boscides to the edge of the oyster's mantle and feed on the mucous and tissues. These ectoparasites are probably a great nuisance to the oyster, but there is no evidence that they can be regarded as important enemies. Two species have been found associated with *C. virginica: O.* (*Menestho*) *bisuturalis* Say which has a range from New England to Delaware Bay, and *O.* (*Menestho*) *impressa* Say which is found from Massachusetts to the Gulf of Mexico.

Starfish

The starfish of the Atlantic Coast is also a highly destructive predator on oysters. The common species, *Asterias forbesi* (Desor), is the most familiar animal in tidal pools, on rocks, and beaches of the Eastern Coast of the United States, often found exposed by the receding tide. Accurate statistics of the destruction caused by this species are not available, but a few selected examples emphasize its deadly efficiency. In 1887 the State of Connecticut estimated the loss caused by starfish at $463,000; the sum represented the destruction of over 634,246 bushels of oysters or nearly half of the total harvest for the year (1,376,000 bushels). The numerical strength of a starfish population over a relatively small area can be visualized from the record of only one company which in 1929 removed over 10 million adult starfish from 11,000 acres of oyster grounds in Narragansett Bay.

As a rule the starfish populations on various parts of the coast fluctuate within wide limits with years of great abundance usually followed by relative scarcity. These fluctuations cause many oystermen to believe that starfishes invade their grounds periodically. Studies of the problem conducted simultaneously in Buzzards Bay, Narragansett Bay, and Long Island Sound (Galtsoff and Loosanoff, 1939) demonstrated that sudden increases in the abundance of *A. forbesi* are due primarily to the high percentage of survival of its free-swimming larvae and their successful setting (fig. 397).

The reproductive season of *A. forbesi* in New England waters slightly precedes that of *C. virginica*. When oyster larvae reach setting stage, the space available for their attachment is already occupied by young starfishes only several mm. in diameter, hungry, and ready to attack the spat. The new set of oysters may be completely wiped out by young starfish.

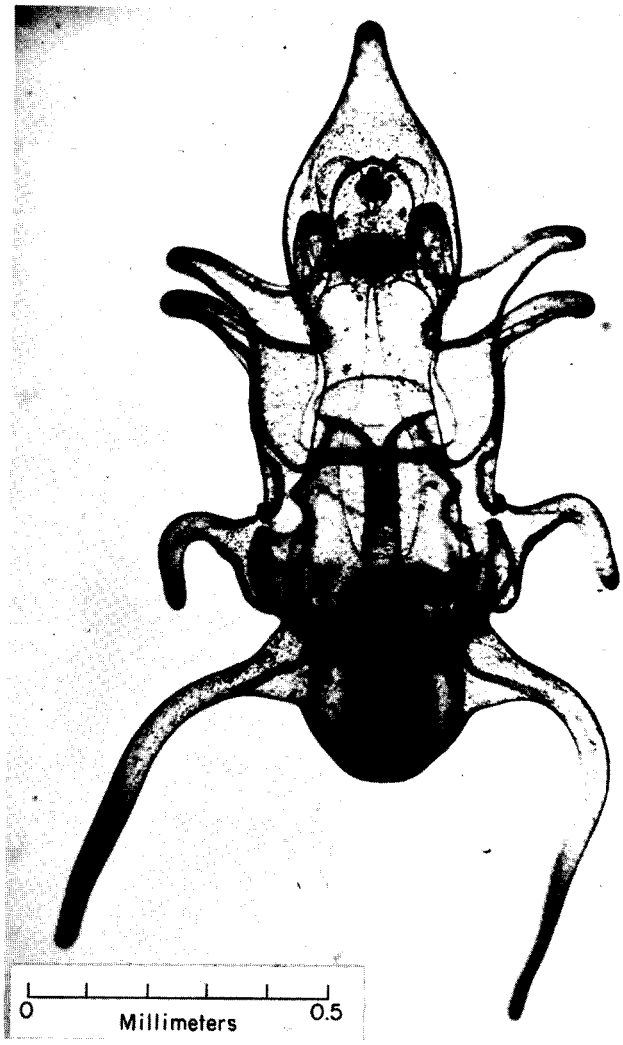

FIGURE 397.—Photomicrograph of live larva, brachiolaria, of *A. forbesi* from a plankton tow in Buzzards Bay.

The movements of *A. forbesi* in concrete tanks are slow, random, and apparently not directed by tactic reactions. Initially it was difficult to reconcile this fact with the experience of oyster growers in Long Island Sound who reported that oyster bottoms thoroughly cleaned by mopping or dredging were invaded within the next 24 hours by swarms of starfish. Underwater observations were made in Long Island Sound by members of the Bureau of Commercial Fisheries Biological Laboratory in Woods Hole who used an underwater television camera. The underwater photographs showed clearly that starfishes are passively transported by the tidal currents which in Long Island Sound are fairly rapid. The animal curls up the tips of the rays, releases its hold on the substratum, and floats just above the bottom.

