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UNDERWATER WORLD

Red Tides

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Canada

Red Tides

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"And Moses and Aaron did so, as the Lord commanded; and he lifted up the rod, and smote the waters that were in the river, in the sight of Pharaoh, and in the sight of his servants; and all the waters that were in the river were turned to blood.
And the fish that were in the river died; and the river stank, and the Egyptians could not drink of the water of the river; and there was blood throughout all the land of Egypt."

Exodus 7: 20–21

The verses quoted above from the Old Testament indicate that red tides have been in existence for a long time. This passage may be one of the earliest recorded instances of a red tide. Red tides are also recorded in place names. The Red Sea received its name because of the red tides which occur there, and the Gulf of California was once named the Vermilion Sea. From these and other examples, we can assume that red tides have been in widespread existence since historic times. In fact, they must have been present for hundreds of millions of years from the time the causative micro-organisms appeared in the oceans.

Although a more comprehensive description of a red tide will be covered in another section, basically, a red tide occurs when there are sufficient numbers of cells of any microscopic algae in the water to cause a discoloration. They can vary in color from almost transparent, through pale yellow and green, to amber and bright red. Often, there are red-water occurrences that have no obvious harmful consequences. These are usually not reported, so the literature gives a biased idea of the harmful events and effects of red tides. The use of the term "red tide" tends to focus mainly on blooms of algae that may have harmful, dramatic or severe consequences. However, in most instances, a water discoloration does not always accompany a toxic outbreak. These outbreaks may be associated with mass mortalities of different marine animals (such as shellfish, finfish, mammals) or contamination of shellfish with potent neurotoxins which can be fatal to humans and other consumers of shellfish.

The economic impact of red tides can be significant and far reaching, with losses of fish and shellfish resources, shellfish harvesting restrictions, consumer wariness (largely unfounded) of all seafood products, and declines in tourism. In Japan, frequent and devastating red tides are a major problem for coastal fisheries and the country's economy. Millions of dollars have been lost annually for decades on Canada's Atlantic and Pacific coasts from closures of shellfish harvesting areas as a result of the red-tide toxins. During late 1987, a new red-tide toxin was discovered in cultured blue mussels from eastern Prince Edward Island. As a result of this episode, loss to the shellfish industry for all of Atlantic Canada was in excess of a million dollars. In fact, the publicity of the adverse effects of red tides affected the sales of all seafood. Costly public awareness campaigns were required to restore consumer confidence in the industry. Mussel sales for Atlantic Canada are today finally back up to levels they were at prior to the crisis. As a result of stringent monitoring and inspection programs, one can be sure that today Canada's shellfish are among the safest in the world.

Fish and shellfish are among those that can fare poorly during red-tide events. For example, in the summer of 1985, massive shellfish mortalities occurred off the coasts of Rhode Island and New York when they were unable to feed as a result of a dense red tide. The organism also blocked sunlight, destroying eelgrass beds, an important habitat for shellfish. In 1988, another serious red tide occurred on the Scandanavian coast, killing 600 tons of farmed fish in Norway. Losses were minimized due to prompt action of fish farmers in having cages towed to "clean" waters. The loss to the industry as a whole was minimal, since the mortalities were less than 1% of their projected output.

Humans can also be severely affected. For example, in 1987 a severe outbreak of a red-tide organism in Guatemala contaminated shellfish, resulting in severe poisoning in 187 persons with 26 deaths. Therefore, red tides are important to fisheries as well as public health.

The following gives some information on where red tides are found, what makes them occur, how they kill and contaminate animals and shellfish, how they seem to be becoming more of a problem and what is being done about them.

Where Are Red Tides Found?

Red tides, whether they are harmful or not, have been found throughout the world. Scientific studies indicate a global increase in occurrence and geographic extent of harmful red tides. Prior to 1980, harmful incidents had been recorded from Argentina, Brazil, Canada, Chile, England, Japan, the Netherlands, Norway, New Guinea, Peru, Scotland, Spain, United States and Venezuela. Since 1980, harmful red tides have become more widespread, with harmful effects now observed almost worldwide. Recent additions to the former list include: Europe (Ireland, France, Sweden, Denmark, Romania, Italy, U.S.S.R.), Asia (Thailand, Hong Kong, the Phillipines, India, Guatemala), Australia and New Zealand. Some of this increase can be attributed to increased awareness resulting from more scientists working in this particular field of research and also availability of better analytical methods for those detecting and analyzing red tides. Additionally, aquaculture is, in many locations, a new industry and has resulted in increased concern and monitoring of adjacent waters for potential threats and/or nutrient enrichment which could promote red tides. There is, however, evidence that particular red tides are spreading hundreds of kilometers. These are thought to be moved within an area by winds, currents or storms, or they may be carried long distances such as across oceans in ships' ballast or by some other means.

