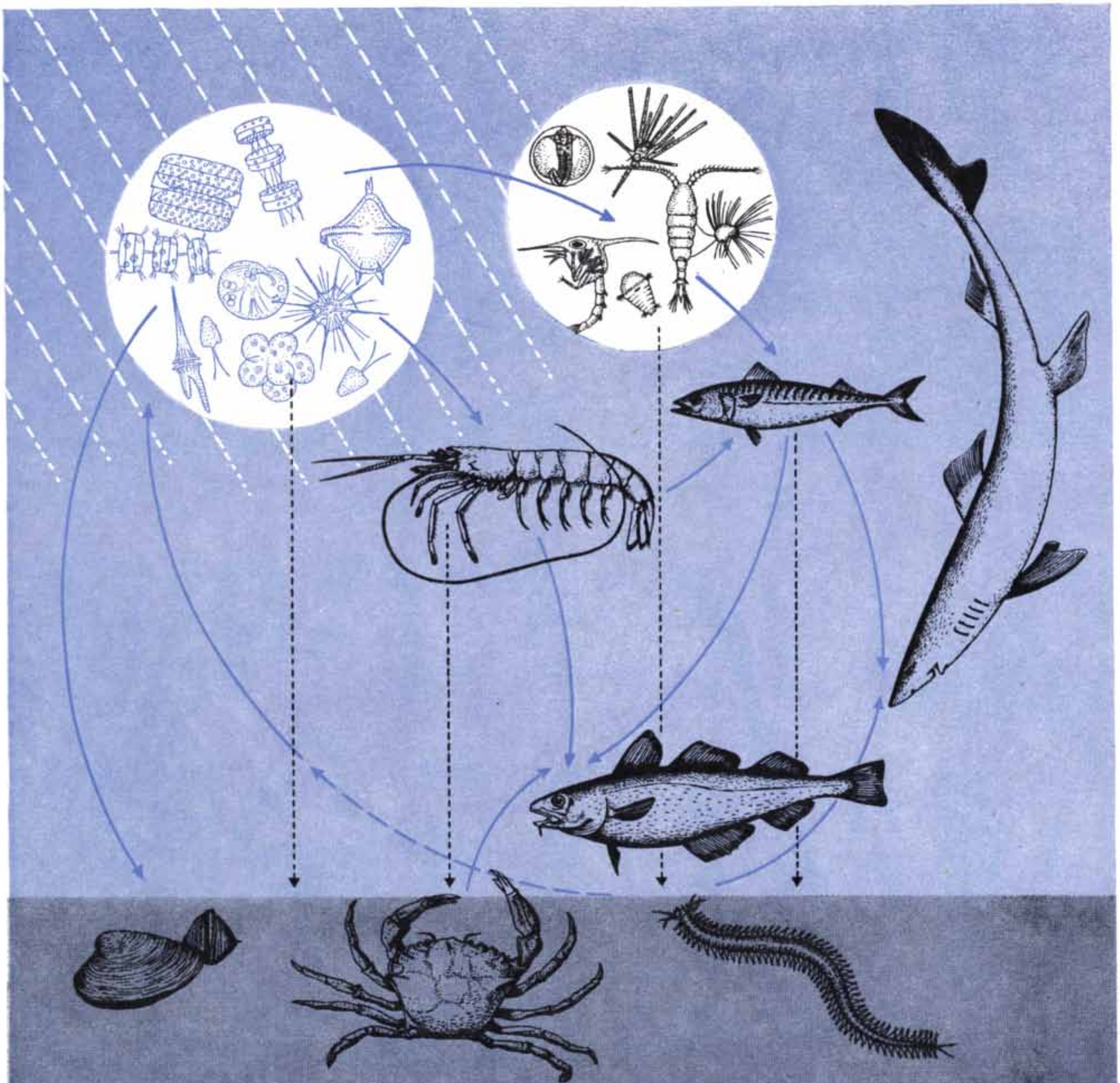
Food from the Sea

Marine life outweighs terrestrial life, so it has been suggested that man turn to the oceans to ease his food shortage. A statement of the problem's biological basis

by Gordon A. Riley



GRAND CYCLE of life in the sea begins with photosynthetic phytoplankton (*upper left*). These are eaten by zooplankton and other creatures, which in turn are eaten by a chain of carnivorous fishes. Decaying biological matter sinks to the bottom, where it is eaten by bottom animals and bacteria. Nitrates and phosphates then rise.

