11

Poison

In assaying the potentialities of marine animals for human use we must recognize that not everything that lives in the sea is edible. A few species are poisonous, some all the time, others only occasionally and in certain areas. Fish poisoning seems to be confined to the tropics. In those latitudes it discourages using many species that are usually safely edible. Its cause has not yet been discovered and it is a subject deserving special study. Poisoning affects not only fishes but marine invertebrates, reptiles, and mammals as well. Under some circumstances which are not fully understood, some dinoflagellates become poisonous and cause mass mortalities of marine animals. Others cause mollusks which ingest them to become poisonous to human beings. This chapter reviews the subject of poisonous marine organisms, emphasizes its importance, and suggests pertinent marine research.

Poisonous Fishes

There are large quantities of shore and reef fishes living throughout the tropical latitudes which are relatively little known and little exploited for human use. Special methods would have to be developed to catch these fish, and the problems of concentrating, preserving, storing, and transporting the catches would be formidable. However, a much more serious condition that must be understood before anyone should attempt to revolutionize fisheries on the shores or the reefs of the tropics is that many kinds of fishes there are sometimes poisonous to eat. This fact is well known throughout the tropics and is the origin of certain food taboos. In some places as many as 15 per cent of the species that are usually edible be-

come toxic from time to time, enough so to make people who eat them become violently and sometimes fatally sick. This is not the consequence of the known bacterial food poisonings associated with putrefaction or of pollution of the water but of some toxic substance in the flesh of the living fish. The identity of this substance probably varies geographically and from one group of fishes to another.

There is a voluminous literature to document the existence of fish poisoning, its widespread occurrence, and its seriousness.[1] What causes it remains a mystery. The symptoms begin from within one to ten hours after eating the fish. They may include any of the following: nausea, vomiting, acute diarrhea; metallic taste in the mouth; tingling sensations of the face, fingers, soles of the feet, and toes; cramps in the extremities, aching muscles and joints, scalding urination with albumin, granular casts, and mucus in the urine. Cold objects may seem warm to the senses and warm objects may seem cold. There may be convulsions. Temporary paralysis of the legs may occur and last a day or two to several weeks. Between 2 and 3 per cent of the cases are fatal. Death has been known to occur within seventeen minutes after eating a poisonous fish. It is impossible to say how many cases of fish poisoning occur annually, owing to the unreliability or nonexistence of health statistics in areas where poisoning occurs.

There is striking geographic variation in the incidence of this condition and in the degree of toxicity of the affected species. Judging from published records of actual observations or of conversations with natives, the Marshall Islands are remarkable for the frequency and the potency of poisoning. The Marianas, on the other hand, have fewer susceptible species, and their toxicity is relatively weaker. In the Carolines poisonous forms are abundant about the western islands, but evidently absent from the eastern islands. Barracudas from the Marshalls and Marianas become poisonous; those from the Carolines do not. At Christmas Island only the lagoon has a bad reputation. In the Caribbean, both at Grand Turk Island and at Cuba, fish on the north side are said to be more dangerous than those on the south side. At St. Thomas, fish near Sail Rock and Peter Island are particularly feared. At Puerto Rico the dangerous area runs from Salinas Playa on the south to Fajardo on the east.

At least twenty families of fishes contain species that have records of sporadic toxicity. Among them are such ordinarily excellent and well known food fishes as the snappers (Lutianidae), sea basses (Serranidae), barracudas (Sphyraenidae), anchovies (Engraulidae), pompanos (Carangidae), surmullets (Mullidae), and such

less familiar families as surgeon fishes (Acanthuridae), triggerfishes (Balistidae), butterflyfishes (Chaetodontidae), porcupine fishes (Diodontidae), snake mackerels (Gempylidae), wrasses (Labridae), anglers (Lophiidae), filefishes (Monocanthidae), moray eels (Muraenidae), trunkfishes (Ostraciidae), demoiselles (Pomacentridae), parrotfishes (Scaridae), puffers (Tetraodontidae).

TABLE 11-1. OCCURRENCE OF RECORDED FISH POISONING CASES IN THE CARIBBEAN AREA

Month	Number of Outbreaks	Species of Fish Responsible					
		Sphyraena barracuda	*Seriola falcata*	*Scomberomorus cavalla*	*Caranx* spp.	*Epinephelus morio*	Unknown
January	0	0	0	0	0	0	0
February	5	0	2	1	2	0	0
March	1	0	0	0	0	0	1
April	2	0	0	0	1	1	0
May	3	2	0	0	0	0	1
June	1	0	1	0	0	0	0
July	2	0	1	0	1	0	0
August	3	1	0	0	2	0	0
September	4	1	0	1	2	0	0
October	3	1	0	0	1	0	0
November	2	0	0	0	1	0	1*
December	0	0	0	0	0	0	0

* This case involving 15 individuals was reported caused by an assortment of fish consisting of amberjack, king mackerel, and snapper.