What Are Red Tides?

A general idea of what occurs in the aquatic food chain may help in the understanding of red tides. There are single-cell plants (known as algae) located in all the water systems throughout the world. These minute aquatic plants capture and use energy from sunlight, as do land plants. The growth of these aquatic algae is one of the most important processes on earth, because it serves as the first step in the system of energy transfer through aquatic food webs. All aquatic animals in both fresh and saltwater require these small plants to maintain their existence.

These microscopic algae, which occur in a vast variety, generally go through yearly cycles of rapid growth and decay. The growth period is characterized by a burst of growth and multiplication for two or three weeks, during which time each single plant may have multiplied into millions of its kind. This phenomenon is called blooming, and it goes on season after season in surface waters all over the world. Which particular microscopic plants grow in any given water body depends upon a number of factors, the major ones being temperature, salinity, light intensity, and nutrient level. Thousands of different species of microalgae exist, periodically blooming and decaying. They are the initiators of the food chain.

In certain instances hydrographic and meteorological events cause the microalgae in a bloom covering a wide area to be concentrated into one or several smaller areas so that very dense accumulations of the organisms occur, with up to millions of algal cells per litre. In such large numbers, the algae discolor the water. The color is due to pigments within the algae which are used for trapping sunlight. Different algae have different pigments, thus different colors. Therefore, depending upon the specific algae involved, discoloration of the water may tend to shades of red, pink, violet, orange, yellow, blue, green or brown. However, many of the discolorations due to algae in marine waters are red, hence the origin of the terms "red tide" or "red water." The terms are now associated with the phenomenon itself, so the color of a "red tide" is not necessarily red, but may be any other color. The phenomenon in fresh water is not referred to as a "red tide," but as a "water bloom."

How Do Red Tides Occur?

What causes algae in one location to form a red tide? A combination of biological, hydrographic and meteorological processes explains how this occurs. Most red-tide algae are either free floating or are positively phototactic, which means they actively swim towards light (small whip-like tails enabling them to do this). Once at the surface, the organisms can be concentrated into areas where the water is "downwelling" or sinking. This occurs where two water masses meet, or where thermal or wind-driven convection patterns (windrows) exist. In short, the water is moving downwards while the organisms are floating or swimming upwards. This is the mechanism by which tremendous numbers of algae from a large area can be accumulated into one spot. Of course, water currents play an important role in transporting algae to these potential red-tide areas and in supplying the nutrients required to maintain growth of the algae. Depending upon continuation of the proper hydrographic condition and upon a supply of nutrients, a red tide may persist in one location for a week or two, often causing extensive mortalities of marine animals, especially fish and shellfish, and sometimes contaminating shellfish to the extent that the lives of those organisms eating the shellfish are endangered.

How Do Red Tides Kill Marine Animals?

Although the "blooming" or "swarming" of algae and the production of red tides does not always result in mortalities, when mortalities do occur, it may be as a result of a number of mechanisms. One involves oxygen depletion where almost any type of algae forms an intense bloom and causes oxygen levels to become undetectable in the affected area. Fish mortalities can occur where algae in such blooms die in restricted waters such as shallow bays. Under normal conditions, algae give off more oxygen during the day (through a process called photosynthesis) than they use during growth or while reproducing. A lack of nutrients or unfavorable conditions of light, salinity or temperature usually produced in stagnant waters can cause the red-tide organisms to die, resulting in a mass of decaying cells. Bacteria in the water grow rapidly on these decaying cells, resulting in removal of all the oxygen from the affected waters and, since few animals can exist in the absence of oxygen, those trapped soon die and add to the decaying matter. The water sometimes feels greasy. Such an incidence occurred in the northeast part of Hong Kong in 1988, where an algal bloom collapsed, depleting the oxygen supply and causing mortalities of shellfish and killing 35 tonnes of fish.

Extensive numbers of algal cells can also be responsible for mortalities with no ill effects to themselves. In parts of the northeastern United States, in 1985, an important new happening among red tide events occurred when the "brown tide" *(Aureococcus anophagefferens)* bloomed. The tiny algae bloomed so densely that shellfish either stopped filtering or provided little food source, resulting in their starvation and death. The blooms were dense enough that they blocked sunlight and therefore destroyed eelgrass beds, an important habitat for shellfish and other marine organisms. This tiny algae has bloomed each year since 1985 along the Long Island area, affecting multi-million dollar scallop and blue mussel industries.