Many thousands of starfish are transported in this way from place to place and settle on new grounds when tidal currents slacken.

The starfish leaves no identifying marks on its victim, and only empty shells remain as evidence of a destructive attack. The recent death of oysters is indicated by the cleanliness of the valves, which contain no foreign growth and are still attached to each other. The method by which the starfish succeeds in forcing oysters or clams to relax their muscles and open the valves has puzzled biologists for a long time. It seemed doubtful that the starfish could exhaust its victim and open it by main force, and suggestions were made, not well corroborated by observations, that the prey was killed by suffocation or that a substance secreted by the stomach of the starfish produced relaxation of the adductor muscle of the oyster. Sawano and Mitsugi (1932) reported that an extract of starfish stomachs poured over the heart of living molluscs produced tetanus and often inhibited the heart beat; this seemed to give some support to the "anesthetic" hypothesis. Critical experiments made in Woods Hole by Lavoie (1956) show, however, that the effects of extracts prepared from digestive organs of starfish and introduced into the adductor muscle or poured over the heart of *Mytilus* were generally identical with those produced by plain water. On the other hand, the force exerted by the tube feet of starfish in opening shellfish was measured manometrically and was found to exceed 3,000 g. The measurement was made using mussels in which the adductor muscles were severed and replaced by steel springs or plastic cylinders.

Lavoie noticed that a tiny opening of about 0.1 mm. between the valves of the mollusks was sufficient to permit the insertion of starfish stomach. The pulling of valves apart is probably repeated at intervals while the stomach remains partially compressed. The observations of Feder (1955) on *Pisaster ochraceus* show that this starfish can open its prey by force alone. Another Pacific Coast species, *Evasterias troschelii*, was found to exert a force in excess of 5,000 g. during an attack on artificial clams baited with *Mytilus* meat (Christensen, 1957). The fact that starfishes are able to open mollusks by force alone does not eliminate the possibility of an additional narcotizing effect produced by starfish secretion. The problem of how the starfish opens its prey has not yet been finally solved, although present evidence favors the mechanical hypothesis.

Not all starfishes feed by everting their stomachs and digesting the body of the victim without ingesting it. Many of them are scavengers feeding on dead animals found on bottoms while others are capable of catching and consuming live fishes. Many interesting cases of starfish attacks on various marine animals including fishes are described by Gudger (1933).

Starfish are usually found in water of high salinity and do not invade the oyster grounds in brackish waters. The salinity level between 16‰ and 18‰ below which *A. forbesi* cannot exist is a natural barrier to the distribution of this species. This conclusion is based on field observations along the Atlantic coast and on experiments at the Bureau of Commercial Fisheries Biological Laboratory, Milford, Conn. (Loosanoff, 1945). In New England waters, starfish are controlled by mopping or dredging to remove them, and by dispersing calcium oxide and other chemicals to kill them or to make a protective chemical barrier around an oyster bed.

Flatworms

Turbellarians of the genus *Stylochus* and *Pseudostylochus*, commonly known as oyster leeches, are predators which attack adult and young mollusks and frequently inflict serious damage to oyster populations. In 1916 and 1917 attacks of *Stylochus* on oysters in Cedar Keys on the west coast of Florida killed about 30 percent and in one or two localities 90 percent of the adult oysters. The mortality of oysters in Apalachicola Bay, Fla., allegedly caused by the "leech," was investigated for the U.S. Bureau of Fisheries by Pearse and Wharton (1938), who could not state definitely that the distruction was due to *S. inimicus* Palombi[10] and suggested that the oysters were first weakened by some unknown cause and that *Stylochus* invaded those which were unable to protect themselves. *S. frontalis* tolerates water of low salinity (6‰), but according to Pearse and Wharton does not lay eggs in salinities less than 15‰.

S. ellipticus (Girard), found in Atlantic coastal waters and also reported from the Gulf (Hyman, 1939, 1954), lives among oysters, shells, barnacles, and rocks. The turbellarian was reported to destroy young oysters on the flats at Milford,

[10] The identification was corrected by Hyman (1939) who found that the Florida leech belongs to the species *S. frontalis* Verrill.

Conn. (Loosanoff, 1956). Apparently it has no difficulty in entering oyster spat through the slightly opened valves. On the Pacific coast, the flatworm *Pseudostylochus ostreophagus* Hyman (Hyman, 1955) was reported to cause mortalities of from 6 to 42 percent among the imported Japanese seed oysters on various grounds. The worm bores keyhole perforations in the shells of young oysters (Woelke, 1957).

Crabs

Ryder (1884) was the first to include the blue crab, *Callinectes sapidus* Rathbun, and the common rock crab, *Cancer irroratus* Say, in the list of oyster enemies. He quoted complaints of oystermen working in Great South Bay, Long Island, N.Y., who stated that the crabs eat small oysters up to the size of a 25-cent coin and invade the the oyster planting grounds.