Puffers and porcupine fishes are dangerous wherever they occur, even in temperate latitudes. In the Philippines all fourteen species of puffers are considered poisonous, and in Hawaii a law prohibits the sale of one species (*Tetraodon hispidus*). In Japan about twenty people die from eating puffers every year. In some puffers the poison seems to be concentrated in the skin and viscera, and the flesh, if carefully removed and thoroughly washed, is edible. Indeed, in Japan puffer flesh is a delicacy.

Halstead describes the Japanese preparation of puffer flesh thus:

> The Japanese government passed a law that cooks preparing fugu (i.e., puffer) for public consumption must pass rigid examinations regarding the identification and preparation of these fishes. There are certain species which are said to be strongly toxic at all seasons of the year and it is difficult to remove the poison, hence they are usually not used for food. If the candidate passes the test, he is then designated as a licensed fugu chef and is permitted to advertise as such. As you enter the restaurant there is usually a sign over the doorway calling your attention to the fact that this is a licensed establishment. . . . The fish is carefully prepared by first removing the viscera under running tap water, with care being taken not to rupture the gall bladder. As much of the skin and blood is washed off as possible. The fish is skinned and the meat removed from the bones, cut into thin slices and then placed

in running tap water for about 3 hours, at which time the poison is leached from the flesh. The fish is then ready for consumption.[2]

There are plenty of theories to explain fish poisoning but no facts. In some species toxicity seems to be associated with the spawning season. Certainly among puffers the poisonous factor is most potent in the gonads; in the California cabezone the roe has been found, on at least one occasion, to be poisonous. Nowhere, however, has anyone made systematic observations to measure seasonal variations of toxicity. Arcisz [3] tabulates the occurrence of twenty-six recorded outbreaks in Puerto Rico and the Virgin Islands (see Table 11-1). These data are not sufficient to justify concluding that December and January are months when it is safe to eat any of the listed fishes.

It seems reasonable to suppose that poisoning results from some sporadically occurring component of the food of the affected fish. Dinoflagellates cause poisoning among mollusks. Could they also affect fishes? So far no evidence has appeared to show that they or any other organism, for that matter, are involved. Fish and Cobb summarize theories on causes of fish poisoning thus:

> Regional variations in toxicity occur in both herbivores and carnivores and are frequently attributed to diet, but this has so far been difficult to prove. Hiyama [4] concluded that a relation exists between the nematocysts (sting cells) of coral polyps and poisonous fishes because in his field investigations he found toxic species concentrated for the most part about isolated tropical islands where clear water favors reef coral, and sparse or absent in areas of heavy terrestrial outwash not conducive to coral growth. Smith also suggests that since surface-feeding fish taken offshore are not known to be harmful, the poison evidently originates in the food of reef and lagoon species. This is hardly conclusive evidence, however, because some edible fishes also feed on coral polyps, and at least one sizeable Japanese jellyfish, *Rhopilema esculenta* Kishinouye, well provided with nematocysts, is sold as a delicacy for human consumption in Nagasaki.
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> Norman believes that forms like the wrasses (Labridae) and parrotfishes (Scaridae) derive their toxic properties from poisonous mussels, echinoderms, polyps and other invertebrates which themselves contain alkaloids. A similar opinion has been expressed by Jordan who found that, although there are no known poisonous marine foods in the Apia area of Samoa, it is reported that fishes sometimes eat poisonous deep-sea growths which appear after storms. These are said to make the flesh poisonous and sometimes kill the fishes themselves. One of the forms which becomes poisonous at times in this area is a large species of *Gymnothorax* known to the natives as "pusi." The fishes that poisoned many persons and domestic animals on Fanning Island in 1946–47 are said to have been nonmigratory species taken from areas in which the American Army had dumped war materials in 1945. The symptoms, however, appear to have been much the same as in cases of fish poisoning elsewhere. Fishermen of Saipan and Tinian believe that fishes in those waters feed on poisonous algae but Matsuo concluded that the alkaloids are more likely derived from echinoderms or crabs, although he could find no trace of any

of these forms in stomach contents. Feeding experiments on Saipan proved equally inconclusive. Intestinal contents, consisting of both animal and vegetable matter, produced no symptoms of poisoning when fed to dogs.

