Harmful algal blooms on the U.S. west coast

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Introduction and historical background

In the U.S, the two major toxic syndromes caused by harmful algal blooms (HABs) that are found along the entire west coast are paralytic shellfish poisoning (PSP) and domoic acid poisoning (DAP), also known as amnesic shellfish poisoning (ASP). Certain species of phytoplankton from the genus *Pseudo-nitzschia*, and the genus *Alexandrium* are concentrated by filter-feeding shellfish and finfish which when consumed by humans, marine mammals, or birds can result in ASP and PSP, respectively. Specifically in the subtropical region of Hawaii, ciguatera fish poisoning (CFP) is also known to be a problem, caused a nerve poison, ciguatoxin, produced by the dinoflagellate, *Gambierdiscus toxicus*. Other harmful species, including the raphidophyte, *Heterosigma akashiwo*, and the diatoms from the genus *Chaetoceros*, kill fish at aquaculture sites, but are not known to be harmful to humans. Water discolorations (red tides) caused by noxious phytoplankton, such as *Noctiluca scintillans* and *Ceratium* spp., also occur throughout the area and are noted to be nuisance species but are not included in this summary. This report will focus on those algae that produce toxins known to be harmful to humans.

The earliest recorded PSP event on the U.S. west coast occurred in 1799, and was documented by Aleksander Baranov, the chief manager of the Russian-American trading company. A party of Aleut hunters under his command paddled to a place called Khutznov Strait, later to be called Peril Strait, where the Natives collected and ate some small, black mussels that were abundant in the area. Two minutes later about half the party experienced nausea and dryness of the throat. Two hours later, about a hundred Aleut Indian hunters had died. Some survived by eating a mixture of gunpowder, tobacco, and spirits to induce vomiting.

Each U.S. west coast state, including Alaska, Washington, Oregon, California, and Hawaii have different monitoring programs for HABs that are described in the sections that follow. Each state has a contact person and/or public hotline number for the most current toxin test results (Table 15). In each state, the mouse bioassay is the standard test for PSP toxins approved by the U.S. Food and Drug Administration. The test procedure uses extracts of toxins from 100 grams of tissue. This extract is injected into 3 mice 18-23 grams in weight. The amount of time required for the mice to die is recorded then converted to micrograms (μg) of toxin per 100 g. The regulatory limit for safe harvest of shellfish and crab, set by the U.S. Food and Drug Administration, is 80 μg toxin per 100 g shellfish tissue. The analytical technique used for domoic acid testing is high performance liquid chromatography (HPLC), which measures levels of toxin in a sample by comparison to a known quantity of purified standard. The regulatory limit for safe harvest of shellfish is 20 ppm (part per million) domoic acid and for Dungeness crab viscera is 30 ppm.

Table 15 Marine biotoxin hotline numbers in the United States.

Alaska	(800) 731-1312
Washington	(800) 562-5632
Oregon	(503) 986-4728
California	(800) 553-4133
Hawaii (Food branch)	(808) 586-4725
Hawaii (Epidemiology branch)	(808) 586-4586

Because the U.S. west coast covers such an expansive area with different toxic species, ranges in toxin levels, and economic impacts due to HABs, each of the states will be considered separately in this report.

Alaska

Testing

The immense coastal area of Alaska makes PSP testing impossible in all regions where shellfish and crabs can be harvested. Therefore, testing for PSP and ASP is done only in areas of commercial operations. When recreational harvesting is permitted in a given area, it is because there is also a commercial operation in the vicinity. Because such a small area of coastline is monitored relative to areas where shellfish can be found, at least one human illness is documented each year. This is due, in part, to the rich Native American cultural tradition of eating shellfish for subsistence in Alaska. At times it may be difficult for Native Americans and other people living in remote areas to resist the temptation of harvesting shellfish from non-certified areas. An epidemiological study estimated that Alaskan natives are ten times more likely to contract PSP than the average resident of Kodiak, a population frequently exposed to PSP toxins (Gnessner and Schloss 1996).

In Alaska between 1973 and 1994, 143 people were believed to have become sick due to PSP. During 1995-2000, at least 51 people became ill. Due to under-reporting of illnesses, or misdiagnosis, the number of people suffering from PSP in Alaska is likely to be 10-30 times higher than reported. Annually, most of the illnesses occur in May and June (Fig. 28). Among the 61 outbreaks where the shellfish species was known, most involved the ingestion of butter clams (*Saxidomus giganteus*) and mussels (*Mytilus edulis* or *M. californianus*). Cockles (*Clinocardium nuttalli*), razor clams (*Siliqua patula*), and littleneck clams (*Protothaca staminea*) were also eaten and caused some of the illnesses. It is interesting that most outbreaks of PSP occurred on Kodiak Island, the southern edge of the eastern half of the Aleutian Islands and Southeastern Alaska. No outbreaks of PSP have yet resulted from shellfish collected from Cook Inlet. The most common symptoms of PSP were paresthesis (tingling on skin), lip numbness and tingling, nausea and numbness of extremities (RaLonde 1996). In Alaska, shellfish (oysters, mussels or clams), crab (king crab, Dungeness crab, Tanner crab, Hair crab), and sea snails (*Fusitriton orgegonensis*) are tested for PSP.

Alaska's current bivalve shellfish fishery consists of the native littleneck clam, razor clam and geoduck clam. A PSP sampling plan for commercially or aquaculturally-produced shellfish, crabs, and snails is implemented by the Alaska Department of Environmental Conservation (ADEC) from its single testing laboratory located in Palmer, 60 km north of Anchorage. There is no agency responsible to monitor beaches for recreational or subsistence harvests. The ADEC regulations require strict compliance with a tiered program that decreases sampling requirements after set time periods of PSP-free samples. Not only do the shellfish and aquaculture operations pay for the collection and shipping of samples, a dry, temperature-controlled holding facility is required for storage of the harvest out of water until the laboratory tests are completed. Consequently, PSP not only causes direct economic impact during toxic events, but the coast of shipping, testing, and storing commercially-harvested shellfish also increases the cost of doing business. Domoic acid testing is done only for the one commercial razor clam operation on the east side of Cook Inlet. Because of this testing, a recreational razor clam fishery on Cook Inlet is allowed.