NO one needs to be told that there is a great deal of life in the sea. Sweep the shallows with a fish net, explore the deeps in a diving bell, dip up but a cupful of ocean and examine it under the microscope—at every level the watery world swarms with a rich and varied population. But only recently have we land-inhabitants begun to get a conception of just how vast, in numbers and bulk, this population is. Even our fragmentary efforts to take a census of it indicate that the life of the sea actually surpasses that of the land. Add up the staggering total of the annual increase of living matter on *terra firma*—grass, crops, forests, jungles, bacteria, fungi, insects, snakes, snails, elephants, cattle, mice, men—all this is less than the annual organic production of the earth's oceans.

Here is a storehouse of potential food to startle the imagination. Man has hitherto taken his food almost entirely from the land; less than one per cent of what he eats comes from the sea. We would like to believe that in the immense, newly explored organic resources of the oceans lies at least part of the solution to the world's increasingly acute food problem. Lately we have heard some highly hopeful proposals and predictions—that "farming" of the sea by the use of fertilizer may multiply its yield of fish and shellfish; that even the sea's microscopic plant and animal life may be converted into food for man.

The truth is that no one at this moment can accurately assess the potential marine food resources. Large areas of the oceans are still relatively unexplored from the biological point of view. And the evidence as to the possibility of increasing our harvest from the sea is confusing, to say the least. A recent international conference of fisheries experts called attention to the fact that increased fishing effort on the major fishing grounds of the North Atlantic had not increased the catch; indeed, some biologists believe that these grounds are now being overfished. Aside from these strictly oceanographic considerations, there are technological problems and unpredictable economic factors that will have an important bearing on how much food we can feasibly get from the oceans. Yet with all these cautious reservations we are justified in taking a hopeful attitude toward the possibilities.

THE basic cycle of life is the same in the sea as on land. The hierarchy of life in the marine world, like that in the terrestrial world, is founded on green plants. They alone have the ability to convert inorganic materials into living substance, and directly or indirectly they support the whole animal population. This system by which organic matter is created by the photosynthesis of green plants, consumed and broken down by animals and recreated by plants is essential to the continued existence of any population, on land or in the sea.

At the base of the oceanic hierarchy is a vast mass of organisms so tiny that they are individually invisible. More than 99 per cent of the marine plants are microscopic, one-celled algae which have a precarious and nomadic existence. They are suspended in the surface waters of the sea and drift idly with the currents. There are hundreds of species of them in various shapes and sizes; their average diameter is about a thousandth of an inch. To the naked eye they are visible only as a greenish or brownish tinge in waters where they are abundant. Under the microscope they are resolved into great multitudes of organisms, ranging from a thousand to several million in a quart of sea water. They add up to a total of perhaps 100 pounds of plant organic matter per acre of ocean.

Associated with the plants is a great variety of small animals. Some spend their whole lives drifting in the surface waters. Others stay with the floating population only until they are grown, and then strike off on their own; examples of these are shellfish and other bottom animals. One of the most important groups of the floating animals are the copepods, tiny crustaceans about a quarter of an inch long that resemble a miniature shrimp. A copepod has a set of spines on its mouth that interlock to form a neat little sieve. The sieve strains out microscopic plants and other bits of food from the water. To help in its feeding the animal is equipped with vibrating appendages that push a flow of water through the sieve. Other plant eaters in the floating population have different kinds of filtering mechanisms, some very elaborate. Not all the animals in this population are plant eaters, however; some have grasping and biting mouth-parts and prey on the smaller animals.

The floating plant and animal society is known collectively as plankton. It provides food for a host of larger and more active creatures that live in the surface waters, including such fishes as herring and mackerel. In coastal waters and the offshore fishing banks, plankton sinking from the surface nourishes the small animals that live on or near the bottom. These in turn are the food of flounders and other ground fish.

Thus the fishes and other large animals in the sea represent the end product of a long and complicated food chain. Through a series of predations, the tiny bits of plant life are transformed into successively bigger bundles of living material. But all along the way from plants to fishes there is a continual loss of organic matter. During its growth to adulthood an animal eats many times its own weight in food. Most of the organic material it consumes is broken down to supply energy for its activity and life processes in general. It follows that the total of plant matter in the sea outweighs the animals that feed upon it, and the herbivores in turn outweigh the carnivores. Fish production is believed to be of the order of only one tenth of one per cent of plant production.

THE investigation of the amount of organic production in the sea is one of the most difficult and fascinating problems in biological oceanography. In the broadest sense it means determining the rate of production at every level in the food chain. It also means investigating the tangled skein of oceanographic and biological relationships that determine the productivity of any given region.

What makes it difficult is that marine populations are highly dynamic and unstable. They do not burgeon and wither in regular cycles as on land. The algae, known collectively as the phytoplankton, often exhibit spectacular bursts of growth of a seasonal nature, but these are hardly comparable to growing periods on land. On the contrary, the plants of the sea keep on growing to some extent the year round. At the same time the plant population suffers continual loss by animal feeding or by sinking into the depths of the ocean. So the quantity of phytoplankton present in the water at any one time may give little indication of the amount that is being produced.