Toxic potency increases with age in some fishes; in fact it has been reported that when young most poisonous species, if at all toxic, are only mildly so. According to Hiyama, *Caranx sexfasciatus* becomes toxic in the Marshalls at 25 cm. (dangerously so at 50 cm.) and *C. ascensionis* at 30 cm.; in New Caledonia *Lethrinus mamlo* is said to be poisonous when larger than 80 cm. The barracuda, *Sphyraena barracuda,* is generally considered to be deadly poisonous in the Marshalls, although some of the other members of the genus do not become inedible until they reach large size.[5]

Arcisz made an extensive bacteriological study of forty-six specimens representing eight species of fishes collected near St. Thomas in areas where poisoning is frequent. He concluded that ". . . some of the fish may be infected with enteric pathogens. A more intensive active research program is needed to determine the cause. . . ." [6]

Wherever fish poisoning occurs it produces the same symptoms. Yet the nature of the poisonous factor remains unknown. Several writers have referred to it as an alkaloid, but as far as I can learn from literature, this is pure supposition. The only properties of the substance, apart from poisonousness, which seem well established, are that it is heat-stable and soluble in water and in alcohol.[7] One specimen, for example, remained toxic after being broiled for twenty minutes and baked for two and one-half hours. A mildly poisonous specimen can be made safe, as well as tasteless, by soaking it in water overnight, then pounding the flesh and rinsing it thoroughly in water.

Every year fish poisoning strikes a few hundred or perhaps thousands of people and kills in the tens or perhaps hundreds. It is thus insignificant as a cause of human morbidity and mortality. At the same time it is serious enough to stop many people from eating fish in the tropics or from promoting fishery industries, and therefore is of the greatest importance to our study. Moreover, the very fact that known species are occasionally poisonous makes one hesitate to recommend exploiting unutilized species anywhere.

The most useful goal of research on fish poisoning is to find a way of making it safe to eat fish whether they be initially poisonous or not. This might be accomplished by adding to the fish during the preparation or cooking process a chemical which would nullify the action of the poison, or at least reveal its presence. Or it might be accomplished by learning what conditions in the sea are associated with the poison, so that people could tell when they must avoid eating fish. Whatever the method of control it must be based on chemical and biological knowledge, not on opinion.

To reach this goal these basic questions must be answered: What is the identity of the poisons which occur in fishes? What are their properties? Where, when, and how do they originate?

These problems should be studied in a place where poisoning is frequent, such as St. Thomas or Palmyra. We might start with the hypothesis that fish poisoning originates with some microscopic organism which swarms sporadically. That would require systematic study of the plankton, with isolation and experimental culture of suspected forms in the laboratory and testing of their effect on fish. The minimum staff of a laboratory devoted to these studies should be a general physiologist, a zoologist who knows how to identify marine organisms accurately, a microbiologist, and two assistants. The most obviously essential and costly piece of equipment is a vessel about 60 feet long, with gear for fishing and collecting plankton, and with laboratory facilities for treating material immediately. In addition, of course, there must be a station ashore suitably equipped for physiological, biochemical, and systematic studies.

Fish poisoning is important enough around the world to deserve establishing a special project to investigate it. On the other hand, it is only one facet of a much larger problem, as we shall see further in this chapter, and a team of scientists studying it should be attached to a laboratory having a more comprehensive interest in the biochemistry of marine organisms.

Other Poisonous Marine Animals

Poisoning is not confined to fishes. Sea turtles are sometimes affected. Cases of poisoning from eating the flesh of hawksbill sea turtles (*Chelonia imbricata* and *C. japanica*) have been reported from Arabia, the Malay Peninsula, Malay Archipelago, Australia, Formosa, Samoa, Guiana, the Bahamas, and Guatemala. Poisoning from eating leathery turtle (*Dermochelys coriacea*) has been reported from the Cape of Good Hope, the Indian Ocean, New Zealand, and the Solomon Islands. Symptoms, which may start immediately to a week later, consist of diarrhea, boils, fever, hallucinations, debility, nausea, vomiting, sore throat and lips, and irresistible somnolence. Coma and death may occur within twelve hours after ingestion, or death may be delayed as long as two weeks.

Among marine mammals, flesh of the lion white seal (*Neophoca cinerea*) of southern Australia and the bearded seal (*Erignathus barbatus*) of southern Greenland and Iceland is at times poisonous; so also is the liver of the polar bear (*Thalarctos maritimus*). According to Rodahl and Moore, the liver of bears and seals is rich in vitamin A. The toxicity is associated with the concentration of

this vitamin. In feeding experiments, one rat died with lesions specific for hypervitaminosis A.