Another mode of suffocation for fish in cage culture operations (such as salmon and trout) that has been attributed to red tides has been a "clogging of the gills." In France, during 1987, rainbow trout were found dead. Red-tide organisms were found trapped in the gills, causing irritation and mucus secretions, and a lowering of the rate for oxygen exchange. Caged salmon on the coast of British Columbia have also suffered mortalities due to this effect. In this case, the red-tide organism responsible, *Chaetoceros convolutus*, has bullet-shaped cells with spines extending from their corners that can break off in the fish gills and penetrate the membranes. The cause of death is due to either capillary hemorrage or to suffocation from an oversecretion of mucus.

Another interesting phenomenon occurred in southeastern Australia during 1987. It has been suggested that a red tide was responsible when mussels, scallops and oysters developed a bitter taste so unpleasant and persistent that they were unable to market the shellfish for 7 months (long after the disappearance of the red tide). After the 7 months, the shellfish became diseased and died.

Mortalities in marine animals can also be related to toxins produced by many red-tide algae. Although little is known about how or why these algae make toxins, the toxins produced are among the most potent natural poisons in the world. Different algae produce different toxins. Some may cause mortalities in marine animals by direct consumption of the red-tide organisms through feeding, or death may be more indirect where toxins are transferred through the food chain. In other words, the toxins are produced by the algae, toxins are concentrated by grazers (which are not killed by them) and illness or death results in animals feeding on the grazers. An incident of this kind may have occurred in late November 1987, where 14 humpback whales died in Cape Cod Bay after eating mackerel that contained a toxin produced by a red tide (*Alexandrium* sp.) responsible for paralytic shellfish poisoning in humans. A similar situation occurred in the Bay of Fundy in eastern Canada in 1976 and 1979, when hundreds of tons of Atlantic herring died as a result of feeding on organisms that had in turn fed on the red-tide organisms that produce paralytic shellfish toxins. Other fish are also sensitive to the toxins (i.e. salmon, cod, pollock, flounder, etc.), raising the possibility that other fish may be killed during *Alexandrium* blooms. In 1984, 27 of 35 tonnes of rainbow trout and Atlantic salmon from aquaculture operations died in the Faroe Islands as a result of PSP. Fish, however, only accumulate the toxins in their digestive or gastrointestinal tract and not in their muscles or meats, thus not affecting their market ability as long as they are "gutted."

Florida's west coast is well known for its frequent red tides, some of which result in extensive fish kills. The organism responsible *(Ptychodiscus brevis)* produces a toxin thought to affect fish through the gills. Since these organisms are very fragile, they break or lyse as they pass over the gill filaments. This allows the toxin produced to be efficiently absorbed into the bloodstream. The toxin bursts the red blood cells that the fish require for oxygen uptake. Aquatic organisms other than fish can also be affected as was discussed during a recent much publicized occurrence in the spring of 1989. An article in the *St. Petersburg Times* (Apr. 14, 1989) recounts:

> "Mantanee and Pinellas beaches were mostly clear of dead fish Thursday as an outbreak of Red Tide seemed to subside... While beaches are looking better, the situation is bad at the Suncoast Seabird Sanctuary Inc., where scores of sick birds (cormorants) — apparently poisoned after eating Red Tide-tainted fish — are being brought in... The birds appear drunk... they can't balance at all, their equilibrium is totally off, they thrash around."

The Florida red-tide organism also produces an irritating "gas." Water from the red tide becomes an aerosol as a result of wind-produced surf. When the winds blow the odorless spray ashore, humans experience stinging eyes and nostrils, a burning throat and severe coughing symptoms of colds. These effects are, however, only temporary and only occur if there is a wind. This particular red tide affected the tourist industry, as mentioned in the *St. Petersburg Times* on Apr. 11, 1989:

> "... several beachgoers came to the emergency room complaining of respiratory irritation. Red Tide has been dumping dead fish on Florida beaches since at least 1844, but back then it wasn't such a big deal... Now thousands of people live and vacation on the beaches, and stinking fish aren't attractive."

How Do Red Tides Contaminate Shellfish and Affect Human Consumers?

Red-tide organisms are an important food source for many filter-feeding shellfish. In many cases, the shellfish accumulate toxins from the organisms and store them in their tissues. Although the shellfish themselves show little effect from these toxins, illness or death can occur in vertebrate or human consumers of the shellfish. There is no visual method for examination of the shellfish — either external or internal — to separate toxic from non-toxic individuals. The toxins, however, do not concentrate in the meats or muscles of scallops, making the meats continually toxin free. Since this is the only portion of the scallop harvested in most regions in Canada, there is no public health risk involved.