For many years crabs were not mentioned in oyster literature as potential enemies, but in the 1930's and 1940's there were reports from the U.S. Bureau of Fisheries Biological Laboratories at Milford, Conn., and at Pensacola (Gulf Breeze), Fla., that under certain conditions the blue crab, the rock crab, and the green crab, *Carcinides moenas* (Linneaus) destroyed oysters kept in outdoor tanks or placed in baskets with the crabs. Lunz (1947) reported that at Wadmalaw Island, S.C., the blue crab was probably the most serious pest in 1946 and destroyed more than 80 percent of the young oysters set on collectors. The crab's diet includes a great variety of food, including oysters. There is no evidence that they are attracted specifically by oysters, but it is apparent that they may destroy many small oysters in clusters by cracking their shells.

Mud prawns and fish

Brief mention should be made of the family Calianassidae (genera Upogebia and Callianassa), popularly known as "mud prawns" or "burrowing shrimps", which excavate deep burrows under oyster bed dikes. This activity drains water from the grounds, exposes the beds of *O. lurida*, and smothers the young oysters with material thrown up in burrowing (Stevens, 1928).

In the southern waters of the Atlantic coast, oyster beds are often invaded by schools of black drum, *Pogonias cromis* (Linnaeus), which feed on mollusks and occasionally cause extensive destruction of oysters, leaving behind piles of crushed shells. The fish uses its powerful pharyngeal teeth to crush the shells (fig. 398).

The diamond stingray of the Pacific coast, *Dasyatis dipterurus* (Jordan and Gilbert), also devours oysters, crushing them with powerful teeth. To ward off attacks by this fish, oyster grounds in California are surrounded by high fences, a practice used for the same purpose by French oystermen.

Birds

Various species of ducks are enemies of small *O. lurida* of the Puget Sound area. The extent of damage to oyster grounds near Olympia, Wash., was estimated in the fall of 1928 by the United States Biological Survey. McAtee, who conducted the field studies, reported (quoted from Galtsoff, 1929) that at that time 87 percent of the bluebills (*Nyroca marilla* and *N. affinis*) fed principally on oysters, which comprised 80.5 percent of the bulk of the food found in their stomachs. In 38 percent of white-winged scoters

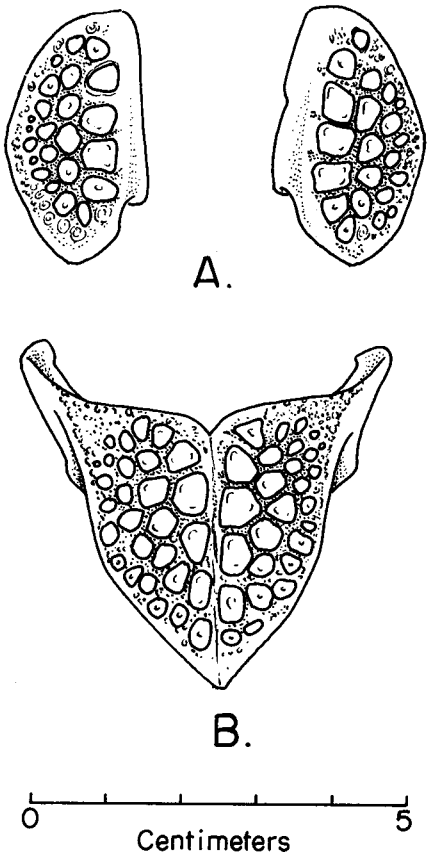

FIGURE 398.—Pharyngeal teeth of small size black drum *P. cromis*, used for crushing oyster shell. A—upper teeth; B—lower teeth.

(*Melamita deglandi*), about 70 percent of their stomach contents consisted of oysters. The number of birds in the Olympia Bay of Puget Sound during the 2-week period of daily observations (November 16–29, 1928) averaged 2,000. Together the three species of ducks were destroying about 8,000 oysters per day and causing material damage to the small oyster industry of the area.

The effect of predators on an oyster population can be evaluated by determining the percentage of oysters killed.

Man

Among the highly destructive predators of oysters, man occupies the most prominent position. Long before our era the stone age dwellers of the coast of Europe subsisted primarily on shellfish which they gathered from shallow water by wading and hand picking. The American Indians used oysters and clams for food, and dried and smoked shellfish meat for the food supplies which they took on their travels. On both continents numerous shell heaps or so-called kitchen middens dot the coastline and indicate the locations of primitive habitations or camp sites. A famous shell heap on the banks of the Damariscotta River, Maine, and many others are evidence of the former productivity of the oyster beds of past centuries. With the development of oyster fishing gear, man became able to gather oysters much more efficiently and extended his efforts to deeper water. Oyster dredges of various designs and dimensions remained for a long time the principal and very effective gear, until the appearance in the last quarter of a century of various mechanical suction pumps and other harvesters of much greater efficiency.