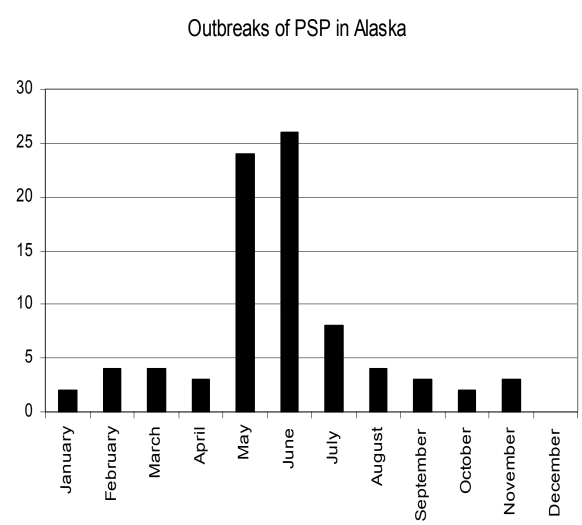

Fig. 28 Reported PSP cases in Alaska from 1973-1994 (from Gnesser and Schloss 1996).

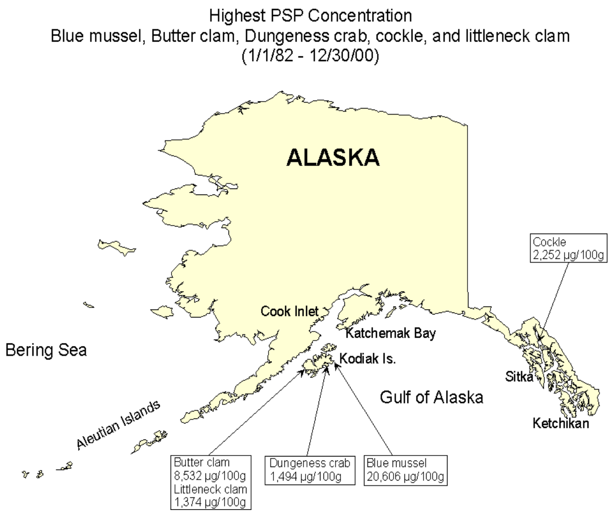

Fig. 29 Locations and levels of highest PSP toxin measured in blue mussel, butter clam, Dungeness crab, cockle, and littleneck clam.

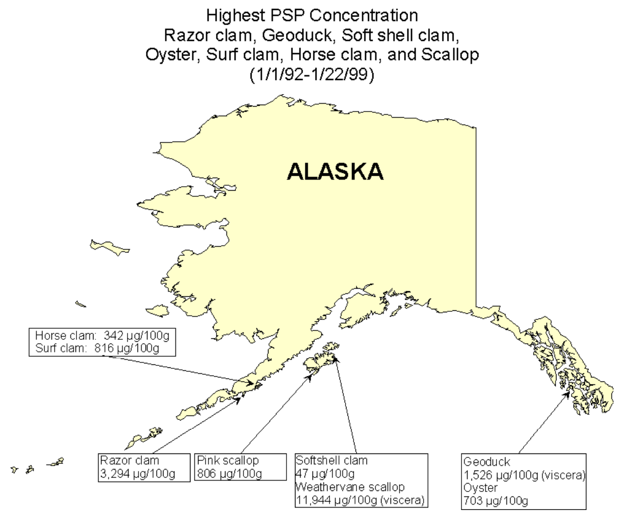

Fig. 30 Locations and levels of highest PSP toxin measured in razor clam, geoduck, softshell clam, oyster, surf clam, horse clam, and scallop.

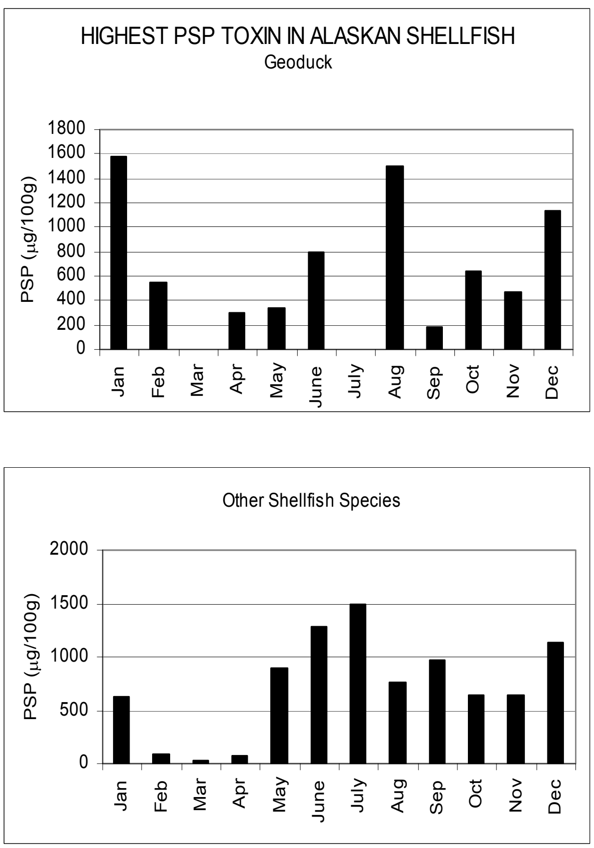

Fig. 31 Highest PSP toxin in Alaska by month for the year 2000.

Seasonality

The highest PSP levels in all shellfish species tested are shown in Figures 29 and 30. There has been some recent documentation of PSP in Alaska where no prior occurrences have been seen.