Among invertebrates, the horseshoe crab of the estuaries of Malaya and Siam (*Carcinoscorpius rotundicauda*) and of Japan (*Tachypleus gigas*) is sometimes poisonous. The flesh and eggs of *Carcinoscorpius* can be fatal.[8] Nigrelli[9] found a sea cucumber (*Actinopyga agassizi*) in the Bahamas which produces a substance (holothurin) which is extremely poisonous to fish and to other invertebrates. The poisonous principle is contained in the "pink gland." A dilution of 1 to 100,000 of a suspension from this gland killed killifish in twenty-three minutes. A dilution of 1 to 1,000,000 killed the same species after several hours. Death was due to breakdown of the capillaries. Mice into which Sarcoma 180 had been implanted were given nonlethal doses of holothurin subcutaneously. Autopsies of the specimens, sacrificed six days after the injections, showed the sarcoma to be considerably reduced and necrotic. Here then is an example of one poison from a marine organism which may eventually prove to have therapeutic value.

Mollusk Poisoning

The dinoflagellates compose a very large class of microscopic primitive organisms, distributed widely throughout the world, with many genera and species and a great variety of characteristics. They have attributes both of plants (they photosynthesize) and of animals (they ingest food). They are almost if not quite as numerous as are diatoms and as important in the sea economy. They enter into the diet of a multitude of invertebrates and small fishes. The great majority of dinoflagellates seem to be benign all the time, but in certain parts of the world a certain few species occasionally burst into a dense flowering called a "red tide" and then give off substances into the water which are deadly to many kinds of marine animals, causing terrible mass mortalities (page 175). In certain other parts of the world, a certain few species which occur near shore are ingested by sea mussels, clams, mole crabs, and other animals of the intertidal zone. And although they seem not to harm these animals they make their flesh poisonous to human beings.

Mollusk poisoning evidently occurs in several regions, notably in Japan, North America, and Europe. The most severely affected region is the Pacific Coast of North America from Southern California to Alaska. In the Atlantic it occurs on the American side in the Bay of Fundy, occasionally southward as far as Cape Cod, and on the European side in Germany, Scotland, Ireland, England, Wales, and Norway.

In Japan, the causative organism has yet to be determined. From California to Alaska several species of the genus *Gonyaulax* are associated with poisoning. However, one, *G. catenella,* is so overwhelmingly predominant that researchers have felt justified in ignoring the others in their studies. In eastern Canada, *G. tamerensis* is the guilty organism. In Northern Europe, it is *Pyrodinium phoneus.*

The dangerous season varies geographically. In Japan, the incidence of poisoning is low in summer and fall. It starts to rise in January, reaches a peak in February and March and declines in April; [10] in Alaska it occurs all year round with fluctuating and evidently irregular intensity which seems to be highest between February and August; in California the dangerous period extends from May to December; in the Bay of Fundy from late summer to early fall, and in Northern Europe from August to December.

All mollusks and some crustaceans, including mussels, clams, oysters, and crabs, become poisonous in the vicinity of an affected area. On the Pacific Coast of America and in the Bay of Fundy, it is generally the shellfish inhabiting the open unprotected shores rather than those in enclosed bays which become infected. In California, the mussel *Mytilus californianus,* which is an open coast form, becomes poisonous, while *Mytilus edulis,* which inhabits bays, never does. In Europe it is the other way round. There the causative organism is a form characteristic of brackish water rather than of the open ocean. Consequently, most of the outbreaks of poisoning have resulted from eating shellfish of estuaries, inner harbors, and small enclosures like canals. In Maine the poison has been found in strongest concentrations in the mollusks and in the mud of the tidal waters of rivers or brackish bays at considerable distances from the open ocean.

Normally these dinoflagellates are yellow green or golden. As they become poisonous, however, the color of most individuals takes on a reddish brown or orange brown cast. When this happens the mollusks in the vicinity become affected very quickly. In one observation, where *Gonyaulax catenella* was flowering, the toxicity of mussels increased a hundred-fold in twelve days. The poison becomes concentrated in the liver of mussels, scallops, and most clams, in the siphon of the butter clam, in the gills as well as the liver of the bar clam and soft-shell clam. When the dinoflagellates go into their non-poisonous phase, the shellfish excrete their stored-up poison into the water and thus purify themselves in a few days.