With the improvement of fishing methods, the oyster bottoms of the northern States became overfished and many were depleted. This was the fate of many oyster grounds along the shores of the Gulf of Maine, in New Hampshire, Massachusetts, and Rhode Island. In colonial times the earliest white settlers of New England feared the disappearance of their favored seafood and saw the necessity of protecting their shellfish resources by such legislative measures as restricting the size of catch and prohibiting the selling of oysters out of town. The results were ineffective, and many oyster bottoms, particularly in the northern part of New England, were destroyed.

The world's richest oyster bottoms in the Chesapeake Bay suffered a similar fate, but the depletion was more gradual and not as complete as in more northern waters. Regulations prohibited power dredging and set aside certain areas for the use of tongers only, but they were not sufficient to maintain the productivity of the oyster bottoms. The production of oysters continued to decline because of a general disregard of the basic conservation principle that the sustained yield of any renewable natural resource can be maintained only if the quantity removed does not exceed the quantity restored annually by reproduction and growth. Throughout the world the shellfish resources are depleted when more are taken than nature is able to replace.

Man must be regarded, therefore, as the most dangerous predator. On the other hand, through his action the productivity of an oyster bottom can be brought to the highest level. Since ancient times it has been known that oysters can be propagated and cultivated. The development of oyster culture in this country was particularly successful in the waters of Long Island Sound where the depleted shellfish resources were not only restored by oyster farming, but many thousands of acres of previously barren bottom were converted into productive farms under water. Thus, man as an ecological factor appears in a dual capacity—as a primitive destructor and as a progressive cultivator. Unfortunately, at present Long Island Sound is no longer a highly productive oyster farming area. The decline may be attributed to poor setting, low survival rate of young oysters, devastation caused by several hurricanes, and the high cost of farming operations.

At present the knowledge of oyster biology has advanced to such a level that effective methods can be employed both for sound management of natural, wild populations of oysters, and for development of highly productive farms for breeding selected strains of oysters. The continuous decline of oyster beds is due not to a lack of knowledge but to failure to apply it.

Aquatic resources of the tidal areas along the Atlantic and Gulf coasts of the United States are threatened by human activities other than overfishing. Many formerly productive areas of the coast have been damaged beyond reconstruction by the filling of marsh lands for industrial sites, by the construction of thruways, marinas, real estate developments, and trash and garbage dis-

posal areas, by ever-increasing discharge of domestic sewage and trade wastes, and by numerous contaminants which reach natural waters as a result of widespread and nonselective use of insecticides and pesticides. Danger from the discharge of radioactive materials from nuclear plants and the disposal of low level radioactive wastes in the sea not far from shore presents a new and serious threat to the usefulness of the renewable aquatic resources of coastal areas.

Some of the changes produced by man such as improvement of coastal waters for navigation, construction of hurricane barriers, use of tidal land for building of industrial plants are consistent with rapid population growth and industrialization. Other changes, such as pollution, destruction of natural oyster beds by failure to return shells and other materials needed for the attachment of young oysters, and overfishing are unnecessary and should be avoided.

A balance between the needs associated with industrial progress and population pressure on one side, and effective conservation of natural aquatic resources on the other can and must be found.

POLLUTION

The pollution problem is complex. It has many facets that should be studied from social, economic, and biological points of view. An investigation of the biological aspects of pollution, discussed in this section, deals with the complex ecological relationship between the life in the tidal areas and the environment affected by the addition of a number of organic and inorganic contaminants.

One of the major difficulties encountered in studies of the biological effects of pollution is the lack of a generally accepted definition of the term. Pollution means different things to different people: to a Public Health officer pollution implies a potential health hazard caused by the discharge of domestic sewage and industrial waste; an engineer of a manufacturing plant is primarily concerned with the quality of water needed for the industry; the conservationist has in mind danger to wildlife and means for its protection; sport and commercial fishermen fear that foreign substances discharged into coastal waters will affect the availability of fish; a marine ecologist tries to find out how the animal and plant life is affected by changes in the environment; and the layman, considering that pollution is synonymous with filthy conditions on beaches and in coastal waters, raises his voice in protest against unsanitary and esthetically objectionable situations.

In court litigations involving damages allegedly caused by pollution, a biologist appearing as an expert for either side is handicapped in his testimony either by lack of a legal definition of pollution or by the generalities used to describe it. No definition of the term pollution is given in the Oil Pollution Acts of 1924 and 1961. The Water Pollution Control Acts of 1948 and 1961 (United States Congress, 1948, 1961) make frequent references to the "abatement of stream pollution" and declare in the 1948 act that pollution is a public nuisance "which endangers the health or welfare of persons in a State other than that in which the discharge originates." The inclusion of the word "welfare" puts emphasis on the economic aspects of pollution and, therefore, increases the scope of the definition.