The seasonality of PSP in Alaska is dependent on shellfish species and location. However, the earliest incidence of PSP in March-May of each year is generally in the Juneau area (SE Alaska). Human illnesses have also been documented in this area more frequently than when monitoring began. High PSP levels are measured farther north (north of the Aleutian chain) later in the spring and early summer. Shellfish south of the Aleutian chain often have high toxin levels whereas areas north of the chain are often toxin free. Generally, all areas have lower levels of PSP in the spring (Fig. 31, example from 2000), while summer and early winter are times when high levels of PSP are generally observed. However, some exceptions exist. In Steamboat Bay (SE Alaska) and Grabina Island (outside Ketchikan), geoducks are toxic all year. In Simons Bay (outside Sitka), an area that is generally free of PSP, there was one peak level of PSP in January 1996 (240 µg/100g). The highest level of PSP ever measured in Alaska was 20,606 µg in blue mussels at Kamisan Bay, Kodiak Island on May 27, 1997 (Fig. 29).

PSP has been measured recently in oysters in SE Alaska where there had been no problem. There is limited testing for ASP in Alaska and levels have been near the detection limit since 1991. The highest was 11 ppm in blue mussel in Cook Inlet.

Causative organisms

Three species of *Alexandrium* occur in Alaska (Scholin and Anderson 1994). *A. catenella* (Whedon and Kofoid) Balech occurs in estuarine and open coast environments from southern California to southeast Alaska, forms chains and blooms when the water temperature is about 20°C. *A. tamarense* (Lebour) Balech, prefers cooler temperatures and less saline waters than *A. catenella*. It has been found in the Gulf of Alaska (RaLonde 1996). *A. fundyense* Balech has been found at Porpoise Is., Alaska. These are the primary species believed to cause PSP in Alaska.

Pseudo-nitzschia species occur from at least Point Barrow (R. Horner, pers. comm, documented by Bursa 1963 as *Nitzschia seriata*) and probably throughout the Bering Sea (listed as *Nitzschia* spp. section *Pseudonitzschia* from shelf-break stations near Unimak Pass by Schandelmeier and Alexander 1981). *Pseudo-nitzschia* spp. probably occur throughout the Gulf of Alaska (records from American Mail Line ships of opportunity cruises between Seattle and Yokohama in 1968-1972). *Pseudo-nitzschia* are also known to occur in Port Valdez since the early 1970s (Horner *et al.* 1973). However, all of the earlier records are of *N. seriata*, which is possibly identified correctly to the species level for the farthest north samples, but is probably not identified correctly for all of the Gulf of Alaska and for Southeast Alaska.

Economic impacts

Alaska has the largest, most productive fishery (shellfish and fish) in the U.S., contributing 54% to the total U.S. landings. The cost of PSP to the commercial fishery, recreational harvest, and aquaculture surpasses $10 million annually (RaLonde 1996). The economic consequences of PSP in Alaska have drastically affected the development of a clam fishery, where an estimated 50 million pounds are available for harvest (U.S. Department of Interior 1968). In 1917, five million pounds of shellfish were harvested from Alaskan waters, but today the state's commercial bivalve industry is virtually nonexistent. The value of the sustainable, but presently unexploited, shellfish resource in Alaska is estimated to be $50 million per year (Neve and Reichardt 1984). An example of the impacts of PSP to a specific fishery is realized in the reduced value of the geoduck fishery. In 2000, the geoduck fishery was receiving $1.60 per pound for processed geoduck that needed evisceration. The price for whole geoduck, in contrast, was $7.00 per pound. Because of the uncertainties of PSP levels in this commercial shellfish, most of the harvested geoduck needed to be sold as eviscerated product. In 1998, the value of the geoduck fishery was $1.2 million. Because processing was required, however, the actual value of the final product was about $500,000, resulting in a loss of revenue of almost $800,000.

The potential problem of PSP and the associated testing requirements are major factors preventing development of a surf clam (*Spisula polynyma*) harvest in the Bering Sea. The sustainable harvest of the Bering Sea surf clam is estimated at about 29,000 metric tons with an annual worth of about $9 million (Hughes *et al.* 1977). The harvest of other clam species that are affected by PSP and net worth of these fisheries is shown in Table 16. Further information about the impacts of both PSP and ASP on Alaskan fisheries can be viewed at http://www.nwfsc.noaa.gov/hab/newsletter/HAB_impacts_Alaska.htm

Table 16 Average commercial clam harvest (*tonnes)* and income in US dollars (thousands), 1990-1999.

Little neck clam				Razor clam		Geoduck clam	
Southeast Alaska		Kachemak Bay		Cook Inlet		Southeast Alaska	
Harvest*	Income	Harvest*	Income	Harvest*	Income	Harvest*	Income
3.5	21.3	23.0	68.4	131.4	156.1	100.9	499.5

* Based on ex-vessel price to the fishermen averaged over the fishing season price (Frenette *et al.* 1977).

Washington State

Human illness due to PSP has been a problem in Washington State. In May 1942, a severe outbreak of PSP near the northwestern Washington town of Sekiu, resulted in the death of two Elwha Indian children and one adult male. At the same time, there were numerous reports of dead cats, dogs and chickens that had been feeding on the clam waste from the outer coast of Washington State. In late August 2000, an outbreak of PSP in mussels from South Puget Sound, at levels of 13,769 μg/100 g, resulted in the illness of nine people. These were recreational harvesters who had collected and consumed blue mussels within a closed area. Five were hospitalized and three of the five were placed on artificial respiration. Two required artificial respiration for about 1 week. One came very close to death, even with medical intervention.

Testing

The Washington State Department of Health (WDOH), in cooperation with the George Williams Hooper Foundation for Medical Research at the University of California in San Francisco, began a shellfish toxicity surveillance program in the early 1930s. In 1942, the WDOH and the Washington Department of Fisheries (WDF) imposed a closure from April 1 until October 31, for the recreational harvest of all bivalve mollusks along the northern and western Washington coastline. In June 1957, PSP monitoring was re-established to include all species of commercially harvestede shellfish in North Puget Sound and the outer coast, after WDOH was advised of the prevalence of PSP in British Columbia shellfish. Only minimal monitoring of recreational shellfish harvesting areas was conducted until 1971. Recreational shellfish harvesting opportunities have been severely restricted since the mid-1970s because of more frequent occurrences of PSP and higher levels of measured toxin (Taylor and Horner 1994). Recently, closures due to PSP toxins in shellfish in Puget Sound are widespread, as seen in the data for the year 2000 (Fig. 32).