The most common of the toxic syndromes are Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP). More recently, or since late 1987, Amnesic Shellfish Poisoning (ASP) has become a problem in eastern Canada.

Paralytic Shellfish Poisoning:
The first report of PSP in Canada was from the diary of the naturalist and surgeon from Captain George Vancouver's expedition to the Pacific northeast. Three members of the expedition were exploring British Columbia's coast and were presumed to have eaten blue mussels. Typical symptoms of PSP are described in Mr. Menzies' diary on June 17, 1793:

> "Near the head of this arm they stopped to breakfast on the morning of the 15th where the people finding some good looking mussels about the rocks and shores, boiled a quantity of them...but unfortunately for them... these mussels proved to be of a deleterious quality as all those who had ate of them in any quantity were, soon after they embarked, seized with sickness, numbness about the mouth, face and arms, which soon spread over the whole body accompanied with giddiness and general lassitude; this was the case with three of the crew of the Discovery's boat...One of them, John Carter, puked a great deal, and found himself so much relieved by it that he kept pulling on his oar till about one o'clock when the whole party stopped to dine; but in attempting to get out of the boat he was so weak and giddy that he fell down and he and the other two were obliged to be carried to shore. On this, Mr. Johnstone instantly directed a fire to be kindled and plenty of warm water to be got ready as soon as possible, that each of them might drink a sufficient quantity of it to operate as an emetic...but, before it could be got ready, John Carter became very ill...his pulse becoming weaker and weaker, his mouth and lips appearing black and his face and neck becoming much swelled together with faintness, general numbness and tremor. Under these circumstances he gradually sank without much struggle and expired just as soon as they were offering him the first draught of warm water which he was unable to swallow, and this sad affair happened within five hours from the time of his eating the mussels."

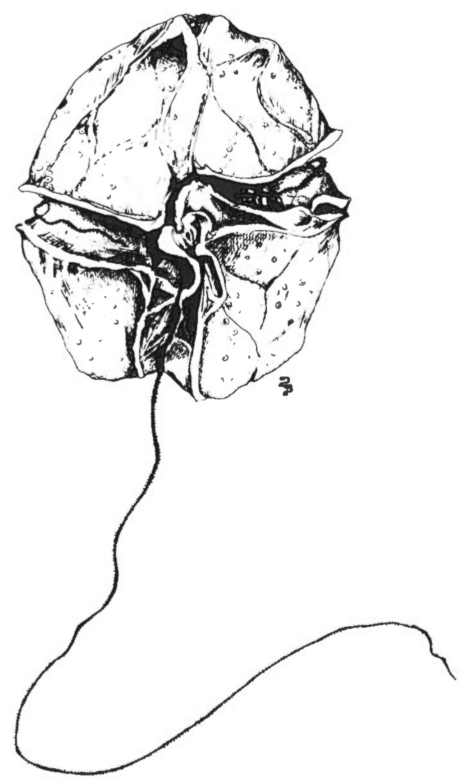

FIG. 1. A drawing of an organism responsible for paralytic shellfish poisoning in Atlantic Canada, *Alexandrium fundyense* (illustration by D. Beatty).

Ingestion of shellfish contaminated with PSP toxins results in disruption of nerve function and paralysis (and hence the name "paralytic shellfish poisoning"). Death usually occurs as a result of asphyxiation or respiratory paralysis. This action is fairly fast and there is no antidote for the present. In extreme cases, just eating several clams or mussels have been fatal to humans. Interestingly, the nerve cells in marine shellfish are not sensitive to the toxins.

The marine red-tide organisms that have been found to produce PSP toxins in Canada are the *Alexandrium* species (Fig. 1) (*Alexandrium* is now the accepted name for those harmful algae previously referred to as *Gonyaulax/Protogonyaulax/Alexandrium* and *Gessnerium*). PSP toxins are wide spread and found in a number of areas throughout the world. The organisms responsible on the Pacific coast of Canada are *Alexandrium catenella* and *A. acatenella*, whereas on the Atlantic coast, its relatives *A. tamarense* and *A. fundyense* are responsible. Occurrences in Canada have been widespread, with occurrences on the Pacific coast along the entire coast of British Columbia (Fig. 2) and on the Atlantic coast (Fig. 2) in the St. Lawrence River estuary, the Gulf of St. Lawrence, Chaleur Bay, the Bay of Fundy and isolated areas in Newfoundland. Although the water seldom actually becomes discolored, these organisms usually bloom annually along both coasts of Canada, causing many areas to be closed to the harvesting of shellfish. *Alexandrium* blooms in British Columbia have remained the same in intensity in recent years, whereas on the Atlantic coast, there have been outbreaks in shellfish toxicity in new areas — such as Newfoundland, southwestern Nova Scotia and the Gulf of St. Lawrence. Also, since 1980, some shellfish harvesting areas in the Bay of Fundy, previously closed seasonally, have remained closed year round as a result of unacceptable levels of toxins in shellfish tissues.