People who study mollusk poisoning measure the degree of toxicity in mouse units. A mouse unit is the amount of poison con-

tained in one milliliter of alcoholic acid extract dissolved in water, which, when injected intraperitoneally into a white mouse weighing 20 grams, will cause death in fifteen minutes. In one analysis made at the Hooper Foundation in California, 240 kilograms of whole mussels contained 58 mouse units per gram. The poison which *Gonyaulax catenella* produces is soluble in water, methyl and ethyl alcohols, acetic acid and acetone; it is insoluble in ether, chloroform, ethyl acetate, butyl alcohol, and toluene. It breaks down on heating, also with increasing alkalinity. It seems to be a nitrogenous base. It has not been isolated but its hydrochloride is said to have the empirical formula of $C_9H_{17}N_6O_4(HCl)_2$. It is one of the most toxic substances known.

Biochemists have detected more than one poison in California marine invertebrates. One they called P-I. In mice this causes central paralysis, severe spasms, heart block, and death, all within twenty minutes.

Another, less potent poison referred to as P-II, may be caused by something different from *Gonyaulax catenella.* This can be demonstrated only when P-I is absent and not interfering with the test, in other words, only in late fall and winter. It causes symptoms similar to those resulting from tetramethyl ammonium salt (which has been found in certain sea anemones)—that is, motor paralysis and feeble heart beat. Symptoms begin from several minutes to several hours after administering the poison, and death may occur from five minutes to several hours after the onset of symptoms.

A third poison, P-III, does not begin to show any effect in mice until six to thirty hours after it has been administered. This was observed only in mussels and sand crabs in La Jolla in May, 1933, when *Prorocentrum micans,* a dinoflagellate, increased in abundance to 200,000 per liter of sea water. This poison causes trembling, incoordination, tetanus; and death occurs in eight to ninety hours. It took a large dose of this to kill a mouse—no less than 30 milligrams of crude extract.

A fourth poison, P-IV, was detected in samples of plankton collected from a pier at Halfmoon Bay, California. This affected mice much like P-I, but caused no heart block, and therefore presumably originated in some organism other than *Gonyaulax catenella.*[11] It may be identical with a poison produced in the Japanese clam *Venerupis,* and called by Japanese scientists "venerupin."[12]

People vary in sensitivity to shellfish poisoning. Evidently the toxicity varies too with differing species of dinoflagellates. Sommer, who studies mussel poisoning, remarked (in a conference at Washington, D.C., in 1946) that people can take a few thousand mouse

units at a time without noticing any ill effects. He considered 40,000 mouse units to be the beginning of dangerous levels.

On the other hand, Canadian scientists, working in the Bay of Fundy, record sixty cases of people taking estimated doses of 300 to 17,000 units without ill effect, but 28 other cases of people taking estimated doses of "1,000+" units up to 36,000 units showed varying degrees of intoxication from mild to extreme. The scientists concluded that some people have a natural tolerance to the poison. Those living in shore communities who eat shellfish regularly may acquire a tolerance to doses which would produce severe symptoms in unconditioned persons.[13]

TABLE 11-2. OCCURRENCE OF RECORDED MOLLUSK POISONING CASES AND MORTALITY FROM POISONING IN SELECTED AREAS

Country	Year	Number of Cases Reported	Number of Deaths
Japan	1889	81	54
	1941	6	3
	1942	334	114
	1943	16	6
	1948	11	1
	1949	67	3
U.S. (Calif.)	1927	102	6
	1929	62	3
	1932	40	1
	1933	22	1
	1934	12	2
	1936	3	2
Germany	1887	3	1
England	1888	3	1
Ireland	1890	7	5

Symptoms depend on the poison present. They can begin almost immediately or as long as twelve hours after eating the affected mollusks and may include feelings of prickling, numbness, or constriction about the lips, tongue, pharynx, and face; prickling sensation of hands or feet; sensation of lightness and the impression that objects have no weight; patients may believe they can fly. The pulse rate may quicken to a frequency of as high as 160 per minute, the pupils of the eyes may become dilated and reactionless, and patients may hold themselves in an upright position with great pain. Urination may be painful and difficult. There may be headache, backache, dizziness, nausea, vomiting, and difficulty in breathing. Various muscles may become temporarily paralyzed for hours and remain weak for several days after recovery.

It is impossible to know the mortality rate from mollusk poisoning, since many cases go unreported. However, Table 11-2 gives sample pertinent statistics.

Governments provide for research about mussel poisoning wherever it is frequent and serious enough to endanger human welfare. Thus scientists in Canada, California, Oregon, and Washington, and in Japan have followed its occurrence and some of them have worked to isolate and identify the poison principle.

In our study we are looking toward fuller utilization of the ocean resources. That might mean doing something with plankton. If some of the organisms of the plankton secrete harmful substances, we should learn all we can about them. This requires studying them, primarily with the aim not of preserving public health, but of learning about their life processes. Before considering what studies ought to be undertaken to achieve this aim, let us consider some other cases of toxicity among marine organisms.