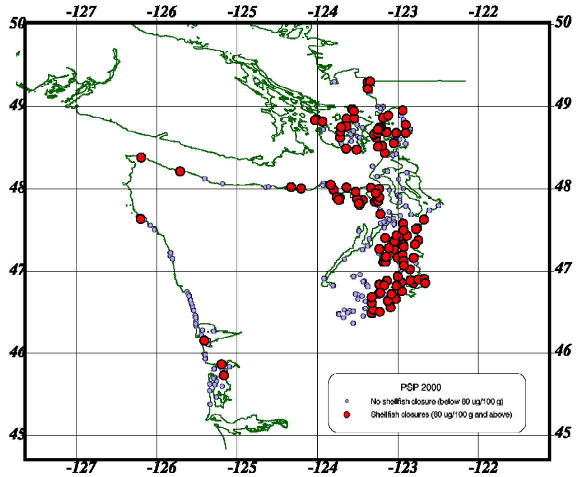

Fig. 32 Locations where closures due to PSP (red circles) occurred in 2000 due to levels of toxin in shellfish at or above 80 μg/100g. Low levels (below 80 μg/100 g) are also shown as smaller blue circles.

Selected representative commercial shellfish operations must submit samples for PSP testing on a biweekly basis during winter and spring, and as often as weekly during summer and fall. Selected recreational areas are sampled weekly from April through October by state and county health departments, with sampling often done by volunteers, including the Puget Sound Restoration Fund program. Since 1989, WDOH has used caged blue mussels (*Mytilus edulis*) as an early warming system for PSP. Mussel cages are located at over 70 sites, most of which are monitored biweekly throughout the year.

Mussels are also routinely used by WDOH to test for domoic acid, but clams and oysters from commercial sites are also used. In addition, the Washington Department of Fish and Wildlife (WDFW), formerly the Washington Departmnt of Fisheries and coastal Tribes (including the Quinault, Quileute, and Hoh tribes) collect razor clams in a number of management areas along the open coast, and these are analyzed by both WDOH and the U.S. National Marine Fisheries Service, Northwest Fisheries Science Center as part of the Olympic Region Harmful Algal Bloom (ORHAB) project (see below).

Retention time of domoic acid in razor clams is extremely long, and the record levels of toxin, approaching 300 ppm in October 1998, took until the fall of 1999 to depurate to below the regulatory level.

A routine phytoplankton monitoring program (ORHAB) was established in Washington State in 2000, with a primary focus on the coastal *Pseudo-nitzschia* species that produce the domoic acid toxin. This 5-year project, funded by NOAA's National Ocean Service, is a collaboration among federal, state (including Indian tribes), local, and private agencies to determine which physical, biological, and chemical factors promote and sustain HABs on the Washington coast. One of the findings of this project allowed the level of domoic acid in razor clams to reach 20 ppm (from 15 ppm), resulting in increased openings on coastal beaches since the fall of 2001.

Deaths of finfish reared in net pens in Puget Sound have been caused by members of the diatom genus *Chaetoceros* at least since 1961 (Bell 1961). Fishes exposed to *Chaetoceros* show massive discharge of gill mucus, causing lamellar degeneration and separation. The biological impacts of this organism as well as those algae that discolor seawater (*Noctiluca scintillans*) and organisms causing some damage to oyster larvae (*Ceratium fusus*) and spot prawns (*Akashiwo sanguinea*, reported as *Gymnodinium sanguineum*) through unknown mechanisms are problems but are not discussed in detail here.

A species that deserves special note because of the great economic distress it has caused to fish farming operations is *Heterosigma akashiwo* (also called *H. carterae* or sometimes erroneously, *Olisthodiscus luteus*). Although there were early reports of a fish kill near Lummi Island in Puget Sound in 1976, and another in central Puget Sound (Manchester) that were attributed to *Heterosigma*, the first confirmed fish kill due to *Heterosigma* was in 1986. In that year, a bloom covering >7000 km^2 caused $4 million losses to aquaculture operations in Washington (Horner *et al.* 1991). In 1990, a bloom in central Puget Sound killed about 1.3 million fish valued at $4-5 million (Horner *et al.* 1991).

The exact mechanism of *Heterosigma* toxicity remains unknown, however there are theories that superoxide radicals or calcium channel agonists are involved.

Seasonality and trends

Recently, levels of PSP in geoduck have been above the regulatory standard in many areas of Puget Sound throughout the year. The highest levels of PSP toxins in blue mussels and other shellfish are measured in August through October as seen in this example from 2000 (Fig. 33). August and September are usually the months with highest PSP levels in all shellfish monitored. At times butter clams are the only species that are toxic in a given area, requiring species-specific closures for butter clams while harvesting all other shellfish is permitted.

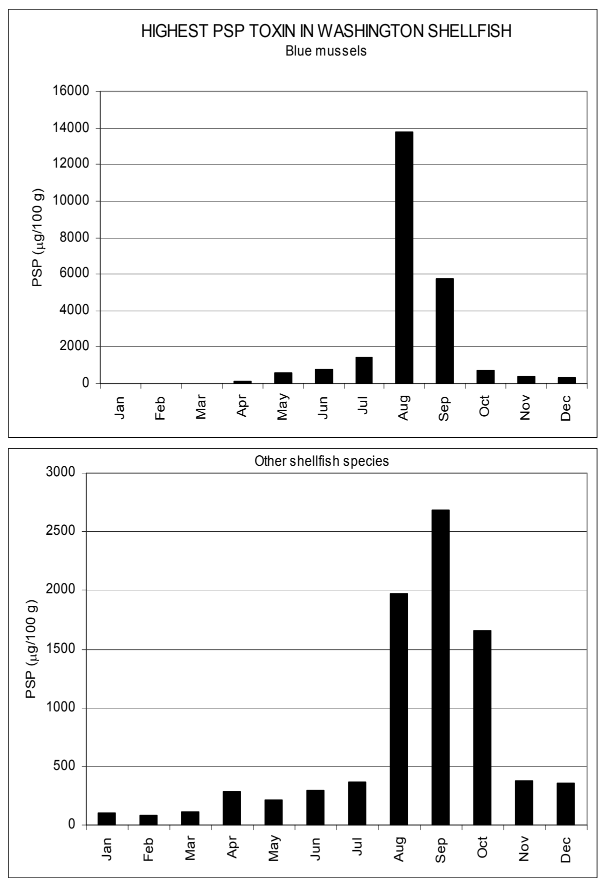

Fig. 33 Highest PSP toxin levels by month in geoduck and other shellfish species (2000).