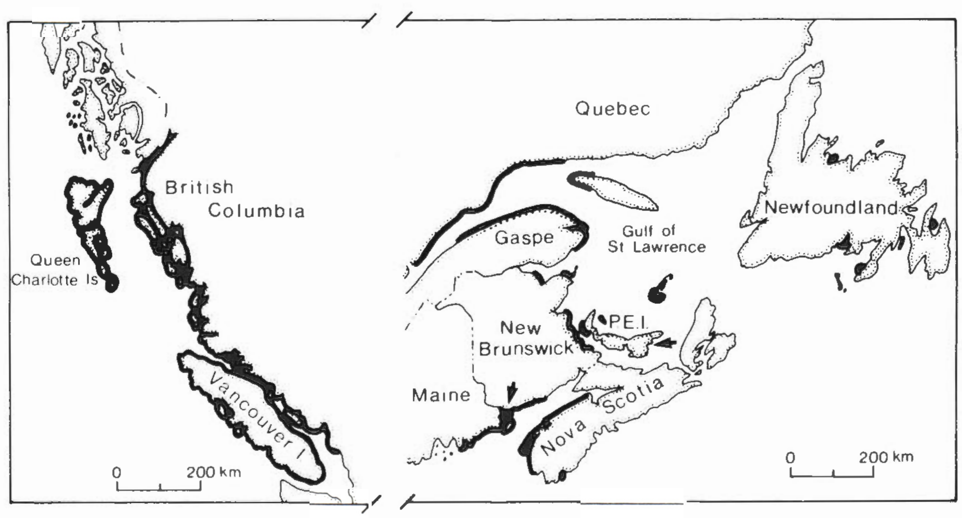

FIG. 2. The locations along Canada's Atlantic and Pacific coasts where shellfish are known to accumulate toxins from red tides. Darkened locations show areas affected by paralytic shellfish toxins. Shellfish areas designated by arrows on the Atlantic coast have been affected by domoic acid.

Diarrhetic Shellfish Poisoning:

Diarrhetic Shellfish Poisoning (DSP) is a recently described intoxication which involves human consumption of shellfish containing DSP toxins. These may be produced by one of several species of the red-tide organism, *Dinophysis* sp. (Fig. 3). There is no record of the water ever being discolored by this organism. The majority of DSP problems have been reported in Japan and Europe; however, the organisms are very much cosmopolitan so that as the knowledge of DSP broadens, the reported incidences may also grow. Many countries — including Canada, Chile, Denmark, France, Ireland, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, Thailand and the United States — now either are conducting scientific studies or are monitoring in response to either confirmed or suspected DSP illness episodes.

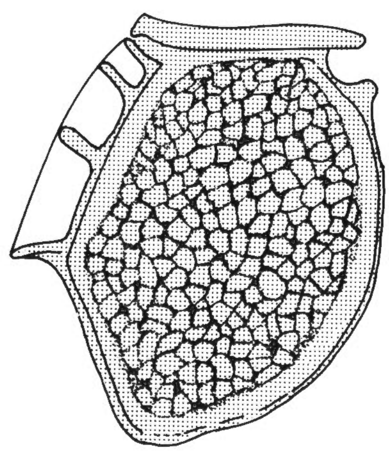

FIG. 3. One of the organisms responsible for diarrhetic shellfish poisoning, *Dinophysis* sp.

The main symptom of DSP is reflected in the name. As well as mild to severe diarrhea, many suffer from nausea and vomiting, abdominal pain and cramps and may be accompanied by chills. To date, there have been no records of mortality as a result of consuming shellfish containing DSP toxins. Recovery is usually by the third day.

Amnesic Shellfish Poisoning:

Prior to late 1987, the concern of monitoring agencies in Canada was for the red-tide organism producing toxins that can cause paralytic shellfish poisoning. The southern Gulf of St. Lawrence, including Prince Edward Island, had no previous documented incidences of shellfish accumulating toxins in their tissues. It was thought to be an ideal location for the culture of bivalves. This changed in November and December of 1987 when mussels in several estuaries became toxic following an intense bloom of a microalgae not previously known to produce a toxin. Approximately 150 poisonings were confirmed and 3 people died from a new toxin not previously known in shellfish.

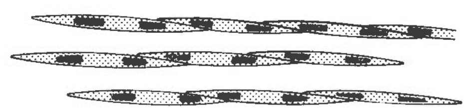

FIG. 4. A sketch of one of the organisms, *Nitzschia pungens* forma. *multiseriata* known to produce domoic acid in eastern Prince Edward Island.

Symptoms of the Amnesic Shellfish Poisoning (ASP) included gastric (within 24 hours) and neurological signs such as dizziness, disorientation and memory loss (within 48 hours). Several months later, some of those over 40 years old that had been affected still showed neurological symptoms and short-term memory loss. The toxin responsible for this poisoning, domoic acid, binds to various areas in the brain which results in memory loss. Organisms from the southern Gulf of St. Lawrence found to produce domoic acid were both planktonic or floating (*Nitzschia pungens* forma. *multiseriata*) (Fig. 4) and benthic or bottom algae (*Amphora coffaeformis*). Domoic acid was also found in soft-shell clams and blue mussels during 1988 in southern New Brunswick. The organism responsible in this case was a smaller and different species of *Nitzschia (Nitzschia pseudodelicatissima)*.

How Are Shellfish Tested for Red-Tide Toxins?

Insuring a non-toxic supply of shellfish to consumers is the responsibility primarily of regulatory (usually governmental) agencies and, to a lesser degree, the harvesters and processors. The danger of PSP, DSP and ASP to public health and industry has necessitated the establishment of shellfish surveillance programs in countries with problems where shellfish accumulate toxins from red-tide organisms in the marine environment. Monitoring programs rely on the availability of rapid and accurate ways of measuring levels of various toxins in the shellfish tissues. Canada's shellfish toxicity monitoring program has been in existence since 1943 and is considered to be one of the best in the world. Similar programs have been initiated by other countries. Shellfish are sampled regularly from selected sites on Canada's east and west coasts, although sampling on the Pacific coast is the more difficult since many sampling points are far removed from centers of population. These sites have been selected on the basis of extensive monitoring and toxicity data from affected shellfish-producing areas. Fish inspection officers or other designated personnel from the Department of Fisheries and Oceans collect samples in all areas affected by marine toxins. Extracts are made from the collected shellfish at local or nearby federal Department of Fisheries and Oceans inspection laboratories and assays are conducted to determine if toxins are present. If toxicity results and it exceeds the limit for a particular toxin, affected areas are closed for harvesting (Fig. 5).

The only method currently approved by the World Health Organization for analysis of marine toxins is the mouse bioassay which involves injection of shellfish tissue extracts into mice and observation for symptoms of toxicity. The mouse bioassay gives a "total toxicity" value since it is not specific to any particular toxin and will indicate the presence of PSP, DSP, domoic acid or any other toxin in a sample. The mouse bioassay test can act as a warning that further investigation is needed. For example, the domoic acid story occurred in eastern Canada in late 1987. There had been no monitoring program in P.E.I. since there had been no previous record of toxic shellfish in that area. When a link was made between illnesses and toxic mussels, extracts from the shellfish were immediately run through the bioassays and, although the initial tests were negative for PSP, the mice did not behave normally and subsequently died. A public health warning was issued against eating mussels from that area. The Department of Fisheries and Oceans halted shipments of shellfish from registered processors and closed harvesting areas. Further tests indicated the toxin to be produced by red-tide organisms.

Although the mouse bioassay is useful and covers a broad spectrum, it does have several disadvantages. It can be very costly, requires the maintenance of large numbers of mice and is time consuming. As well, some European countries are in the process of banning the use of live animals for testing procedures. Newer analytical techniques are still in the experimental stages; however, they show promise as being faster, more sensitive and more accurate. Separation techniques such as High Performance Liquid Chromatography (HPLC) can separate the toxins, show their distributions and provide a greater understanding of the distribution in nature including the biochemistry and chemistry involved. Immunological tests are being developed in Japan and Canada for detection of DSP and PSP toxins in shellfish above the regulatory levels.

In conjunction with some of the shellfish monitoring programs in Canada, phytoplankton monitoring surveys are being conducted. At present, these are primarily research tools requiring highly trained personnel for the identification and enumeration of phytoplankton species. Phytoplankton monitoring can, in some cases, serve as an early warning indicator for some harmful blooms. These studies also establish baseline data in areas of salmonid aquaculture.

