson, Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.

THE Annual dinners of the Associates of the Woods Hole Oceanographic Institution will be held on 19 March, at the American Museum of Natural History in New York. On 25 March at the Museum of Science in Boston, and on 31 March at the Hotel duPont in Wilmington, Delaware.

Published by the
WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASSACHUSETTS