PLANKTON

By

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UNITED STATES DEPARTMENT OF THE INTERIOR
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INTRODUCTION

The word "plankton" was derived from the Greek "planktos," which means "wandering." It is a collective term applied chiefly to all those small,[2] extremely diverse forms of plants (phytoplankton, fig. 1) and animals (zooplankton, figs. 2 and 3) that drift aimlessly with the currents in all natural waters and in artificial impoundments. Most of the forms swim feebly and are incapable of making long horizontal journeys except as they are swept along by persistent winds and currents. Some, nevertheless, make extended vertical migrations in response to stimuli not clearly understood. These movements have been partially correlated with diurnal changes in the intensity of light; the salinity, temperature, and density of the water at different levels, and community pressures may also be important factors. Most planktonic organisms, especially the one-celled plants and animals, are extremely small and were unknown prior to the invention of the compound microscope late in the 17th century.

Although most of the waters of the world are inhabited principally by plankton, little is known about these organisms compared with the great store of knowledge available on land plants and animals. The plankton and their environment have been difficult to study. For the most part, knowledge has been gained indirectly by the use of electronic and other specialized instruments that record movements of the animals and the depths, temperatures, and chemical composition of the aquatic environment, or directly by analyses of samples of water, bottom sediments, and living organisms brought to the surface and preserved for later study in laboratories.

[1] A revision of "The value of plankton as a food" by Louella E. Cable. Fish. Market News 5(11):6-12.

[2] Although the minute plants (diatoms and blue-green algae) and very small animals (protozoa, entomostracans, and larvae of various other forms) make up the great bulk of the plankton, a few larger forms (jellyfish and salpae) that have only weak powers of locomotion are also included.

The future holds promise of more intimate observations of the plankton in their underwater habitats than were possible in the past. Soon the observations will be made from maneuverable submarines capable of sustained operation at great depths and from permanent underwater research stations. The research stations are still in the planning stage and may not become reality for some time, but the deep-water submarine is already in use for close scrutiny of the bottom and study of plankton and other inhabitants in all strata of the seas. The Woods Hole Oceanographic Institution has operated the Alvin, one of the first of a series of these specialized submarine laboratories that are being developed. The Deepster, with an outer hull of fiber glass, and the Aluminaut, with a hull composed of a number of thick aluminum rings bolted and glued together, are joining the deep-water fleet. Some of these vessels may be equipped with blue-green lasers for underwater communication and for improvement of visibility for television and photography.

CLASSIFICATIONS OF PLANKTON

The major taxonomic units, or primary divisions, of the plant and animal kingdoms are called phyla. Each phylum is a unit composed of organisms sharing one or more fundamental characters that reflect a common descent. Many levels of this systematic classification of life are represented in the plankton, from the simplest one-celled plants (Thallophyta) and animals (Protozoa) to very complex little animals such as crustaceans and fish larvae (fig. 4). Certain many-celled animals are planktonic for a short period during early development even though, as adults, they become either sedentary (e.g., oysters, clams, and sponges) or free swimming (e.g., shrimp and fish). Plankton of less than 1/600-inch maximum diameter make up the nannoplankton or microplankton. Forms large enough to be seen with the naked eye are macroplankton.