After conducting a comprehensive study of all available State, Federal, and international pollution laws, the U.S. Public Health Service (1950) prepared the following broad definition of pollution:

> "Pollution" means such contamination, or other alteration of the physical, chemical or biological properties, of any waters of the State, or such discharge of any liquid, gaseous or solid substance into any waters of the State as will or is likely to create a nuisance or render such waters harmful or detrimental or injurious to public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish or other aquatic life.

Although this definition is broad and useful, it has not been incorporated in existing Federal statutes and, therefore, lacks legal weight.

The amount of waste discharged into coastal waters of the United States from municipalities and industrial plants in the last decade has reached astronomical proportions and is being augmented by runoff water which carries the numerous organic phosphorus and hydrocarbon insecticides used in both control and eradication of agricultural crop-damaging pests. Under present conditions it is probably impossible to find water along our coast which has not been contaminated.

Some pollutants contain highly toxic substances and cause mortalities among marine populations. Others are less toxic and have no lethal effect on adult organisms but decrease the rate of survival of their larvae; decrease the rate of growth of juvenile forms and affect the reproductive capa-

bility of an organism. Sublethal concentrations of such poisons can also destroy one or several links of the food chain in the sea, and so affect the food supply for the population of animals or plants important for human welfare. The normal ecological environment may be so changed that some planktonic organisms, most useful to shellfish as food, disappear and are replaced by a luxurious growth of microorganisms not only useless but even harmful to water-filtering mollusks. Although great advances have been made in the technique of bioassays, the results of short-term tests lasting no longer than 72 hours are of little use in determining the effects of prolonged exposures of fish or shellfish to low concentrations of poison. Furthermore, since the criteria for the welfare of marine populations are not known, it is impossible to set requirements for purification of pollutants before they are permitted to be discharged into the sea. The Federal Water Pollution Control Act of 1961 authorizes the Secretary of Health, Education, and Welfare to organize comprehensive programs of investigation which in the course of years will solve many of the existing pollution problems.

Detailed descriptions of all types of pollution that may affect the productivity of oyster bottoms and methods of their detection and control are beyond the scope of the present chapter, which is limited to a discussion of the general principles applicable to the majority of situations and to a description of the most important types of pollutants encountered on oyster bottoms. Bibliographical references listed at the end of the chapter are limited to the more pertinent papers. Discussions of more specialized pollution problems are listed in a bibliography prepared by Ingram (1957) and also appear in papers published in Tarzwell (1957, 1960).

The production of oysters in the United States is declining at a rapid rate (Galtsoff, 1956). As a sedentary animal devoid of any means of locomotion after setting, the oyster is vulnerable to environmental changes which weaken it and make it less resistant to infection. Under natural conditions unspoiled by human activities, the oyster is in an equilibrium with its environment; this adjustment, which may be called a steady state, is the result of thousands of years of adaptation and natural selection. It may be upset by the sudden presence of materials not normally found in sea water or by excesses or deficiencies of its normal components.

Two types of pollution are commonly found on oyster grounds: domestic sewage and trade wastes. In natural waters both types of pollutants undergo gradual changes which lead to a degree of purification, but at the same time deposit sediments that cover oyster beds and change the character of the bottom. Natural purification is not effective, however, in the case of detergents and radioactive waste, which constitute a growing menace to the safety and purity of our coastal waters.

Domestic sewage

Contamination of water by domestic sewage is the oldest type of pollution; it probably began during prehistoric times when man settled on the shores of the rivers and bays and used natural waters as the easiest and most convenient way of disposing of the excrements and unwanted waste. The problem has reached enormous proportions with the population growth and the necessity of disposing of quantities of domestic sewage in an organized manner.

The discharge of untreated domestic waste has a threefold effect. It covers the bottom with a sludge which smothers the oyster bed, affects the normal functions of mollusks by reducing the oxygen content of the water, and at the same time greatly increases the bacterial content of the water. Oysters, in common with other water-filtering mollusks, retain and accumulate these bacteria in their bodies. The degree of pollution is determined by the abundance of *Escherichia coli* found in the water. The bacterium itself is not pathogenic, but is used as an index of pollution. Procedures for determining the abundance of *E. coli*, the so-called MPN (most probable number), are described in great detail in Jensen (1959). They are strictly followed by State and Federal Public Health Officers and other officials responsible for certifying grounds from which shellfish may be harvested for human consumption. Areas in which the MPN of *E. coli* exceed the permissible maximum of 70 per 100 ml. are condemned and cannot be used for harvesting, but under certain specified conditions the polluted oysters and clams can be taken for planting to an unpolluted area. The presence of *E. coli* above the prescribed MPN eliminates the utilization of grounds for commercial fishery, but does not affect the survival and growth of the oyster population.

Industrial waste

The most common industrial pollutants entering oyster-producing areas stem primarily from the following industries: oil; paper; steel; chemicals; paints; plastics; leather; and food. The character of industrial waste varies with the product.