Highest toxin levels

The highest level of PSP ever recorded in Washington State was 30,360 µg/100g in blue mussels in September 1978 in an unusual event in the Whidby Basin, central Puget Sound (Fig. 34). The highest level of domoic acid measuring 297 ppm in razor clams was recorded in October 1998, on the central Washington coast. Widespread closures of the commercial, recreational and subsistence (tribal) harvests exceeded one year due to the slow depuration of razor clams.

The first occurrences of PSP in Washington State were documented in the Strait of Juan de Fuca. Monitoring by WDOH has shown that both Sequim Bay and Discovery Bay in northern Puget Sound have the longest recorded history of PSP in the state. PSP levels in these areas were first measured in the 1950s. PSP was absent from South Puget Sound until 1988. The first closure there occurred in Carr Inlet when PSP levels in oysters reached 2000 µg/100g. Since that time, yearly PSP closures have occurred in this southern area, possibly indicating that the spread of *Alexandrium* cysts has occurred over several decades to "seed" most of the Puget Sound region. PSP toxins can therefore be expected to occur in shellfish throughout most of Puget Sound in future years.

To date, levels of domoic acid above the regulatory limit in shellfish have only occurred on the outer coast of Washington. This is the only area in Washington State where razor clams are found. It is likely that because domoic acid is not retained for long periods of time by shellfish other than razor clams, ASP has not been a problem in Puget Sound. However, because the ingestion of mussels containing domoic acid caused human deaths in eastern Canada in 1987 (Bates *et al.* 1989), vigilant monitoring of this toxin is required in Washington State. October and November appear to be the months when domoic acid is most likely to be measured in razor clams on the coast, however, in 2000 and 2001, levels of domoic acid slightly above the regulatory limit were measured at select coastal beaches in March (ORHAB project, unpublished results).

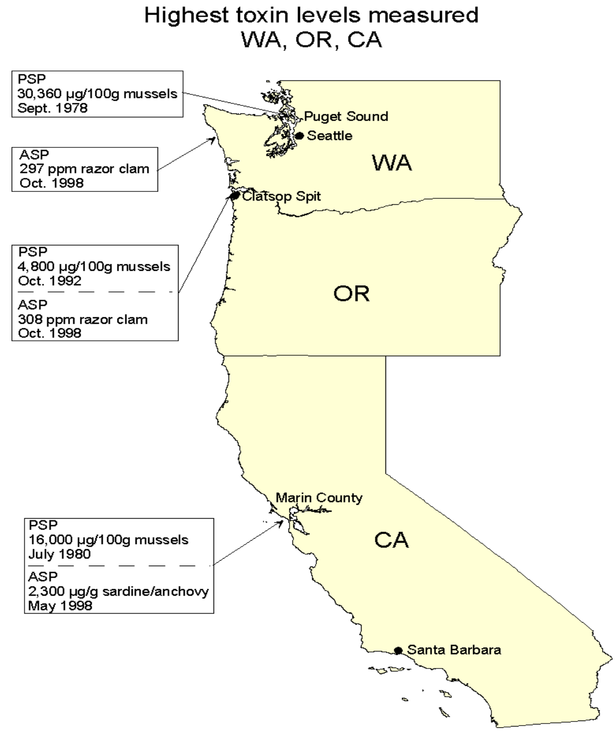

Fig. 34 Highest PSP and ASP toxin levels measured in Washington, Oregon and California.

Causative species

The primary species of *Alexandrium* responsible for PSP in Washington State is *A. catenella*. Potentially toxic *Pseudo-nitzschia* species found in Washington coastal waters are *P. australis, P. multiseries, P. pseudodelicatissima, P. fraudulenta, P. delicatissima,* and *P. pungens*. Since 1998, it is believed that *P. pseudodelicatissima* accounts for the largest toxigenic coastal blooms with *P. australis* contributing only occasionally to low level razor clam toxicity on the beaches on the south coast.

Impacts

The outbreak of domoic acid on the Washington and Oregon coasts in 1991 is estimated to have cost $23-28 million to the commercial and recreational razor clam fishery (Nosho 1999). Dungeness crab harvesters also lost at least $9 million during this episode. In all, the state's shellfish processors experienced a 50% decline in sales. Razor clam harvesting days lost due to domoic acid and paralytic shellfish toxins from 1991-2000 are summarized in Table 17. During these toxic episodes, coastal oyster farmers also suffered economic losses although there was no evidence that oysters had accumulated any toxin. Oyster farmers lost around $2.17 million in sales in 1991, because of the public's fears about eating toxin-tainted product. In 1998, when record levels of domoic acid were detected in Oregon and Washington razor clams, the coastal tourism industry alone experienced an estimated $15 million loss (Nosho 1999). Repeated closures have reduced tourist visits to the Washington coast during the razor clam harvesting season and have resulted in loss of product confidence in the shellfish consumer.

In November 1997, a late season bloom of *Alexandrium* cause toxin accumulation in oysters in bays on Washington's outer coast. Revenue losses to oyster farmers due to the harvest closures approached $7 million after only 2-3 weeks. In South Puget Sound, where closures were in effect for 2 months that same year, shellfish farmers lost a total of about $2 million (Nosho 1999).