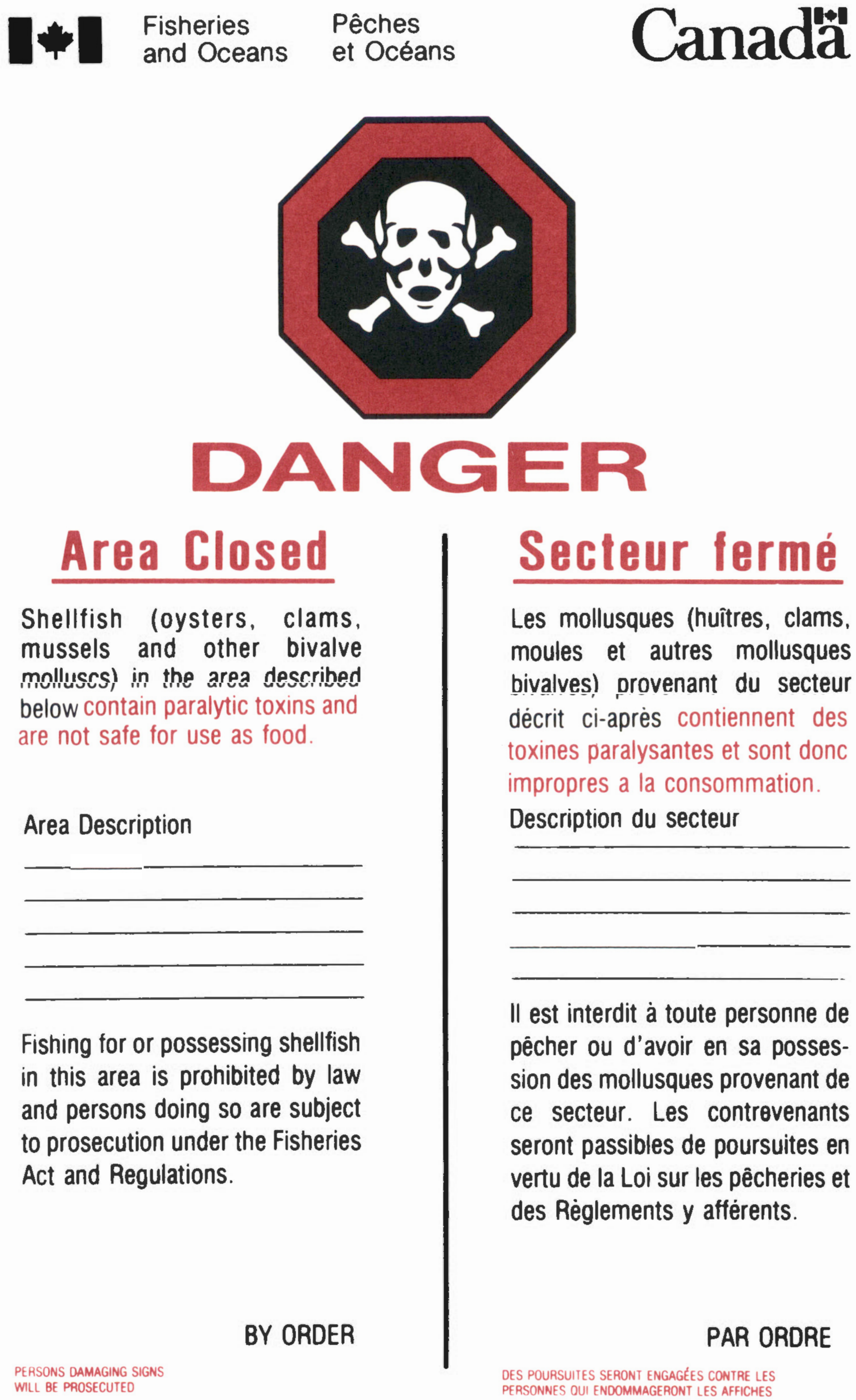

FIG. 5. A sign posted to notify the public of a shellfish area closure due to the shellfish containing toxins produced by red-tide organisms.

What is Being Done About Red Tides?

Red tides — harmful and non-harmful — have a long history and are a "fact of life" or a part of nature. However, there appears to be a global increase in the numbers of these events in recent years. Questions one might ask are: Is this increase real or the result of closer monitoring? If real, what are the causes of this increase? Is there increased coastal pollution and is this having an effect on algal blooms? These questions are not easily answered. Scientists are looking for possible explanations. Those involved in studying red tides are now better informed through international exchanges of scientific knowledge. They also have improved analytical capabilities for the detection of individual toxins. Studies are ongoing to determine whether red tides may be stimulated by coastal pollution and whether the use of inshore waters for shellfish and finfish farming causes a nutrient enrichment from feed and/or excretion products. Also, researchers are studying the theory that introducing an aquaculture operation could make an existing organism that may be harmful or toxic more noticeable. This may have been the case in the Gulf of St. Lawrence with the domoic acid incident and the mussel industry.