Red Tides

It is puzzling that fishes and mollusks should become deadly poisonous to warm-blooded land vertebrates without becoming affected themselves. Could it be that the marine animals have grown immune to the poison through long conditioning, whereas the land animals have not had the same opportunity? This would seem a logical explanation were it not for the fact that there are other kinds of marine microorganisms which go through a phase when they give off substances that intoxicate and kill fishes and invertebrates, but which may have no noticeable ill effect on warm-blooded land vertebrates. In fact in some places people regard these marine catastrophes as opportunities to gather the dying fishes, crabs, and shrimp for market.

For one possible example, a very mild form of mass intoxication of fishes is a common though sporadic event in Mobile Bay, Alabama. It occurs during summer, not every year, but some years several times, generally after a period of excessive rainfall accompanying a shift of winds. These conditions make for a diminished salinity in the Bay and a dead calm sea. Then some quality of the water, perhaps merely a diminution of oxygen, but perhaps instead swarming organisms which the tide has brought in from the sea, has a curious and rather sudden effect on the fauna of the Bay. For hundreds of yards or even for several miles blue crabs leave the deeper water to gather in masses close to shore, some of them even emerging onto the beaches; others jam together on pilings while all

sorts of fishes, especially flounders, catfish, sting rays, and eels, and also shrimp, congregate close to shore, and lie in the shallows, moving about sluggishly, aimlessly, as though intoxicated. While all of this is going on, crowds of people gather close to shore to spear the helpless fish by the hundreds and with scoop nets take in crabs by truck loads.

This massing of fishes and crabs, which is locally called a "fish jubilee," may break up within a few minutes, or it may last a few hours until the tide goes out. Then the animals disappear into the depths to return to their normal habits. These episodes are characteristic of the eastern shore of Mobile Bay, but rarely happen on the western shore.

For a more clear-cut example, at Malabar, India, there is a frequent, perhaps annual, blooming of flagellates which devastate marine life with their poison.[14] These episodes happen after the rainy season is over and the southwest monsoon has subsided. Then, with a week or so of calm weather and a slackening of the coastal current, conditions are favorable for a red tide. At first there may be a swarming of the harmless organism, *Noctiluca,* densely enough to color the sea bright red. This the Malabar people regard as presaging the poison water.

Within a few days the flagellate *Euglena,* may have succeeded *Noctiluca.* Now the water becomes brownish, and the first sign of the poisoning shows when fish and crabs move sluggishly towards the shallows as though in a state of exhaustion very much as in the Mobile Bay "jubilees." And just as in the jubilees, men and boys crowd down to the shore, and with spears and nets make great catches for market. As time goes on the color of the water gets redder and gives forth a "horrible stench," probably of hydrogen sulfide. Then fish of all sorts that have not left the poison area at the beginning of the bloom die and are cast up on shore. Those that suffer the heaviest losses are bottom-living fishes such as soles, catfish, and croakers, and invertebrates such as hermit crabs, rock crabs, mole crabs, spiny lobsters, clams, mussels, and other bivalves, and alcyonarians. At infrequent intervals sardines may be trapped in the poison water, and when that happens the sea may be covered for miles with dead or dying sardines "in enormous multitudes." The poison water may persist for several days until a freshening wind disperses it.

In the Walvis Bay region of Southwest Africa, poison water is a common visitation. It generally occurs during December or January, but may extend into March. It may appear four or five times in a season, nearly always killing some fish, and occasionally it dev-

astates the whole area of its marine life. Here the mechanism seems to be more complicated than in most other places where mass mortalities occur, for it may involve bacteria as well as dinoflagellates. An azoic zone extends for about 200 miles along that part of the African coast and seaward for 25 or 30 miles. The bottom there, almost destitute of animal or plant life, is composed of a diatomaceous ooze which gives off hydrogen sulfide when any of it comes to the surface. This happens from time to time in a curious way. Islands of mud, sometimes measuring several thousand square feet, rise to the surface, remain perhaps an hour or even several days, and then vanish without trace, leaving the bottom as deep as it had been before. During their short existence, they give off a stench of hydrogen sulfide which people can smell 25 miles away. The water around them is turbid, and full of bubbles. Dead fish float about. Sometimes what people describe as steam issues from these islands, but there is no noticeable heat either on the islands or in the surrounding water.

Occasionally, bubbles of hydrogen sulfide gas rise to the surface accompanied by clods of mud. Once a large ship stirred the bottom mud while berthing. Shortly afterward there rose to the surface hundreds of dead soles, which the people gathered and ate without any ill effect.