In 1996, WDOH began monitoring PSP toxins in the gut of geoduck. The agency was informed that Asian and tribal communities were eating the stomach in soups, pâtés, and other recipes. During that same year, various Indian tribes began commercially harvesting geoduck in several areas of Puget Sound, therefore the careful testing of all tissues consumed was essential. The testing of geoduck gut resulted in six product recalls that resulted in loss of sales to companies and a reduction in price by many markets. During 1996, 11 geoduck tracts were closed due to PSP. Since that time, levels of PSP toxins in geoduck viscera in a given tract vary substantially from one week to another. The lack of PSP toxin predictability in geoduck has resulted in managers calling this the "light switch phenomenon" (Cox 2001) in which toxin levels rise and fall rapidly.

In 1989, *H. akashiwo* was responsible for the loss of $4 million worth of pen-reared salmon. Since then, substantial economic losses from these blooms have occurred (Table 18). *H. akashiwo* has been linked to mortalities of salmon in the wild.

Table 17 Washington State outer coast razor clamming days lost due to ASP or PSP.

Season	HAB	Days lost (%)
1991 Fall	ASP	37.5
1992 Spring	ASP	100
1992 Fall	PSP	30.9
1993 Spring	PSP	5.7
1993 Fall	ASP	21.4
1998 Fall	ASP	100
1999 Spring	ASP	100
1999 Fall	ASP	37.8
2000 Spring	ASP	41.2

Oregon

The geography of the Oregon coast differs from its more northerly neighbors as there are no inland waterways or fjords which must be monitored for HAB toxins. There are 350 miles of mostly accessible coastline with sandy beaches, rocky intertidal shoreline, long stretches of dunes, and 20 estuaries of varying sizes. Tillamook, Netarts, Yaquina, and Coos are larger bays with commercial shellfish production, mainly cultured oysters. Native oysters are scarce in Oregon and their harvest is prohibited.

Testing

The State of Oregon has tested shellfish for PSP since the late 1950s. One death in Oregon in 1958 was linked to PSP. At present, the Food Safety Division of the Oregon Department of Agriculture monitors up to 30 sites for PSP and domoic acid. Shellfish collected from each site can include razor clams, mussels, oysters, and bay clams including: gaper (*Tresus capax*), cockle (*Clinocardium nuttali*), littleneck (*Prototheca staminea*), butter (*Saxidomus giganteus*), and softshell (*Mya arenaria*).

The majority of recreational razor clam harvest (90-95%) occurs in northern Oregon from Tillamook Head to the Columbia River (Clatsop Beach). The Oregon Department of Fish and Wildlife assists with collection of shellfish used for testing.

Table 18 Recent losses in Puget Sound due to *Heterosigma* (L. Connell, unpubl. data).

Location	Date	Salmon Species	Loss (# of fish)
Cypress Island, commercial farms[1]	1989	Atlantic	364,000
Manchester pens (research and endangered species)	June-July 1990	Chinook, sockeye, coho, Atlantic	1910
Rich passage, commercial farms	June-July 1990	Atlantic, chinook	649,544
Case Inlet, free ranging fish	September 1994	Coho, chum, chinook	35[2]
Manchester pens (research fish)	July 1997	Coho, chinook, sockeye	737 (100% mortality of coho)
Rich passage, commercial farms	July 1997	Atlantic	401,639
Port Angeles, commercial farms	August 1997	Atlantic	62,000

[1] there were many more dead fish seen but not collected for identification
[2] at least one farm closed because of heavy losses in 1989

Clatsop Beach is the only area where commercial digging is allowed. The number of harvesters varies with the abundance of razor clams. Fewer than five harvesters dive for wild clams in Nehalem, Tillamook, and Coos Bays. In the past, a small number of commercial mussel farming operations were located in central to southern Oregon, however all have discontinued business or changed to oyster farming. There are approximately 15 commercial oyster growers in Tillamook, Netarts, Yaquina, Winchester (Umpqua River), and Coos Bays.

Site monitoring occurs weekly in the summer and bi-monthly in the winter. Mussels hung under piers at the mouth of bays are the preferred sample specimens, because they can, theoretically, be collected independently of tidal fluctuations and weather. However, rough waves and vandals have taken the mussel "hangings", so that often the wild mussels must be used. These wild mussels are collected from rocks on extended jetties. Mussels are placed at the mouths of commercial bays as sentinels for determining the safety of shellfish inside the bays. The exception to this procedure is at Netarts and Winchester bays where oysters are monitored directly due to the proximity of these bays to the ocean. When toxin levels are on the rise, samples from the commercial areas are also tested. Program policy is to consider opening beaches for shellfish harvest after two consecutive sampling periods showing a strong declining trend in toxin below 20 ppm domoic acid and 80 μg/100 g PSP.

Seasonality

The seasonality of coastal domoic acid events in Oregon is very similar to that observed in Washington State. Typically, domoic acid poisoning has occurred in October and November, but events are occasionally documented in the spring. For example, in April and May 2001, a domoic acid event closed Oregon beaches to razor clam harvest. In October 1998, record levels of domoic acid reached 308 ppm in razor clams, resulting in closure of most beaches in Oregon for over 1 year. This event also impacted the Washington coast.

In August 1992, there was a record PSP event that closed razor clam harvests in northern Oregon for two years (1992-1994 at Clatsop beach on the north coast). Over the past seven years, the Tillamook Bay commercial oyster harvest has been closed once due to PSP. During that same period, the cockle harvest was closed at least three times due to high levels of PSP. Domoic acid toxicity was responsible for a one year razor clam closure (1991-1992) on northern Oregon beaches. There were also significant PSP events in 1958, 1973, 1977, and 1982.

A geographical difference in HAB occurrences in the northern and southern Oregon beaches has been observed over the past few years. For example, in 2001, PSP affected the southern beaches during the entire summer, whereas the northern beaches were not affected. In that same year, domoic acid poisoning affected razor clams on the northern beaches, but was not a problem in the southern beaches. The 1992 PSP event mentioned above affected the north and central coasts, but not the south coast. Clearly, different oceanographic processes must be influencing the distribution of HAB species on Oregon's southern and northern beaches.