Because of the increase in the number of oil burning ships and the necessity of transporting crude oil in huge tankers that occasionally break and spill their cargo, oil pollution of the open sea has become a difficult international problem. Although federal and state laws forbid the discharge of oil into coastal waters, many of the bays and harbors of the United States are heavily polluted by oil. Through surface tension oil spilled on the surface of water spreads rapidly into a thin film or oil slick. In muddy waters suspended particles of clay and sand absorb oil, coalesce, and gradually sink to the bottom. In shallow waters oil laden sediment is disturbed by waves, and an oil slick reappears on the surface, sometimes considerable distances from the source of pollution. The absence of an oil slick is not, therefore, a reliable sign that water is not polluted. Crude oil absorbed by sediments retains its toxicity to oysters and other organisms for a considerable time (Chipman and Galtsoff, 1949).

With the expansion of the pulp and paper industry along the Atlantic and Pacific Coasts, pollution of coastal waters by red and black liquors, the waste products of this industry, became serious. Both types of waste contain toxic substances which adversely affect oyster physiology. As in other types of pollution, the discarded material is usually oxidizable and has high oxygen demand. It is, however, only in extreme instances of gross pollution that the oxygen content of the water is lowered to the point that it suppresses the principal physiological functions. Poisons, present in trade waste, are more dangerous than the high oxygen demand because they directly affect the function of the various organs. In spite of great variety in the composition of trade wastes their toxic effect can be demonstrated by constructing a toxicity curve which shows how the pollutant depresses the function that was selected for testing. An oyster heart preparation (see ch. XI, p. 247) can be used conveniently because of the great sensitivity of the heart muscle to many poisons and drugs. Another measurable function is the transport of water by the gills for feeding, respiration, and discharge of excreta. This function ceases when the valves are closed. The presence of pulp mill pollutants reduces the number of hours the valves are open in proportion to the concentration of toxic substances in the water. Under normal conditions and at temperatures of 60° to 70° F. oysters remain open on an average of 20 to 22 hours a day. If the logarithm of concentration of black liquor or crude oil extract is plotted against the number of hours closed, the relationship can be expressed by a straight line as shown in fig. 399. Toxic substances of pulp mill effluents and the extracts of crude oil affect the frequency of ciliary beat and so interfere with the coordination of ciliary motion with the result that the pumping capacity of the gills is reduced. The reduction is proportional to the concentration of physiologically active materials (fig. 400). This type of relationship was found in studies on the pollution of oysters by red and black liquor and by water soluble components of crude oil (Galtsoff, 1931b; Galtsoff, Chipman, Engle, and Calderwood, 1947; Chipman and Galtsoff, 1949). The observations on crude oil are in agreement with data reported

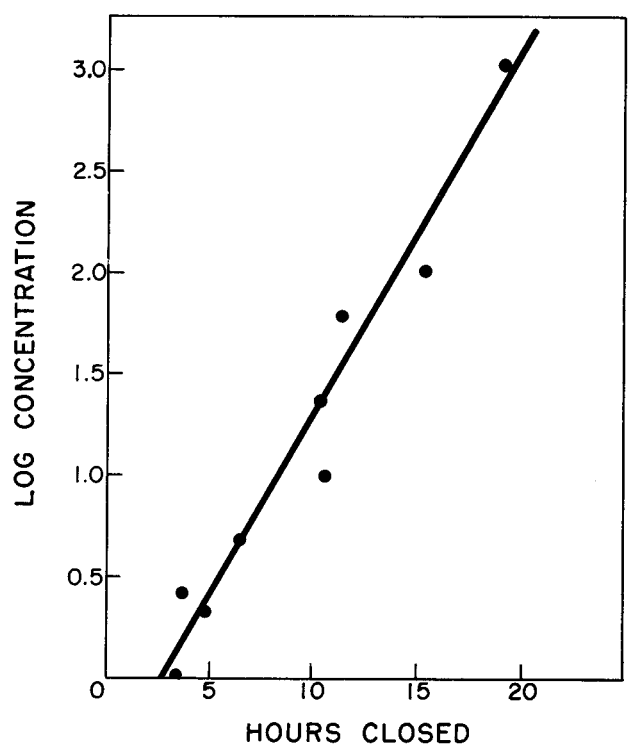

FIGURE 399.—Effect of concentration of pulp mill effluent discharged into the York River on the number of hours oysters are closed during every 24-hour period. From Galtsoff, Chipman, Engle, and Calderwood, 1947.