According to Copenhagen,[15] the gas is generated in this way: The oxygen content of the water in the "azoic zone" diminishes towards the bottom to zero. Thus sulfate-reducing bacteria (*Desulphovibrio desulphuricans*), which can exist only under anaerobic conditions, thrive there. Part of the year the cold Benguela Current flows over the azoic area. This is an extraordinarily fertile body of water, full of plankton, and with large populations of pelagic fishes. During the summer, a shift of winds from north to west, diverts or retards the Benguela Current, whilst warm, highly saline tropical Atlantic water invades the coastal area and usually raises the temperature five or six degrees centigrade, but occasionally as much as ten or eleven degrees. These sudden changes, when severe enough, are destructive to the Benguela fauna, killing masses of animals among the plankton and fish, whose dead bodies enrich the azoic zone and stimulate growth of the sulfate-reducing bacteria. But the hydrogen sulfide is also destructive, for it depletes the water of its dissolved oxygen and moreover is toxic enough so that when meteorological conditions cause the bottom water to rise to the surface, it kills pelagic fish that happen to be there.

Quite apart from the role of hydrographic changes and of sulfate-reducing bacteria in causing mortalities of marine life at Walvis

Bay, poisonous dinoflagellates bloom there sporadically during the summer. The Danish research ship *Galathea,* visiting in 1950 a few days after a fish kill, found the surface of the sea in and about Walvis Bay, down to a depth of about a meter, khaki colored, and densely populated with a dinoflagellate subsequently named *Gymnodinium galathea.*[16] Moreover, many accounts of mass mortalities at Walvis Bay refer to the sea being blood red and soupy-thick with a dinoflagellate identified (probably erroneously) as *Noctiluca.*

Frequent as are the mass mortalities at Walvis Bay, evidently no one has yet had the opportunity to make the year round systematic hydrographic and biological observations which would be necessary to observe all the sequence of events leading to the mortalities. Until that is done, no one can weigh the relative contributions to the mortalities by hydrographic changes, by sulfate-reducing bacteria, and by poisonous dinoflagellates.

Red tides occur at irregular intervals on the west coast of Florida. Outbreaks in the winter of 1946 and spring and summer of 1947, reached such spectacular proportions that the United States Congress passed a special appropriation to investigate the phenomenon. Galtsoff [17] estimated that somewhere between 100 and 200 million pounds of fish were destroyed. At one time masses of dead fish extended along the coast offshore for 120 miles in a band 20 miles wide. All kinds of animals died, turtles and porpoises among them, pelagic fishes as well as bottom dwellers, and invertebrates, including crabs, barnacles, oysters, and clams. About 80 per cent of the edible oysters grown on piles were killed. This destruction was associated with the occurrence of large streaks of discolored water which ranged in hue through shades of green, yellow, amber, brown, and red. As fish entered these patches, they would come to the surface, whirl about crazily, then turn on their sides, float a while belly up, and then sink to the bottom. The plankton within the discolored area included several species of diatoms, copepods, cladocera, and lamellibranch larvae. The predominant species was a dinoflagellate, *Gymnodinium brevis,* which occurred in concentrations up to 56 million per liter. At the same time the water was slimy with a mucous which was apparently derived from broken bodies of this organism.

People ashore were affected too. With the onshore wind and breaking of the surf, particles of the dinoflagellate borne into the air in a mist gave a burning sensation to the nostrils, eyes, and throat, and made people cough, sneeze, and suffer symptoms of heavy colds or hay fever. The economic consequences of red tide were serious, for both local fisheries and tourism were hard hit.