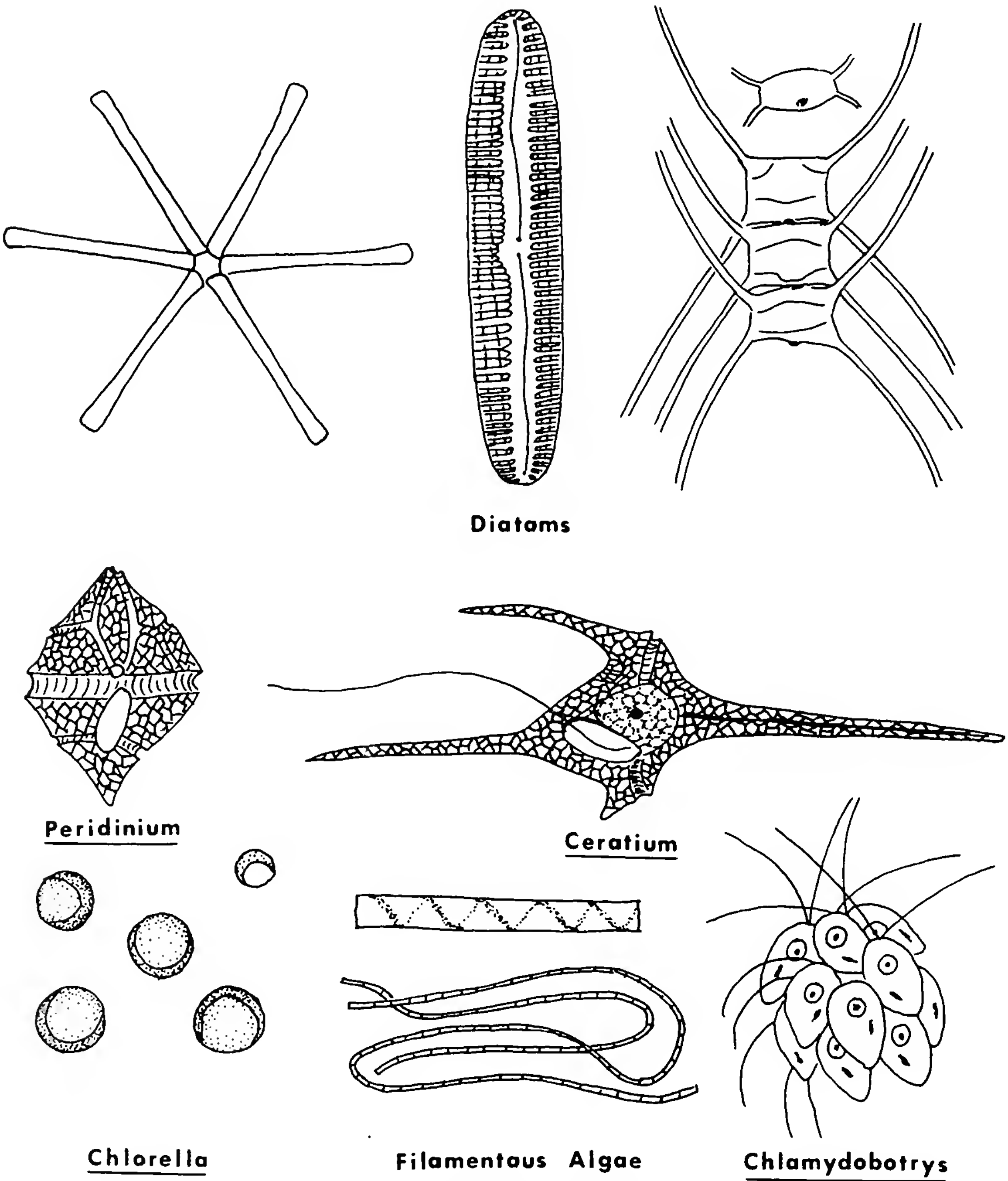
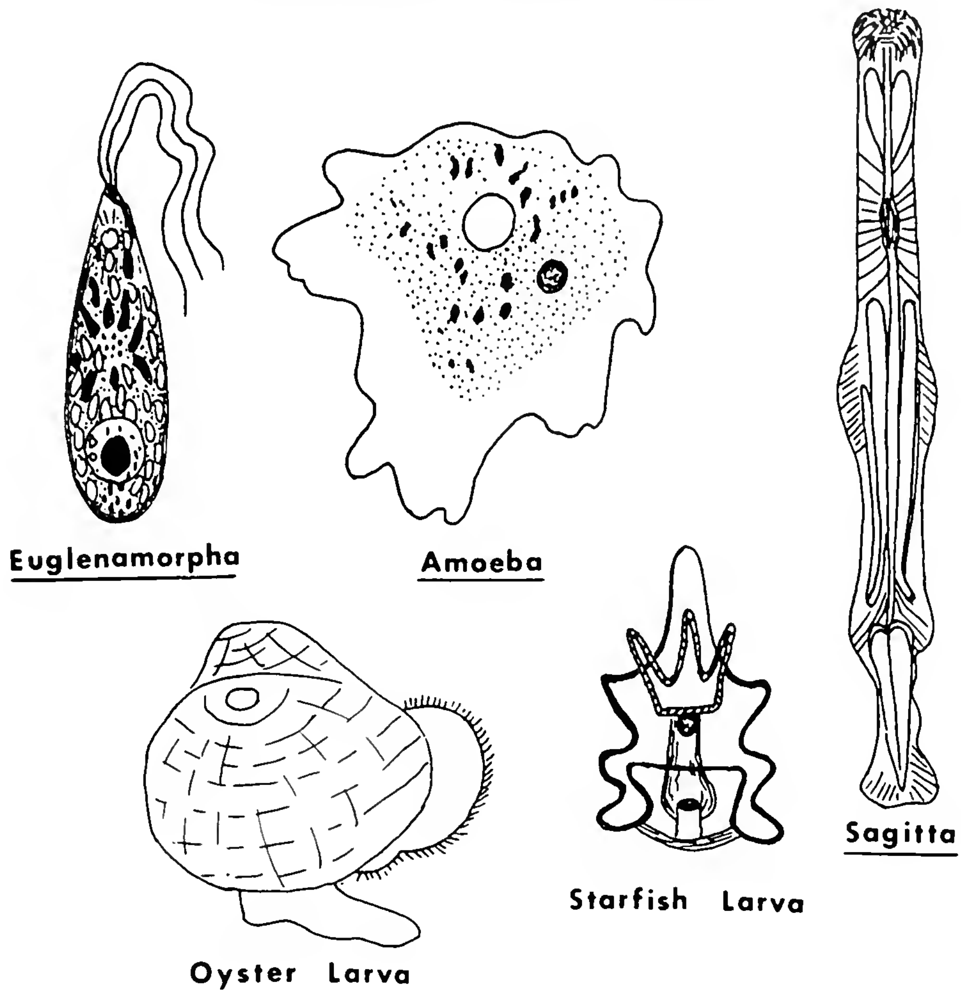


Figure 1.--Some typical forms of phytoplankton (greatly magnified): Peridinum and Ceratium (dinoflagellates), Chlorella (chlorococcales), Chlamydobatrys (volvocales).

INVERTEBRATE ZOOPLANKTON



VERTEBRATE ZOOPLANKTON

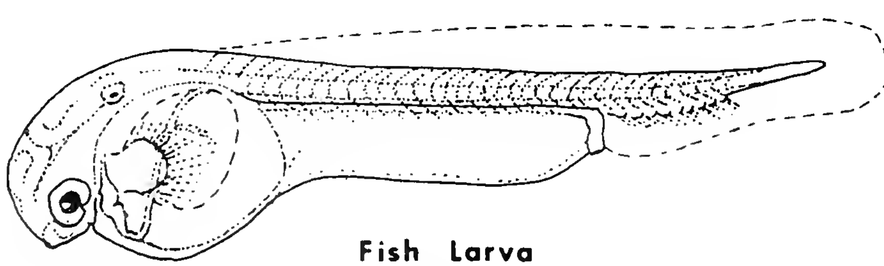


Figure 2.--Some typical forms of invertebrate and vertebrate zooplankton (greatly magnified).

ZOOPLANKTON
CRUSTACEA

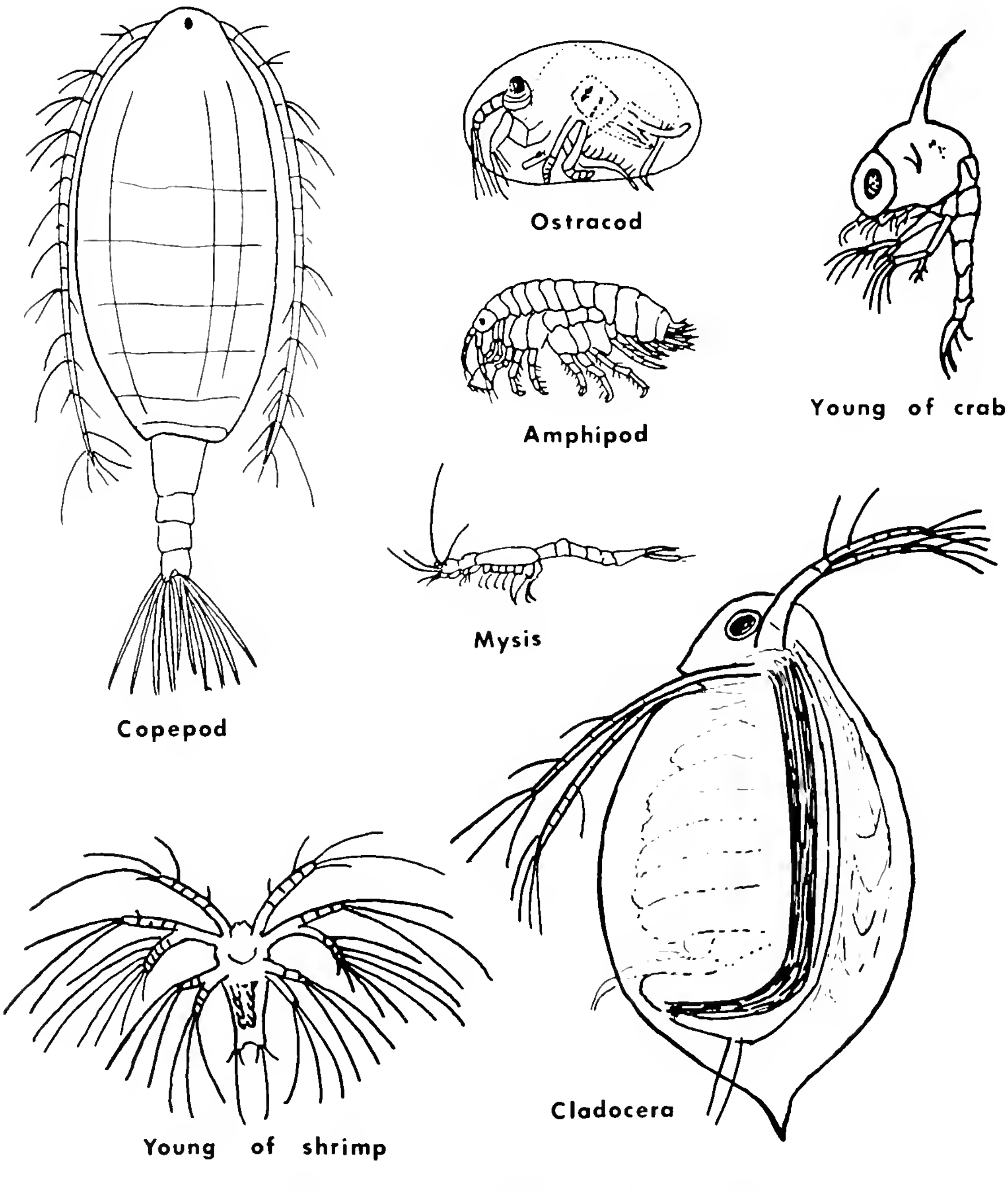


Figure 3.--Invertebrate zooplankton (greatly magnified).

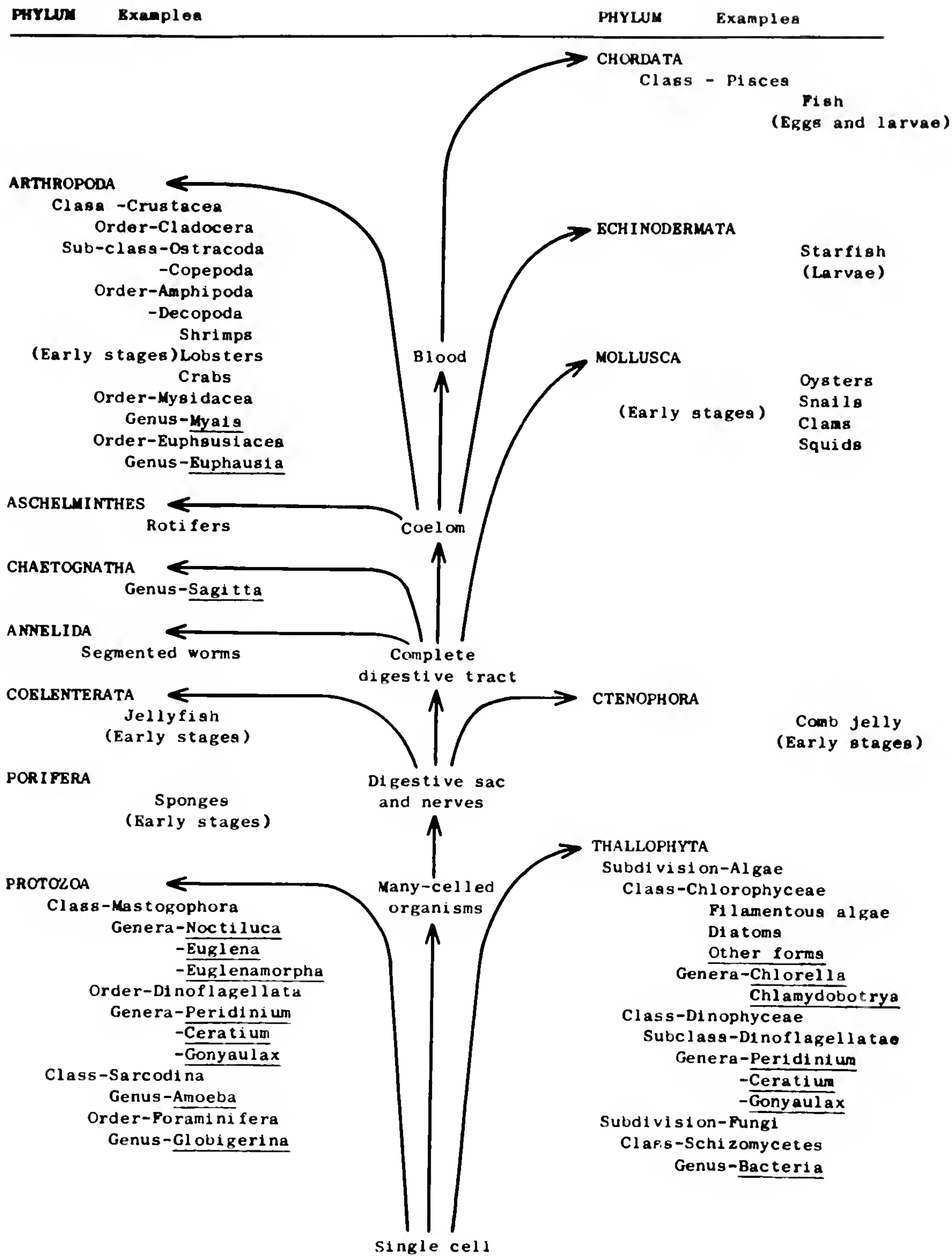


Figure 4.--A geneological tree showing the probable relationship of some of the more important phyla in the plant and animal kingdoms that are represented in the plankton at some stage in their lives.

Marine plankton also may be classified in general terms as oceanic and neritic (coast-bound). Oceanic plankton contains forms that normally inhabit areas of the open sea, such as certain species of copepods, diatoms, and peridinians that thrive best in intercontinental areas (arctic, temperate, and tropical sea forms differ from each other). Neritic plankton is made up of forms that remain comparatively close inshore and may include: (1) the pelagic larvae of the bottom dwellers such as oysters and starfish; (2) pelagic eggs and larvae of fish; and (3) organisms held inshore by specific requirements for food, temperature, water chemistry, and possibly other environmental demands related to land masses. The distinction between oceanic and neritic plankton becomes difficult when members of either type are transported by wind or water currents from their usual habitat into that of the other.

DISTRIBUTION

The distribution of planktonic organisms is almost universal in aquatic environments. They are in the oceans, rivers, lakes, and ponds the world over. Some cosmopolitan forms of plankton are found at all latitudes, while other forms have disconnected distributions and occur in scattered discrete areas where conditions favor their existence. No climate is too warm or too cold to support plankton of one type or another. The greatest concentrations of phytoplankters occur in the upper layers of water down to the limit of effective penetration by light (100 to 130 feet). Maximum density of zooplankters also occurs in the surface strata where the herbivorous species feed on the phytoplankton. Some forms, primarily zooplankton, inhabit the bottom zones of lakes and streams, and also the profound depths of the oceans.

REPRODUCTION

Reproduction of planktonic forms, as of land creatures, provides for the multiplication of individuals to ensure preservation of species. The various groups in the plankton reproduce in different ways. The resulting diversity of methods to accomplish this very necessary biological function makes it possible to trace nature's gradual development of the reproductive process from asexual (without sex) to sexual. The most primitive method is simple asexual division, in which the protoplasm of one-celled plants and animals divides into two equal parts to form two new individuals. In slightly more advanced organisms an intermediate stage of sexual behavior is found. Individuals that are alike in size and structure reproduce only after they fuse and exchange micronuclear materials. In general, morphologically complex forms have more highly developed sexual organs and behavior. Rarely, individual animals of all species may have both male and female organs (hermaphroditism), and at least one group of common animals, the oysters, may change sex from time to time.

SWARMS AND BLOOMS

Especially dense concentrations of a single species of zooplankton or phytoplankton are population explosions known as swarms, and flowers or blooms. They occur seasonally or at irregular intervals when environmental conditions are exceptionally favorable for the growth and reproduction of a particular species. Swarming or flowering communities occur most often when the water is enriched by runoff from agricultural land, by upwelling from the bottom, by overturn of a body of water due to wind and thermal changes, or by the addition of small quantities of organic wastes from urban communities.

A bloom in the Vermillion River, S.Dak., lasted 2 or 3 days after the spring runoff in 1923. It formed a thick red scum from bank to bank for many miles along the river's course. Under the microscope, the scum was seen to be made up of Euglena, a single-celled organism. Some authorities believe Euglena is a plant because it contains chloroplasts (green bodies containing chlorophyll); others believe it is an animal because its body structure and habits of life are more similar to those of animals than to those of plants.

The blooming or swarming of Euglena was not an annual occurrence, and large crowds gathered to view this unusual phenomenon. Most of these people had lived near the river many years but had never seen the red scum before. A similar occurrence at some earlier time probably gave the river its name.

Ostracods (small zooplankters belonging to the Crustacea) swarmed in the Pamunkey River, Va., in April 1940. They formed a brown coating on the surface of the water and clogged fine-meshed collecting nets fished near the bottom. The Chief of the Pamunkey Indians, who lived nearby, had never before seen such a swarming.

Blooms of filamentous algae form dense green rafts on bodies of enriched fresh water in stagnant pools, small lakes, and protected places in larger bodies of water during the summer. Nearly everyone has seen them. They sometimes interfere with boating and swimming at resorts, where the blooms are a nuisance. The blooms usually last only a few days, for the life span of filamentous algae is short.

Most such rafts of filamentous algae are formed of Spirogyra, an alga that has two methods of reproduction--vegetative (asexual) and sexual.

By the vegetative method, Spirogyra rapidly forms long strands of cells while the environment is most favorable. The strands grow by the elongation and division of all cells in the filament. Division usually takes place at night. After elongation of the cell, the nucleus divides by mitosis, and then the cell is cut in two by a ring of cellulose which grows inward from the outer wall of the cell between the two nuclei to form two identical cells which usually remain attached to each other.

Later, when the environment has changed, perhaps by the mere presence of the Spirogyra in it (food consumed, wastes released) or by external factors such as drought or extremes of temperature, the Spirogyra reproduce sexually. Conjugation usually takes place between the cells of two vegetative strands, but it may take place between adjacent cells on the same strand. The contents of the cells of one strand pass into corresponding cells of the other strand, thus leaving the cells of one strand empty, or, if the cells are adjacent in the same strand, every other cell is left empty. Although the contents of both participating cells are morphologically alike, the fact that those of one strand remain passive and those in the other strand are motile indicates a slight physiological differentiation of the contents of the cells that at this time become sex organs called gametes. The organism resulting from their union is a zygote. The zygote forms a thick three-layered wall about itself. It is then called a zygospore and is the resting stage of the Spyrogyra. The zygospore is highly resistant to extreme cold and to drought. It falls to the bottom of the water on which the green raft had rested a short time before. The cell walls that formed the raft disintegrate and also sink to the bottom.

The zygotes germinate after an indeterminate period of rest. The time of germination is entirely dependent upon environmental conditions required for the development of the vegetative and sexual reproductive cycles. The length of these cycles also depends on the environment. They will be longer in some places and times than others, but never longer than a few weeks.

Some species of salt-water plankton also flower or swarm occasionally. The most publicized example is the "red tide," which occurs most often in subtropical marine waters, such as the Gulf of Mexico and the Pacific Ocean off southern California. The red tide has occurred in the Gulf of Mexico at least 20 times since its first recorded appearance in 1844; 17 of these events were off the west coast of Florida and 3 off Texas and Mexico.

The red tide appears as a dense concentration of dinoflagellates of the genera Gymnodinium or Gonyaulax. These organisms measure about 1/1,270 to 1/726 inch. The great numbers of dinoflagellates often impart a reddish amber color to the water, but shades of green interlaced with yellow and brown are also characteristic of the blooms. They may cover hundreds of square miles, and some species produce sufficient toxin to kill millions of fish. Death comes suddenly after the fish enter the area of the bloom. Dead fish of all species and sizes drift ashore, occasionally to the amount of 100 pounds per linear foot of shoreline, causing unpleasant odors and serious disposal problems for cities and resort areas. The deeply colored water sometimes has an oily appearance; when dipped up and allowed to stand a few minutes, it has a thick, slimy feeling.

Flowerings and swarmings of plankton are spectacular events, for the clumping of vast numbers of organisms (as many as 15,982,560 cells of the dinoflagellate, Ceratium furca, were counted per quart of water off the west coast of Florida in 1955) makes them visible to the human eye. Between population explosions the animals reproduce at a greatly reduced rate. Even then, local plankton populations often are dominated by one species almost to the exclusion of others, as shown by the contents of collecting nets.

SURVIVAL

Ostracods, cladocerans, copepods, brine shrimp, and many other, but not all, small aquatic animals and plants survive unfavorable seasons, severe droughts, and critically high or low temperatures in a quiescent state known as a resting spore or, in some cases, a winter egg. Resting spores and winter eggs remain viable for long periods, sometimes for many years, and still develop a vigorous new generation of individuals when suitable living conditions return. Because organisms that make up the plankton are able to survive in this manner they appear in temporary ponds formed after rain, although no water may have been there for months or years. This mode of survival also explains why it is possible to obtain many tiny organisms within a few days by the simple method of placing a bit of meadow hay in a shallow dish of water. Windblown spores and eggs that have settled upon and adhered to the vegetation develop rapidly in water with proper light and temperature.

YIELD

Rough estimates of the annual yield of phytoplankton in all the seas approximate 165 million tons of organically bound carbon, and estimates of live weight run from 6 billion to 6 trillion tons. No reliable method has been developed for measuring the total yield of plankton. The number of organisms in the standing crop (the number of individuals living at one instant) in any area is limited by the amount and combination of nutrients in the water; by temperature; by the quality, duration, and penetration of light; and by the total mortality of the organisms. The standing crop, therefore, varies sharply from one place to another at a given time and from time to time in the same place.

Among the smaller and more abundant forms of algae in the phytoplankton are the diatoms. Areas where diatoms occur in heavy concentrations often are referred to as "pastures of the sea"; here diatoms may contribute as much as 98 percent of the standing crop of organic matter. The fish and even the great whales depend ultimately on them for sustenance. Fossil remains of diatoms indicate that in eons past, as at present, billions, possibly trillions, of tons of them must have been produced annually in excess of the enormous amounts required to feed the animals of the sea.

Diatoms surround themselves with walls of silicon dioxide in the form of two valves, one of which overlaps the other. These walls are ornamented by characteristic patterns--some of exceptional beauty--which taxonomists use to identify species. After death of the diatom, bacteria dispose of the soft body, but the walls remain intact and sink to the bottom. The accumulation of shells may reach a considerable thickness over a long period of time. One deposit at Lompoc, Calif., formed on the bottom of a prehistoric sea but now a part of the land area as a result of geological changes in the earth's crust, extends over many square miles and is more than 700 feet thick in places. One scarcely can conceive the myriads of individuals required to produce such immense bulk.

Bacteria, too, are very small[3] and are present almost everywhere in the aquatic and terrestrial worlds. Bacteria are much like algae but lack chlorophyll and must secure their food ready made from the bodies of other organisms or their products. Vegetative cells of bacteria grow to a maximum size and then divide by fission into two bacteria of equal size. Some surround themselves with a thick wall and thus become spores or resting cells that are resistant to far more unfavorable conditions than are the vegetative cells. No estimate of the abundance of bacteria in the plankton has been made, but many investigators believe that the total bulk of bacteria would be considerably more than that of the diatoms.

Together with yeasts and molds, bacteria cause the decay of plant and animal tissues. Through this process, bacteria release the carbon, oxygen, and phosphorus that are locked into the tissues and reduce them to simple compounds such as carbon dioxide, water, nitrates, sulphates, and phosphates that can be used again as food by living phytoplankters.

[3] 1/50,000 to 1/12,500 inch long and 1/125,000 to 1/50,000 inch wide.

USES OF PLANKTON

Manufacture of Basic Nutriment

Extensive investigations have shown that a great preponderance of the basic or primary nutriment in the aquatic environment is manufactured by the unicellular microscopic algae in the phytoplankton. These tiny plants contain chloroplasts that can produce carbohydrates from carbon dioxide and water in the presence of light (a process called photosynthesis). The plant cells then synthesize complex organic compounds from suitable salts of essential inorganic substances--chiefly carbon, phosphorus, and nitrogen. The plants that perform this miracle of chemical conversion then become the food of the zooplankton, which, by themselves, are incapable of gaining nourishment from inorganic substances in the water. Whereas most primary producers are minute single-celled plants from the microplankton, the consumers are comparatively large single- or many-celled animals from the macroplankton.

Food for Aquatic Animals

The zooplankton that browse on diatoms become the food of the larval young of nearly all species of fish, and of adult fish that remain plankton feeders throughout life (e.g., minnows, anchovies, and menhaden). These in turn, are food for large, carnivorous (flesh-eating) fish and the whalebone (baleen) whales.

Fish that have floating eggs must spawn either on the feeding grounds for the young or in places where the winds and water currents will take the eggs to the feeding grounds by the end of the incubation period. The tiny, newly hatched fish (less than 1/3 inch long) feed on small plankters and will perish unless food of appropriate size and variety is available to them a few hours to a few days after they hatch. As the young fish grow, they eat proportionately larger forms of plankton.

Mackerel are voracious feeders. They frequently cram their stomachs until they become distended when certain types of plankton are abundant. The young eat chiefly immature copepods and ostracods, larvae of shrimp, crabs, and some small fish. At times during summer and fall, adult mackerel fill their stomachs with Sagitta, an arrow-shaped worm, and mollusks known as pteropods, in localities where these animals are plentiful. During spring in the North Atlantic, mackerel commonly eat large quantities of copepods of the genus Calanus, which are known as "red feed" because they are turned reddish-orange by stomach enzymes. Fishermen report that painful sores develop on their hands after handling mackerel containing red feed, which is known to them as "red pepper." The presence of this food in the stomachs of mackerel causes rapid and extensive breakdown of the surrounding flesh within 24 hours after the fish have been caught and packed in ice. Fishermen occasionally experience heavy losses from such spoilage.

The herring, one of the most abundant fish in the world, occurs on both sides of the Atlantic and the Pacific Oceans, where it feeds while young on small planktonic forms--diatoms, Peridinium, Crustacea, larvae of worms, pelecypods (bivalve mollusks: e.g., oysters and clams), and gastropods (univalve mollusks: e.g., snails). Among the crustaceans eaten by herring, the Calanus, red feed, has a very great influence on the economy of the herring industry of the United States and Canada. In these two countries small herring are canned as sardines. When a catch of herring is to be canned, it must be inspected for red feed, and if Calanus was injested recently enough to be present in the alimentary tract, the fish must be held until both stomach and intestine are cleared of the red feed.

Menhaden are among the few fishes that throughout life feed chiefly on diatoms and Peridinium (two of the most common planktonic forms). They also feed on the most minute crustaceans.

Many fishes prefer one or more groups of plankters to the exclusion of others. The stomachs of fish often contain only one or a few species, even when other organisms of similar size are known to be in the particular locality where the fish were feeding. Whales that feed on plankton also are selective. They roam the seas to locate massive blooms of their favorite organisms. The reasons for these food preferences and the bases of selection (sight, taste, odor) are not fully understood.

Food for Man

The value of plankton as food for fish and other aquatic fauna has long been recognized, but the value of phytoplankton as a primary source of food for man, and the tremendous potential economic importance of its industrial culture, have only begun to be appreciated. As the human population grows, the need for additional foods will increase. Even now, many peoples of the world are underfed while an enormous aquatic resource remains undeveloped and is wasted.

Large deposits of the remains of diatoms like the one at Lompoc, Calif., are mute evidence that long ago greater quantities were produced annually than were consumed. Although excess production of other components of the plankton has not been demonstrated so dramatically, their numbers also surpass the needs of their natural predators. Here in America little consideration has been given to the possibility of using this surplus for human food. Fortunately we are capable of producing more land-grown foods than are required to supply the needs of the present population.

In some European and Asian countries such as Germany, England, Japan, China, and India, however, scientists have given much serious thought to the use of plankton for food. As early as 1939, the German State Biological Institute of Helgoland was "investigating the possibility of harvesting plankton of the sea as a new food source to make Germany more independent of foreign imports." The Institute found the nutritive value of zooplankton equivalent to that of the best meats, and the nutritive value of phytoplankton equal to that of rye flour. An English scientist, William A. Herdman, who became interested in the flavor of zooplankton, reported in 1891 that he had eaten copepods boiled in butter; he liked the preparation and stated that the flavor was similar to that of lobster. H. Tamiya, who has done extensive work in Japan on man's use of planktonic green algae, found that blanched algae are palatable and that man can convert 30 to 50 percent of the algal material to his bodily needs. During World War II, the United States made intensive studies of plankton as food and recommended its use as food for downed aviators or shipwrecked persons. Plankton nets were made part of survival kits.

An unprecedented increase in the world population during the past century has caused scientists to estimate that by the year 2000 the total will rise from the present 2.7 billion to 7 billion people. Agriculture and known natural resources may be developed adequately to sustain a population of that size, but segments of this horde no doubt will suffer protein and fat deficiencies as they do even now. Looking to the future, one can envisage a world with 50 billion or more people. Sometime during this tremendous expansion, a critical worldwide food shortage is certain to occur. Then, or before--depending upon current technical knowledge--harvest or culture of phytoplankton must be undertaken to ensure survival of the populace.

Man is not likely to compete soon with fish for the plankton of the sea. Collection of plankton there is impractical now because the tiny creatures rarely are sufficiently concentrated to support a commercial enterprise. On the west coast of Scotland, where the growth of plankton is particularly rich in the lochs and estuaries, a total of 525 pounds (dry weight) of plankton was procured with 10 nets[4] hung

[4] The nets were necessarily of fine mesh cloth in order to catch plankton but the exact size of mesh and dimensions of the net were not given in the article published. The amount of water filtered was not measured.

collecting 12 hours each through a strong flood and ebb tide sequence. The plankton taken was considered sufficient to feed 357 people a meal. It is not known whether equivalent amounts could be obtained anywhere along the American coast. Heavy concentrations of plankton exist in polar regions, but harvesting these would be hazardous owing to adverse weather and would entail the added expense of transporting the catches long distances for use in the populous areas of the world, although the bulk could be reduced to a minimum by dehydrating the catch aboard factory ships. Cropping plankton on a large scale for human food might critically reduce the food supply of fish, lobsters, clams, whales, and other fishery resources which now produce a worldwide annual yield of 45 to 60 million tons of choice foods. Yet some authorities estimate that only about 10 percent of the ocean's annual production is now being used, that the present harvest could be increased from 1-1/2 to 10 times by the use of more effectual fishing gear, and that production could be increased even more by cultivation and fertilization of the water masses.

Man scarcely can afford to jeopardize the continuance and improvement of this food supply from the seas, lakes, and rivers by competing directly with the aquatic animals for their food. He may, more wisely, supply his growing needs by cultivating the plankton ashore in automated factories established near markets, thus eliminating the problem of collecting under adverse weather and sea conditions.

Phytoplankton can be cultured in vats wherever water and proper light, temperature, and nutrients are available, and the organisms can then be floated off the nutrient into handy containers. The single-celled alga, Chlorella, which has the capacity for rapid growth, is particularly well suited to artificial culture. With suitable media and an appropriate apparatus, a bloom can be generated as often as nine times daily and these blooms can be repeated indefinitely. When algal food for human consumption is produced under controlled conditions, yields will be high and crops can be harvested continuously by mechanical means requiring a minimum of human labor. Culture of algae in the future may become a big business.

At present, great strides are being made toward producing, in a closed ecological system with only a small amount of electrical energy, sufficient algae to satisfy the food requirements of one man in space travel and to convert his wastes into nutrients for the algae.

Purification of Water Supplies

The health of the people in a community is influenced by the purity of the water they drink; moderate numbers of algae help purify lake and stream waters. Algae use as nutrients nitrogen and phosphorus compounds that have been washed from the land, and convert into oxygen the carbon dioxide dissolved in the water from the atmosphere and from the decay of submerged organic matter. Blooming plankton, because they feed on the inorganic solutes, actually change the chemical composition of the water. Nitrogen and phosphorus compounds normally are not abundant in most surface waters, and a real scarcity of either compound slows the growth of algae, thus gradually diminishing their value for purification as the season progresses.

Excessive enrichment (pollution) of water supplies, and consequent blooms of algae, has emerged as a major problem in the purification of water for human consumption in recent times. The rate of removal of nutrient materials by biological means is dependent upon the kind of planktonic organisms present and upon the environmental conditions; consequently, the actual performances have been erratic and unpredictable. Light intensity is one of the critical factors. The minimum requirement to produce rapid biological extraction of phosphate appears to be about 100 to 200 foot-candles. Under normal conditions adequate light intensities seldom are attained in algal cultures in excess of a foot below the surface; if the water is deeper than that, the illumination decreases sharply. For these reasons, in the treatment of wastes from urban areas the purest water and the greatest return of nutrients are obtained in industrial plants where the best environmental conditions for the algae and the most active species can be maintained.

High fertility of the water need not necessarily generate noxious blooms. On the Eniwetok coral reefs, where community production was well balanced, E. P. Odum was impressed not only by the importance of water movement, but by the intimate association of algae with the corals and with many other animals. This association was a highly developed symbiosis (living together) of organisms, some (i.e., green plants, some bacteria, and true fungi) able to feed on simple inorganic substances and others (i.e., animals, some bacteria, and true fungi) dependent on complex organic food materials which have originated in other plants and animals. In this environment lived, in addition, a large standing crop of consumers including great numbers of herbivorous fish, which, Odum believed, "were capable of consuming algae as fast as produced." This is an ideal situation with no outside pollution that could not be duplicated in the effluent from a modern city.

Odum suggested that man "get into the food chain" at the primary level not only to alleviate his crying need for additional foods but, at the same time, to, "make use of the increased productivity created by cities rather than attempting to destroy it." Man, then, would be an important factor in the purification of his own drinking water. Appropriate planktonic organisms would consume objectionable inorganic solutes in the water, use them in the manufacture of proteins, and then be eaten by man. The purified water could also be consumed safely by man.

Industrial Uses

The importance of planktonic organisms to mankind does not end with their death. The shells of certain groups of these organisms have sunk to the bottom of the sea for millions of years. In some localities, these shells became fossilized and were eventually raised above the surface of the water by movements of the earth's crust. The uses made of some of these materials are essential to our modern way of life.

Diatoms--diatomaceous earth.--Deposits of fossil diatoms, called diatomaceous earth, have many industrial uses. The oldest use is as a powder for polishing metals and cleaning kitchen utensils. Because of its porosity, diatomaceous earth is used as an absorbent for nitroglycerine in the manufacture of dynamite, and as a filter for liquids, especially in the refining of sugar and in the manufacture of rubber. Diatomaceous earth is also used to insulate blast furnaces and to strengthen concrete.

Foraminifera--chalk and limestone.--Another well-known commodity that owes its origin to the plankton of ancient seas is the chalk so widely used by teachers and students. Huge chalk deposits, formed by shells of dead Foraminifera (especially Globigerina and its allies), are the famous Cliffs of Dover, England; Fort Hayes Chalk in Kansas; Niobrara Chalk in Nebraska; and other deposits in Alabama, Mississippi, and Tennessee.

The shells of Foraminifera also contributed much to the formation of calcareous rock or limestone. Limestone has many commercial uses, including the making of the most important building materials of our time--directly as stone blocks and marble, and indirectly in steel, cement, and plaster. It is also used in building roads and for reducing the acidity of soils in agriculture.

The Foraminifera that contribute to the formation of limestone are strange little one-celled animals that secrete calcareous shells around themselves. As they grow larger, they build and move into progressively larger chambers which usually are arranged in a spiral. The name Foraminifera, from the Latin foramen (a hole) and fero (to bear), was given the organism because the shells are perforated by a large number of small holes through which are extended slender strands of protoplasm called pseudopodia. Outside the shell, these protoplasmic strands branch and interweave to form a living network which resembles a spider's web but operates very differently; it is both the spider and the web. When a victim is caught in this sticky web the strands of the net pour out digestive juices that convert the prey into a solution or emulsion which passes into the protoplasm of the foraminiferan.

Not all Foraminifera have been tiny. The Camerina, which reached its peak of abundance in rather recent geologic time but is now extinct, attained a diameter of 7-1/2 inches. Its shells formed limestone in Europe, Asia, and northern Africa.

All plankton--petroleum.--The origin of petroleum (rock oil) is still a mystery to authorities in geology, chemistry, and astronomy who have spent many years studying it. Two opposing theories have been advanced: (1) that the oil was formed from inorganic substances during volcanic action and later seeped into sedimentary rocks, and (2) that it was formed from organic substances leached from decaying plants and animals. The latter theory was advanced first and is still held by most scientists. If this is the true origin of oil, then microscopic algae may have been an important, if not the most important, source of petroleum in sediments from paleozoic to tertiary time. The shells of radiolarians, foraminifers, and diatoms are present in sediments closely associated with oil.

Petroleum is of prime importance in the world today. A tremendous variety of important products are derived from crude petroleum, many of which are essential for development of the activities of modern civilization. Natural gas, gasoline, diesel oil, fuel oil, and lubricating oils and greases are used to heat buildings in cold climates, to provide heat for cooking, and to power and lubricate high speed motors that make possible modern rapid transportation on land and sea, and in the air. They also supply heat and power for the operation of most industries. Other important products are: asphalt to build smooth roads; synthetic rubber to provide tires for automobiles that travel these roads; antifreeze preparations to protect the cooling systems of the cars in freezing weather; soaps and antiseptics for sanitation and cleanliness; paints, paint driers, a turpentine substitute; auto, furniture, and metal polishes to protect surfaces and enhance beauty; inks for writing; and fertilizers to improve yields of food crops. In addition there are medicines, explosives, solvents, acids, carbon bricks, and many other products too numerous to mention here.

Aid to Science

Geologists have spent much time attempting to learn the age of the world and to date events that have led to the development of the present land masses. Some recent advances in this knowledge depended on determination of the age of fossil shells of planktonic organisms by the radiocarbon technique. This method measures the amount of radiocarbon remaining in a sample of the shells. Studies of fossil diatoms in deposits such as the one at Lompoc, Calif., have yielded much valuable information.

A complete time scale, determined by radiocarbon study of cores bored from deep-sea sediments, dates the beginning of the ice age at about 1-1/2 million years ago. Well-defined changes in the abundance of the shells of certain species of Foraminifera in cores from the equatorial Atlantic and around the world give a legible record of major climatic events during the ice age.

Intensive oceanographic studies now being organized cooperatively by many nations and the international expeditions of recent years[5] are expected to add much new information about the sea and its inhabitants. No doubt, new uses for plankton will be developed as a result of this greater knowledge.

LUMINESCENCE

A boat ride after dark at sea is pure delight when the bow wave and the wake behind the boat sparkle with tiny points of light known as luminescence. If the boat happens to be small, reach into the water; your hand will come out with some of the points of light clinging to it. Rub your hands gently together and feel small prickles. Put the bits of light into a drop of water under a microscope, and the wonderful world of dinoflagellates comes to life for you. Think then, as many others have done, how light is produced by these small creatures. The chemical nature of their photogenic cells was still unknown as recently as 1962. The dinoflagellates, minute animals or plants (experts disagree), are characterized by the presence of two flagella in grooves (see Peridinium and Ceratium, fig. 1). Usually the body is covered by a cellulose shell. Many of these strange little creatures possess photosynthetic pigment but cannot exist without organic food; they are able to survive indefinitely without light if all required food elements are present.