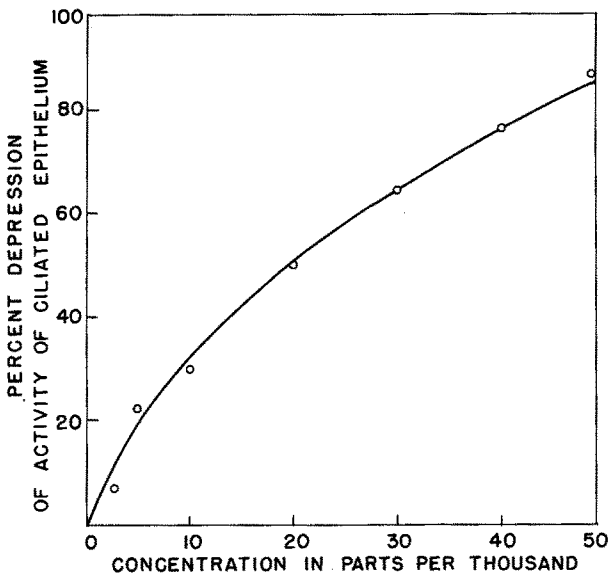

FIGURE 400.—Depression of the activity of ciliated epithelium of oyster gill by increased concentration of pulp mill effluent (black liquor) of specific gravity 1.0028. From Galtsoff, Chipman, Engle, and Calderwood, 1947.

by other investigators (Seydel, 1913; Veselov, 1948) on the toxicity of crude oil to fishes.

Determination of the toxicity of some pollutants is difficult because they may be present in such low concentrations that they are near or below the threshold of sensitivity to chemical methods. Their presence in even minimal quantities should be considered potentially dangerous to sedentary animals unable to avoid them. Another detection problem is that in many industrial plants the discharge of effluents is not continuous but is frequently interrupted or made during the night and early hours of the morning. Pollution studies must include taking composite samples of water with automatic samplers over a period of several hours. Some contaminants are unstable; after being discharged into sea water they are gradually oxidized, precipitated, neutralized, and become less harmful. The rate of this self-purification of water depends on many conditions, temperature, salinity gradient, sedimentation, and currents. To avoid inconsistencies in results, toxicity tests with such materials should be carried out only with stabilized samples (Odlaug, 1949).

Bioassays made within a few days indicate the presence or absence in water of a physiologically active substance but do not determine whether the pollution is lethal to the animal. Long-term field and laboratory observations are needed to determine the lethal effects of a low concentration of pollutants.

Ecological studies in polluted waters show that under certain conditions the normal environment may be modified by the contaminant and become unsuitable for growth and reproduction of oysters. Pollution of Shelton Bay, Puget Sound, Wash., with red liquor discharged by a local pulp mill boosted the production of the diatom *Melosira* sp. to such an extent that the beds of *O. lurida* in the bay became covered with a thick layer of this fouling plant. A similar effect occurred in laboratory tests with red liquor made by Odlaug (1949). Oysters affected by red liquor were useless because of their poor quality and poor taste; their reproduction stopped completely. Normal conditions were restored after discharge of the pollutant was discontinued (McKernan, Tartar, and Tollefson, 1949).

The biologist who studies pollution of natural water should remember that there is no harmless pollution. All types of pollution are harmful to marine populations; only the degree of their effects differs. Frequently it is claimed that the enrichment of sea water by phosphates, nitrates, carbohydrates, and other organic matter is beneficial and will tend to increase productivity. In the case of water pollution by duck farms in Moriches Bay, Long Island, N.Y., indiscriminate pollution by duck manure caused an imbalance of nutrient salts and boosted the outbreak of microorganisms which had an adverse effect on shellfish (Redfield, 1952). Useful enrichment of sea water can be achieved only by controlled and balanced fertilization.

Oxidation is important in reducing or destroying the toxicity of certain contaminants of sea water (Galtsoff, Chipman, Engle, and Calderwood, 1947). The efficiency of oxidation is influenced by temperature and by the manner in which the pollutant is added to the water. Preliminary storage in tanks is helpful in removing objectionable solids, and cascading the effluent from storage tanks to the place of discharge will expedite its oxidation. The U.S. Public Health Service found that 10,400 factory outlets in 1950 were pouring their waste into natural waters of the United States; only 657 of them had waste treatment plants of adequate capacities. In about 30 percent of the plants, the method of treatment was unsatisfactory. The number of plants which at present discharge their

waste into coastal waters and the amount of waste are not known.

Radioactive waste

The disposal of radioactive waste in the sea presents a new threat to shellfish resources; the concentration of radioactive materials in the bodies of water-filtering mollusks may render them unsafe for human consumption. Chipman (1960) showed that many of the radionuclides added to sea water become associated with both living and nonliving particles suspended in water. Experiments at the Radiobiological Laboratory of the Bureau of Commercial Fisheries at Beaufort, N.C. (Chipman, Rice, and Price, 1958; Rice and Willis, 1959), indicated that nearly all fission product radionuclides, and also those of the trace metals, that are added to algal cultures associate with marine plankton used by shellfish. If continuously available, radioactive particles may accumulate in filtering organs, on the body surface, and in the digestive tract of oysters and other shellfish.

The accumulation of radioactive pollutants in coastal waters is likely to become higher than it is at present if the current practice of dumping radioactive wastes from nuclear plants and many research institutions close to shore or in the lower parts of a river (Columbia River) continues indefinitely. This unwelcome possibility must be watched carefully, and a great deal of research remains to be done before a clear picture emerges of the potential dangers associated with the disposal of low level radioactive waste and the contamination of our fisheries resources.