There is little doubt that *Gymnodinium brevis* is the cause of the mass mortalities in the red tides. When it is swarming, there are red tides and mass mortalities; when it is absent, there are none. Fish put into laboratory cultures of various species of phytoplankters, including *Gymnodinium splendens* (a closely related dinoflagellate), remain unaffected, but in a culture of *G. brevis* they die quickly, just as they do at sea.[18] Collier, Wilson, and Ray, of the United States Fish and Wildlife Service, have succeeded in cultivating *G. brevis,* thus creating red tides under artificial conditions. In this way they have been able to learn much about the mechanism producing it. It appears that this dinoflagellate is peculiarly sensitive to the ions of heavy metals, even in the minute amounts in which they occur in sea water. Under the conditions which normally prevail, *G. brevis* evidently persists in a non-swarming, benign phase along the shore. Among the factors which make it possible for this organism to live are sulfides, chiefly hydrogen sulfide, and organic matter, such as detritus, large quantities of which occur in the organically rich soils of the nearby swamps. When this material comes into contact with the metallic ions in the sea water, it enters into union with them, taking them out of solution. Thus the metals, which are a natural barrier to *G brevis* (there may be others) are removed. The mechanism of the process is only partly understood. Perhaps normally the balance between the material from the swamps and metal ions is such as to hold the numbers of the organism down to a low level. Occasionally, however, under certain circumstances, abnormally high quantities of it may accumulate along shore. Besides taking the metal ions out of solution, the sulfides seem to have a direct physiological effect on the dinoflagellates, further contributing to the swarming stimulus. In the ordinary course of events, with normal intermittent rainfall, run-off from the swamps, wind, and sea currents, the sulfides carried down to sea are dispersed. When rainfall is abnormally high and prolonged, an abnormal amount of fresh water is carried down from the land. If this coincides with a period when winds retard the dispersal of this sulfide-rich water, and when surface temperatures are peculiarly favorable (probably around 26° to 28° C., judging from laboratory experiments) *G. brevis* is released from its usual barriers, bursts into a swarming phase, and poisons the water. As fish die, their rotting bodies generate sulfides, and a vicious circle becomes established, the sulfides taking more metallic ions from the water and thereby enlarging the area favorable to red tide. This horrible sequence continues until the circle becomes broken; then *Gymnodinium brevis* retreats to its usual habitat, and the red tide disappears. Fortu-

nately severe episodes are not frequent (1854, 1878, 1880, 1882, 1883, 1908, 1916, 1946, 1947, 1953, 1954, 1957).

The records of mass poisoning of marine organisms, exasperatingly fragmentary though they are, show that there must be considerable variation in the characteristics of red tides from one part of the world to another. A few circumstances appear in the records often enough to suggest a common pattern.

These episodes occur in areas which are well fertilized by nutrients usually brought to the surface in the process of upwelling or carried from land down to the sea by rivers. They occur when anomalous meteorological conditions hold the enriched water mass stagnant long enough to allow certain microorganisms to accumulate up to some critical level of abundance. Under these circumstances their physiological processes change, as evidenced by their explosion into "blooms" and by their secretion of poisonous substances. Meteorological conditions which seem to be often associated with red tides in areas where fertility and topography are suitable are heavy rainfall, followed first by a shift of the normally prevailing wind, and then by an abnormally calm sea. The red tide always disappears when the water mass is dissipated. This may happen with a change of tide or with a freshening and change of direction of the wind. In some places, as at Walvis Bay and in the Black Sea, where anaerobic sulfate-reducing bacteria flourish at the bottom, the bodies of animals killed by a change of surface temperatures or more probably by poisonous dinoflagellates may feed the bacteria, thus increasing the production of hydrogen sulfide. The hydrogen sulfide contributes to the lethal influences, perhaps through its action on trace metals such as copper.

Poison in fishes and mollusks discourages the full use of sea food resources in certain areas. Red tides are destructive to sea life. There are good practical reasons for giving special study to these phenomena. Governmental research agencies do study them in various places, with the idea of understanding them, predicting them, and perhaps controlling them. There is another viewpoint, however, which has not been considered. Food is not necessarily the only biological resource of the sea. Substances which are deadly poisonous in some circumstances may be beneficial in others. For example, opium, strychnin, caffein, quinine, camphor, atropin, and digitalis are all products of land plants, which though poisonous, nevertheless have great medical value when properly used. The possibilities of deriving medicinal or industrial products (insecticides, herbicides, poisons for chemical fishing) from marine plants and animals have hardly been touched.

Concerning the possibilities of obtaining pharmacologically active substances from the sea, Emerson and Taft say:

> The lack of application of substances from marine sources to medicine, aside from those materials which have proven their worth over the years (I, Mg and Br compounds, agar, fish oils), is due more to lack of study of the highly potent agents available and search for others than to a paucity of pharmacologically interesting substances from the sea. There is little doubt that if the chemical isolation of insulin had been more difficult to perfect, fish would constitute a major source since their islets are readily obtained essentially free of acinar tissue. The search for antibiotics more satisfactory than penicillin has not, to our knowledge, been extended to marine forms, although *Chlorella vulgaris* and *C. pyrenoidosa* yield an antibiotic.[19]

This is a field of research that is wide open and not likely to be explored much by government scientists, because the need, the promise, and the ultimate application are not clearly evident. Moreover, there are precious few men available to do such work. The sea may occupy 71 per cent of the earth, the majority of species may inhabit the sea, and they may have an infinitude of unknown properties; nevertheless, the number of scientists in the world studying the biochemistry of marine organisms is negligible. Few laboratories have any provision for such scientists.