The problem, then, is to find some method of separating the rates of growth and death and measuring them independently. The first method that occurred to oceanographers was to examine the water for chemical changes that might be a measure of biological activity. Some 20 years ago investigators observed that the chemical composition of sea water changes with the seasons. Phosphate, nitrate and other substances required for plant growth attain a maximum concentration in the surface waters in midwinter, when the light is too poor to favor active plant growth and when turbulence induced by winter storms brings up these chemicals from the nutrient-rich deep water. During the spring growing season, when the surface zone is well lighted, plants absorb these substances at a more rapid rate and the concentration of them in the surface water drops. By summer it is reduced to a low level. Later, as the remains of dead plankton sink into deep water, the nitrate and phosphate are liberated again.

Shortly after this discovery H. W. Harvey, L. H. N. Cooper and their co-workers at the marine laboratory at Plymouth, England, made a careful survey of the plankton and nutrients of the English Channel. They noticed that the amount of nutrients disappearing from the water during the period of intense spring growth was many times the amount present in the plant population at any one time. In other words the quantity of food vanishing down the small boy's gullet was out of all proportion to the apparently slight results achieved in growth of stature. This seemingly contradictory situation could only be explained by these assumptions: (a) the plants were actually growing very rapidly, in some cases increasing as much as 50 per cent per day, and (b) they were being eaten as fast as they grew (somewhat as the active small boy spends energy almost as fast as he ingests it).

Similar results have since been obtained in many other regions, and there is not the slightest doubt that the phytoplankton, although it appears to be comparatively small in amount, is an active producer of organic material. However, accurate estimates of plant production cannot be obtained by trying to measure the amount of nutrients consumed. This method does not take into account the fact that some nutrients are liberated in the surface layer by the death of plankton or that some are brought up to the surface from deep water by vertical turbulence. In summer (and in the tropics throughout the year) these processes approximately balance the rate of utilization of the nutrients by plants.

IN search of a more generally useful method, oceanographers turned to experimental techniques. The Norwegian investigator H. H. Gran filled bottles with sea water containing its natural plankton population, suspended them in the sea so that they would be exposed to reasonably normal conditions of light and temperature, and measured the growth of plankton that occurred during a period of a day or two. By enclosing the plankton in bottles he made sure that no nutrients would be added to the mixture. To measure the production of organic matter he divided the bottles into two groups. One group he wrapped in dark cloth; by excluding light he prevented the process of photosynthesis, and so in these bottles the plankton did not produce organic matter but only consumed it. In the lighted bottles, on the other hand, both production and consumption went on, just as in the sea. The difference in the organic content of the two sets of bottles showed the total amount of organic production.

Several hundred such experiments have now been made: by Steemann Nielsen in Danish waters, by the writer in the western Atlantic, by M. C. Sargent of the Scripps Institution of Oceanography in California coastal waters and the tropical Pacific, and by others. They are enough to draw some tentative conclusions about phytoplankton production. In most of the regions examined, the sea yields from one to three tons of dry organic matter per acre per year. This means that on the average the plant population must grow about 10 per cent per day. The most fertile areas of the ocean have approximately the same annual production as a forest. The lower limits of productivity correspond more nearly to the grass crop of a semi-arid plain. Thus acre for acre, the plant production of the sea and of the land is of the same order of magnitude. But because of the larger area of the sea, its total production is almost certainly greater.

The production of animal plankton has not been studied as thoroughly as phytoplankton. The animal crop is from one tenth to one half of the plant crop. But the animal production cannot yet be estimated with a satisfactory degree of accuracy.

We are in the same situation with regard to most of the higher members of the food chain—the fishes, shellfish, and so on. The best we can do is to estimate that in the case of some commercially important species which are intensively fished the annual catch must nearly equal the annual production.

Fishes and other animals at high levels of the food chain have a much slower growth rate than plankton. Several years ago Daniel Merriman and his associates on the staff of the Bingham Oceanographic Laboratory of Yale University began an intensive study of the flounder fishery off the southern New England coast. There the total fish population at any given time averages about 80 pounds per acre. From an area of roughly 200 square miles, fishermen annually take from three to six million pounds of marketable fish. Their total catch also includes an equal or larger quantity of "trash" fish that are thrown away or sometimes marketed for fish meal. Thus the total catch represents roughly 50 to 100 pounds per acre. While these figures are very rough, they suggest that the annual production of fish approximately equals the population at any one time. The average phytoplankton population in this area appears to be about four times the weight of the fish. But it grows much faster; the annual phytoplankton production is over 500 times the annual fish catch. Similarly, the Woods Hole Oceanographic Institution and the U. S. Fish and Wildlife Service found that on Georges Bank, a large and important fishing area east of New England, annual fish landings ranged from seven to 33 pounds per acre, while phytoplankton production was estimated to be of the order of 1,000 times the maximum commercial catch.