The spreading of red tides, however, cannot be blamed solely on man's changing of the coastal environment. Currents, tides or other major water movements certainly must play an important part in the dispersal of organisms. These transport mechanisms are also being explored. The occurrence of PSP in the Magdaleine Islands, northeastern New Brunswick and western Prince Edward Island in 1988, places with no previous recorded outbreaks, is indicative of the spreading. The organism may have been present for a long time at low concentrations but not with ideal conditions for blooming or cells may have been transported from the St. Lawrence estuary or other regions by water masses or other dispersal methods.

The possibility exists that cyst (or winter) stages or resistant microalgal spores (from red-tide algae) may be introduced to areas either through the ballast holds of large cargo ships or through shellfish stock transfer between regions. To minimize the transport of toxic or harmful algae from one region to another, most countries either have a ban on transferring shellfish stocks from one area to another or shellfish to be transported must be certified disease-free and waters and sediment from which they were collected must have been free of harmful or toxin-producing organisms. PSP was first noticed in southern Tasmania in 1980 and two human poisonings resulted in 1986. Spores have been found in sediments from ballast tanks of incoming Japanese ships to Tasmanian ports. As a first control measure, a law has been established forcing ships enroute to Tasmania to exchange the waters in their ballast tanks in mid-ocean.

Extensive surveillance programs are in existence throughout many countries to monitor both phytoplankton blooms and the uptake of toxins. These are continually being expanded and modified so as to ensure safe products to the consumer. When necessary, there are permanent closures of some shellfish areas to harvesting and temporary closures of other areas. Since 1980, in the Bay of Fundy, there have been several prime shellfish harvesting areas closed year round because of unacceptable PSP toxin levels. Studies have been undertaken to try and determine why these shellfish are not able to rid themselves of the toxins during non-bloom periods. The possibility that shellfish from these areas may be biologically different from other areas is being investigated.

Shellfish may remain toxic for varying lengths of time after exposure, depending on the organism, toxin load, area and time of year. A depuration or cleaning of the toxin from shellfish would enable them to be marketed (plants for depurating bacteria from shellfish have been in existence for a long time). Although depuration of PSP toxins will eventually occur in red-tide-free seawater, it takes too long to be economically feasible. By contrast, mussels containing domoic acid can rid themselves of toxins in a few days when held in clean water.

Research is continuing on the development of chemical and immunological assays for the measurement of toxins. An immunoassay test for PSP has been formulated and has potential for use as a rapid diagnostic method. Although it is costly and still in the experimental stages, the ultimate idea is simple and toxicities can be determined rapidly.

As previously mentioned, indications in recent years point toward a major expansion in red tides. The geographic extent, frequency, magnitude and the number of different organisms implicated tends to be growing throughout the world. Although research on red tides is ongoing at many laboratories the world over and much new information has been unravelled in the past few years, there is so much still to find out. Examples of studies being conducted include: causes for increased blooming, whether it is caused by coastal pollution or naturally occurring environmental phenomena; mechanisms for bloom formations; further studies on toxin uptake and effects in shellfish and other members of the food chain; remote sensing to follow bloom patterns, etc. Links are presently being investigated between bacteria and toxin production for some red-tide organisms. Long-term time series results from shellfish toxicities and phytoplankton blooms are proving essential to determine patterns or trends that may be used in modeling and predicting blooms such as in the Bay of Fundy. Records from these date to 1943, suggesting that the intensity of *Alexandrium* blooms and shellfish toxicities may be linked to an 18.6-year tidal cycle. Many countries are in the process of collecting data to establish similar data bases. Ships' ballast waters and other means of dispersal of organisms such as currents, frontal regions or movement of water masses are being explored. A greater knowledge is being sought for the mechanisms or effects of harmful red tides on both marine finfish and mammals since they both seem to be affected more in recent years. Scientists are now more concerned with studying all algal species since new organisms are being implicated as harmful that were not previously thought to be a threat, such as the recent *Chrysochromulina polylepis* bloom in Scandanavia, the "brown tide" in the United States and Amnesic Shellfish Poisoning in Canada. Other such unexpected consequences may occur.

Many parts of the world are suffering the consequences of red tides; many more scientists are working on the problems in recent years; however, the problem still exists and a remedy is not on the horizon as yet.

Further reading

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