Highest toxin levels

The highest level of domoic acid was measured in October 1998 at 308 ppm in razor clam at Clatsop Spit, near the Columbia River in northern Oregon. The highest PSP level (>4367 μg/100 g) was measured in mussels from the south jetty of the Columbia River in late September 1992 (Clatsop Beach, Fig. 34).

Causative species

The causative species of PSP in Oregon is *A. catenella*. Detailed studies of *Pseudo-nitzschia* species present at the time of high domoic acid on the Oregon coast have not been done. However, a research cruise in the summer of 1998, prior to the toxic bloom that fall, measured high numbers of toxic *P. australis* in Oregon coastal waters (Trainer *et al.* 2001). Additionally *P. australis, P. fraudulenta, P. heimii, P. multiseries, P. pungens*, and *P. pseudodelicatissima* have all been reported from Oregon (Fryxell *et al.* 1997).

Impacts

The razor clam industry in both Washington and Oregon has been affected by domoic acid poisoning in recent years, most notably in 1991 and 1998. The economic impacts of these events were discussed in detail in the Washington State report (above). The effects of domoic acid poisoning on human health in this area is unknown.

Relying on commercial harvesters to provide specimens to monitor for PSP becomes difficult when commercial harvests are closed. There have also been some years when the abundance of razor clam "set" on the beach was quite low, making sampling difficult. Long closures have been necessary in recent years due to lack of extensive monitoring, resulting in the loss of consumer confidence in the shellfish product.

California

The first outbreak of PSP recorded in California involved 12 people who ate mussels from Timber Cove, Sonoma County, in 1903 (Meyer *et al.* 1928). Five of those people died. The next reported cases of PSP were reported from Santa Cruz County (4 people) in 1915 and (12 people including 2 deaths) in 1917. An additional case in San Diego County was reported in 1918 (Price *et al.* 1991).

Health officials recognized PSP as a serious health risk in California in 1927. Since then, there have been over 500 reported incidents, with more than 30 deaths. From the 1960s through the 1980s, there were toxic events most years along the California coast (Price *et al.* 1991). The most recent recorded death was in 1980, and the last reported illness was in 1991 (RaLonde 1996). Today, most toxic events occur in the summer and fall, and the state imposes an annual mussel quarantine of sport-harvested mussels from May 1 through October 31, along the entire California coastline (Price *et al.* 1991). The California Marine Biotoxin Monitoring Program, managed by the California Department of Health Services (CDHS), is the oldest HAB monitoring program in the United States.

Indians of the Pacific Coast, in the state now known as California, would not eat shellfish when bioluminescence was evident in ocean waters because they were apparently aware of the relationship between this event and toxicity in shellfish. Meyer *et al.* (1928) wrote, "From time immemorial it has been the custom among coast tribes of Indians, particularly the Poma, to place sentries on watch for Kal ko-o (mussel poison). Luminescence of the waves, which appeared rarely and then only during very hot weather, caused shellfishing to be forbidden for two days; those eating shellfish caught at such times suffered sickness and death. According to a report, a band of Indians died about fifty years ago from eating mussels gathered on the Mendocino coast during the month of August".

The first documented occurrence of domoic acid poisoning on the Pacific coast of the U.S. was in September and October 1991, near Santa Cruz, Monterey Bay, California. Pelicans and Brandt's cormorants fed on anchovies that had eaten toxic *Pseudo-nitzschia* (Buck *et al.* 1992; Fritz *et al.* 1992; Work *et al.* 1993). These birds were found dead and dying on the beach. A bloom of *P. australis*, identified for the first time as a species producing high level of domoic acid (Garrison *et al.* 1992; Villac *et al.* 1993), was observed in Monterey Bay during this event. Mussels collected at this time had concentrations of domoic acid that exceeded the federal alert level. Another domoic acid event in Monterey Bay that involved illness or death of over 70 California sea lions occurred in May 1998. About one month later, sea otters were also sickened by domoic acid. Mussels tested for toxin content at the same time as this event showed only very low levels of domoic acid, indicating that this may not be an effective sentinel species for exposure of marine wildlife to toxins. However, mussel testing may provide sufficient warning for the risk of toxin exposure in humans because no cases of human poisoning by domoic acid are known to have occurred in California.

Testing

The annual quarantine applies only to recreational harvesting of mussels. Mussels and all other bivalves grown and harvested by licensed commercial operators in California are subject to a separate PSP testing program. In 1981, the CDHS required that commercial shellfish growers submit samples from their shellfishing beds at weekly intervals, year-round, during all harvesting periods. This requirement was imposed as a consequence of a PSP outbreak in 1980, during which 61 people became ill from eating commercially grown oysters. All harvesters and growers of bivalve shellfish (*e.g.*, oysters, clams, and mussels) must obtain a certificate from the CDHS prior to harvest.

In addition, county environmental health departments submit sentinel mussel samples from their regions 1-2 times per month for testing. This voluntary sampling protocol was formulated as an agreement between the CDHS and several coastal county health departments. The program first involved the northern counties, and later grew to include southern counties. The sampling protocol suggested that each county select two sampling locations, and submit a sample from each site at biweekly intervals during the quarantine period and at monthly intervals during the non-quarantine period. However, some coastal county health departments have not been able to collect all samples as outlined in the sampling protocol. Monitoring by coastal counties is augmented in some areas by samples collected by the CDHS, the California Department of Fish and Game, and various other participants. Domoic acid was measured in California mussels in spring 1991. Since that time, the CDHS has included testing of domoic acid in its biotoxin monitoring program.

An extensive phytoplankton monitoring program in California that provides a valuable adjunct to shellfish monitoring for PSP toxicity and domoic acid was established in 1992. The benefit of phytoplankton monitoring is that many of the observations are made in the field, so the lag time associated with mussel monitoring is eliminated. These plankton monitoring efforts have detected the early stages of several toxigenic blooms prior to the detection of toxicity in any species of fish or shellfish. California's phytoplankton monitoring sites, sampled at frequencies ranging from once a week to once a month, include all commercial shellfish growing areas and numerous coastal sites. Over 45 volunteers collect samples for the program. A core group of participants performs all the field identifications and communicates results with program manager. Data from this program are qualitative because they are based on net tows and the assignment of a "relative abundance" index to each species present in a sample.