The most common luminescent flagellate is Noctiluca scintillans, which is 12 percent dry matter in the form of granules that are believed to be the source of luminescence upon mechanical or chemical stimulation. A number of other dinoflagellates--Gymnodinium, Ceratium, and Gonyaulax--also emit light in response to similar stimuli. These luminescent flagellates are widely distributed in salt water.

[5] Examples are the International Indian Ocean Expedition and the International Cooperative Investigations of the Tropical Atlantic.

HARMFUL EFFECTS OF PLANKTON

Waters that receive domestic and industrial wastes containing large amounts of nitrogen and phosphorus compounds often nourish heavy growths of algae. The algae may interfere at such times in manufacturing processes and in the operation of city water plants by clogging filters, and also may decrease recreational and esthetic values of shore property by producing unsightly accumulations in the water at bathing beaches and boating areas. Although algae use carbon dioxide and produce oxygen in photosynthesis during their short life span, the decay of large concentrations of their dead cells frequently depletes the oxygen in the water. Massive fish-kills may result. The decay of algal masses occasionally gives disagreeable tastes and odors to city water supplies and sometimes releases sufficient hydrogen sulfide into the air to discolor paint on boats and on nearby houses.

Some species of algae produce toxins injurious or fatal to animals. One of these, Gonyaulax catenalla, when eaten by sea mussels and clams, produces an alkaloid substance that is harmless to the bivalves but is poisonous to the people who eat them. Many cases of illness and some deaths have been reported from this so-called mussel-poisoning.

REFERENCES

ABRAMOVA, V. D.
1956. Plankton as an indicator of waters of different origin in the North Atlantic seas. Tr. Polyarn. Nauch.-issled. Inst. Morsk. Rybn. Khoz. i Okeanogr., No. 9:69-92. In Russian. Transl. avail. in U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 327: 77-103.

ALFIMOV, N. N., and O. G. MIRONOV.
1958. The effect of diatomaceous plankton of rivers on certain chemical indices of water contamination. Bot. Zhur. 43-(12): 1763-1765.

AL'TOVSKII, M. E., Z. I. KUZNETSOVA, and V. M. SHVETS.
1961. Origin of oil and oil deposits. Russian text published by Gostoptekhizdat, the State Scientific and Technical Publishing House of the Petroleum and Mineral-Fuel Industry, Moscow, 1958, vii + 107 p. Transl. avail. Consultants Bureau Enterprises, Inc., 227 W. 17th St., New York, N.Y.

BIGELOW, HENRY B.
1924. Plankton of the offshore waters of the Gulf of Maine. Bull. U.S. Bur. Fish. 40(2), 1027 p.

BROWN, HARRISON.
1958. The challenge of man's future. The Viking Press, New York, xii + 290 p.

COLLIER, ALBERT.
1958. Some biochemical aspects of red tides and related oceanographic problems. Limnol. Oceanogr. 3(1): 33-39.

DEEVEY, EDWARD S., Jr.
1952. Radio-carbon dating. Sci. Amer. 186-(2): 24-28.

GALTSOFF, PAUL S.
1964. The American oyster, Crassostrea virginica Gmelin. U.S. Fish Wildl. Serv., Fish. Bull. 64, iii + 480 p.

GUNTER, GORDON, ROBERT H. WILLIAMS, CHARLES C. DAVIS, and F. G. WALTON SMITH.
1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. Ecol. Monogr. 18(3): 309-324.

HERDMAN, WILLIAM A.
1891. Copepoda as an article of food. Nature 44(1134): 273-274.

HUTTON, ROBERT F.
1956. An annotated bibliography of red tides occurring in the marine waters of Florida. Quart. J. Fla. Acad. Sci. 19-(2-3): 123-146.

KRALL, A. R., and B. KOK.
1960. Studies on algal gas exchangers with reference to space flight. Develop. Industr. Microbiol. 1: 33-34.

McELROY, WILLIAM D., and HOWARD H. SEILIGER.
1962. Biological luminescence. Sci. Amer. 207(6): 76-89.

McHUGH, J. L.
1962. How much fish can the oceans produce? A talk presented to the American Fisheries Advisory Committee, Bureau of Commercial Fisheries, Washington, D.C., May 24, 1962.

ODUM, EUGENE P.
1961. Factors which regulate primary productivity and heterotrophic utilization in the ecosystem. In Algae and Metropolitan wastes, p. 65-71. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

PHILLIPS, J. NEAL, Jr.
1962. Closed ecological systems for space travel and extra-terrestrial habitation. Develop. Industr. Microbiol. 3: 5-13.

POLUNIN, NICHOLAS.
1942. Some proposals for the war-time use of plankton. Chronica Bot. 7(3), p. 133.

RUEDEMANN, RUDOLF.
1934. Paleozoic plankton of North America. Geol. Soc. Amer., Mem. 2: 1-141.

SMITH, GILBERT M.
1933. The freshwater algae of the United States. McGraw-Hill Book Company, Inc., New York and London, 716 p.

STANSBY, MAURICE E., and JAMES M. LEMON.
1941. Studies on the handling of fresh mackerel (Scomber scombrus). U.S. Fish Wildl. Serv., Res. Rep. 1, 46 p.

STORER, TRACY I., and ROBERT L. USINGER.
1957. General zoology. 3d ed. McGraw-Hill Book Company, Inc., New York, N.Y., vi + 664 p.

SVERDRUP, HARALD ULRIK, MARTIN W. JOHNSON, and RICHARD H. FLEMING.
1942. The oceans, their physics, chemistry, and general biology. Prentice Hall Inc., New York, N.Y., x + 1087 p.

U.S. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEX.
1961. The Florida red tide. U.S. Fish Wildl. Serv., Fish. Leafl. 506, 8 p.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE.
1961. Algae and metropolitan wastes. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 162 p.

WALFORD, LIONEL A.
1958. Living resources of the sea. The Ronald Press Company, New York, N.Y., 321 p.

WARD, HENRY BALDWIN, and GEORGE CHANDLER WHIPPLE.
1959. Fresh-water biology. John Wiley and Sons, Inc., New York, 2d ed., edited by Walter Thomas Edmondson, xx + 1248 p.

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