THESE studies of marine productivity are a step along the way toward two goals that oceanographers have in mind. One is purely scientific—to gain an understanding of the principles that govern the existence and growth of marine plants and animals. The other is to apply this knowledge wherever possible to practical affairs.

What are the factors that control the sea's productivity? In a general way, we know some of them. We know that light and temperature strongly affect the growth rate of the plants, and that temperature also influences the rate at which these plants sink to deeper levels and the rate at which animals feed on them. Currents and accompanying turbulence in the water are important: if the turbulence is too great, it slaughters the surface population by carrying plants down below the zone of active growth; if the turbulence is too weak, the population again suffers because less phosphate and other food is brought up from below.

The best fishing areas are generally in shallow water. There the plant population is concentrated in a small space, and the animal plankton can feed intensively and grow rapidly. There also an abundant supply of plankton falls to the bottom and nourishes the animals that live there. In deeper waters the dead plankton decomposes as it sinks, and little reaches the bottom. This is one reason why on a deep ocean bottom animal life is scanty.

During the past few years, the writer and his associates have made preliminary attempts to deal with plankton in mathematical terms. An equation can be written to predict the quantity of plankton in a given region or its seasonal changes, on the basis of the environmental characteristics of the region—light, temperature, turbulence, the depth of water, and the deep water concentration of nutrients. Precise application of the equation requires a great deal of information about the effect of environmental factors on growth rates and physiological processes in general. Unfortunately, present knowledge of these subjects is not nearly as precise and complete as might be desired. Nevertheless, in various regions where the equations have been applied, the quantities of plankton predicted by these equations agree with observations within about 25 per cent.

ALTHOUGH oceanographers are still far from satisfied with their knowledge of the life of the sea, some of their observations have already begun to bear practical fruit. The British herring fishery is an example of what may come of a few simple oceanographic observations. The herring reaches commercial size at the age of three years. It has been found that the magnitude of the catch in any year is closely correlated with the amount of phosphate that was in the water three years previously, when the herring first hatched. The implication is that the food supply during the first few months of life is a critical factor in determining survival, and a large amount of phosphate ensures abundant food.

Whatever the explanation may be, the phosphate index is a simple means of predicting the herring crop three years in advance, making it possible to plan for good years and bad.

Predictions of one kind or another will be a major function of the practical oceanographer of the future. It will be necessary also to consider controls to prevent overfishing, which endangers the production of young. This is particularly important in the case of fishes that lay a relatively small number of eggs. Even when we have solved the problems of fish conservation, however, there will remain the challenging fact that we still will be using only a tiny fraction of the total organic production of the sea.

One way to increase our harvest is by intensive oyster and clam farming. These animals exist at a low level in the food chain, living on small plankton and detritus, and production is therefore relatively efficient. In the Philippines, the East Indies, China, and various other regions, considerable success has been attained in farming fishes and prawns. When shallow coastal areas are impounded and artificially fertilized, the increase in production is sometimes 20-fold. Annual yields of 4,000 pounds of fish per acre have been reported. Development and extension of fish culture in both marine and fresh waters is undoubtedly one of the best approaches toward remedying the protein deficiency of the Oriental diet.

Some people even suggest catching and using plankton. It is not an attractive food as such, but it is nutritious, and special processing might make it acceptable. But there are no large concentrations of plankton in the water at any one time, and filtering out a sizable quantity of such small creatures would require an enormous output of energy. It might be done on a limited scale, for example by utilizing tidal energy. But to harvest any considerable fraction of the plankton of the world seems as fantastic as the old dream of extracting gold from sea water. By and large we must leave the plankton to the fishes.

We can certainly learn to use the fishes more effectively, however, and catch them farther afield. There are vast fishery resources in various parts of the world that remain virtually untapped, simply because their quality or their distance from marketing centers makes them less profitable than our present commercial fisheries. Changing economic patterns and increased demand may lead to the development of such resources. Quite possibly the world's fish catch could be increased five or ten times or more.

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DIATOMS are a large part of the phytoplankton, the tiny plant life of the oceans. They are principally distinguished by their siliceous skeletons. When diatoms die these settle to the bottom to make up the diatomaceous earths.

COPEPODS are an important group of the zooplankton, the tiny animal life that feeds on the phytoplankton. Copepods are similar to shrimps. They have delicate spines about their mouths with which to trap the phytoplankton.