To evaluate the effect of pollution on the productivity of oyster bottoms the following data are needed: the type and extent of pollution in relation to the total volume and movements of water in an estuary; the stability of the pollutant; its physiological action; the effect of long-continued exposure of oysters to low concentrations; and the determination of the lethal concentration of a pollutant killing 50 percent of a population, the so-called LD 50.

COMBINED EFFECT OF ENVIRONMENTAL FACTORS

Known effects of any single factor of the environment do not give a true picture of the situation found in nature. Factors of the environment always act jointly. One serious weakness of many ecological studies of marine populations is the tendency to correlate the results of biological observations with one or possibly two selected factors of the environment, such as temperature, salinity, or hydrography, and to disregard the effect of others. In reality, any factor can exert its effect only in conjunction with others. It is impossible to separate the effect of chemical changes caused by a pollutant from the movements of water and from the effects of the pollutant on the food chain. Changes in the character of a bottom brought about by sedimentation cannot be separated from changes in sea water chemistry, or the food chain. An increase in the salinity of water encourages the invasion of grounds by some competitors and predators, while lowered salinity forms a barrier to inroads by starfishes and drills.

The combined action of several factors produces a far greater effect than that caused by any single factor. Findings of what effects combined factors have on agricultural plants (Rübel, 1935) are fully applicable to conditions affecting aquatic animals. So far, however, no adequate studies have been made on the problem of measuring the joint effect of several factors of aquatic environment. The relationship of all factors probably can be expressed by a very complex formula of the type developed by Riley (1947) for seasonal fluctuations of phytoplankton populations in New England coastal waters. The very complexity of a formula of this type precludes its usefulness for the practical purpose of evaluating conditions on oyster bottoms. The oyster biologist is often confronted with the necessity of expressing his opinion on the quality of the oyster beds. His impression is given in general, nonspecific terms as adequate, good, very good, marginal, etc., which do not disclose the reasons for a particular evaluation.

My proposed method of scoring eliminates the uncertainty of personal impressions and assigns to each factor a value which indicates the degree of its effectiveness on a given population of oysters. The method has been applied successfully in the evaluation of oyster bottoms in New England, the south Atlantic coast, and in some Gulf States (Galtsoff, 1959). It has been already stated above (p. 399) that the optimal condition of existence with reference to a single positive factor can be assigned the numerical value of 10. Degrees of inadequacies are given numerical values in descending numbers from nine to one. Negative factors are treated in much the same

way. Complete absence of a negative factor refers to optimal conditions, and therefore, is designated zero, while the degrees by which the factor adversely affects an oyster population are assigned the numbers diminishing from nine, for 90 percent of negative influence, to one, which denotes 10 percent or less of harmful effect. The zero value of a positive and 10 value of a negative factor are omitted because under the proposed system such values denote complete unsuitability of environment for the existence of an oyster population.

A combination of environmental conditions which determine the productivity of an oyster bottom is summarized in simple tabular form by listing in two separate columns all positive (+) and all negative (−) factors and assigning to them their rank. As an example of the method, the data for one of the highly productive areas in the northern Cape Cod area, where observations were made for several years, are presented in table 46. In this area, which approaches ideal conditions, the presence of predators is the only serious problem.

The overall evaluation is made by summing up all positive factors, Σf^+ and all negative factors, Σf^- and by deducting the sum of the negative factors from the sum of the positive. Under this system the highest score of 50 refers to a theoretical situation where all positive factors are optimal and negative factors are absent. The low score of 10 and less refers to marginal conditions. Tabulation of factors is of great practical advantage because it shows at a glance the causes of low productivity and how it can be improved. The following tabulation shows the scores that in my opinion apply to various degrees of productiveness of oyster bottoms:

Excellent	41–50
Good	31–40
Average	21–30
Poor	11–20
Marginal	10 and less.

TABLE 46.—*Evaluation of the productiveness of an oyster ground in the northern part of Cape Cod*

Positive factors (+)	Score	Negative factors (−)	Score
Bottom	10	Sedimentation	----
Water movement	10	Disease	----
Temperature	5	Competition	2
Water quality	10	Predation	5
Food	10	Pollution	----
Total	45	Total	7

Note.—Overall score 45−7=38; ---- in negative score indicates absence of a factor.

In its present form, the method obviously oversimplifies the problem because it considers all the factors as equally significant, which may not be true. The present lack of understanding of the interaction within a complex ecological system bars expression of this interrelation in a more precise form. Growing interest in studies of the sea and its resources, however, gives promise of rapid progress in determining the intricate relationships among the principal factors that govern the prosperity of marine populations. The resulting knowledge will provide the basic data for designing effective methods of utilization and conservation of the renewable resources of the sea.

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