Seasonality

The two largest PSP outbreaks in California, in 1927 and 1980, began during July. The majority of PSP cases in other years have occurred during the 4-month period from June through September, with July being the peak month. These peaks appear to correlate with relaxations of upwelling that result in the transport of toxic cells to the coast (Langlois 2002). However, toxic dinoflagellate blooms are not limited to the warmer months of the year. Toxic blooms have caused numerous extensions of the quarantine period beyond October 31, and early-season quarantines prior to May 1 have been common in recent years. The geographic center for coastal PSP toxins appears to be Marin county in central California (highest intensity) with lower levels of toxin measured both north and south of this area.
Domoic acid in shellfish has been monitored since it was first identified along the west coast of the U.S. in 1991, and no strong seasonality has been observed. However, most domoic acid events occur in the spring, summer and fall months.

Results of several years of volunteer monitoring by the DHS Phytoplankton Monitoring Program suggest that there may also be a northward progression of *Pseudo-nitzschia* from the Santa Barbara and San Luis Obispo areas that appear to have some of the first blooms of the season (G. Langlois, pers. comm).

Highest toxin levels

Mussels have been responsible for the majority of California PSP cases and deaths. The highest PSP level recorded was 16,000 µg/100 g mussel in July 1980, in Marin county. The highest level of domoic acid (2300 µg/g) was measured in anchovy in May 1998, at the same time that sea lions were observed dead and dying on central California beaches (Fig. 34). During this time, measurements of domoic acid in mussels did not exceed the regulatory level. The highest level of domoic acid in mussels was measured at 49 ppm on the central California coast near Monterey Bay in the fall of 1991.

Causative species

The species known to cause PSP in California is *A. catenella*. Domoic acid poisoning in California is primarily due to blooms of *P. australis*, although other potentially-toxic species, including *P. multiseries, P. fraudulenta, P. heimii, P. pungens*, and *P. pseudodelicatissima* have been observed in coastal waters.

Impacts

California has a relatively small commercial shellfish industry with about 12-16 companies statewide that could potentially be impacted by PSP and ASP. Many of these industries are located in bays that are at least partially buffered from the immediate impact of toxins that affect the open coast. The annual quarantine for recreational shellfish concerns only mussels, therefore clams can still be harvested. Only rarely has toxin in mussels increased to levels that require closure of the entire recreational harvest on the California coast. Therefore, impacts of toxins on the California fishery are relatively small compared to Oregon and Washington.

Other organisms

Strongly visible red water discolorations due to blooms of *Lingulodinium polyedra (=Gonyaulax polyedra)* are common off the coasts of southern California and Baja California. Although they are usually harmless, there have been occasional reports of marine fauna mortalities due to excessive concentrations, decay, and high biological oxygen demand (B.O.D.) on beaches. These reports go back as far as Torrey (1902).

Hawaii

Ciguatera fish poisoning (CFP) is the most significant HAB problem in the tropical waters of Hawaii. Incidences of CFP in the eastern Pacific appear to be very low, and represent a small risk to both human health and the economy. However, ciguatera fish poisoning is an emerging human health risk outside the tropics because of importation of tropical seafood to areas such as the continental U.S and the visit of tourists to Hawaii.

Unanswered questions and hopes for the future

Due to the vastness of the western U.S. coastline, with its many bays, fjords, and estuaries, testing is expensive and difficult. It can cost several hundred dollars to submit one sample for testing, because sampling areas are remote and distant from testing centers. Ideally, a simple, reliable test for both PSP and ASP will be developed for use at remote sites of harvest. Currently, an assay is being tested in Alaska by Jellet Biotek®, a Canadian company that specializes in the development of "test strip" immunoassays for toxin detection. It shows some promise, but must pass the rigorous criterion to avoid false negatives. A monitoring tool that would give aquaculturists a "safe/not safe" result would greatly reduce the number of samples sent for expensive testing at state monitoring labs.

Not only does the remoteness of sampling sites contribute to the expense of toxin testing, but lengthy and tedious extraction procedures add to the cost. A more rapid or automated procedure for the extraction of toxins from shellfish would also greatly reduce the costs of monitoring. If a single extraction procedure could be used for both domoic acid and PSP toxin testing, a greater saving of time and money would be realized.

The biggest HAB-related question remaining in Alaska is, "which areas have little or no toxin and are safe for development of aquaculture facilities?" An extensive study would be required to "map" clean sites in Alaska. The identification of these specific sites of little or no toxicity then would reduce the amount of testing required, and would enable a sustainable resource to be more efficiently managed. Only through large, collaborative studies of physical, biological and chemical processes that influence HAB initiation and development, will areas that are generally free from toxic episodes be identified.

In all U.S. west coast regions, if not all regions in the world that suffer from HABs, the remaining unanswered questions include: what are the environmental factors that initiate and drive HABs, what environmental factors cause algae to be toxigenic, end blooms, and result in no toxin production? What role do cysts and vegetative cells play in promoting PSP toxicity? Answers to these questions would assist in more efficient management of HABs in all U.S. west coast states.

Hopes for the future include the possibility to predict blooms. Only through large-scale collaborative studies, will the answers to the questions posed above be obtained. HABs cross borders freely and international studies should therefore be encouraged. For example, toxic *Pseudo-nitzschia* blooms that arrive on both the Washington State and British Columbia, Canada coasts, are thought to originate at the U.S./Canadian border, in an oceanographic feature known as the Juan de Fuca eddy. Only through strong U.S. and Canadian collaboration will the precise environmental factors contributing to HAB initiation at this site be understood. This collaboration must include representatives from management agencies, research groups, and commercial and subsistence marine farmers in order to gain complete insight on HABs that know no borders.

Acknowledgement

Much of the data presented in this report was collected by the Health Departments and Fish and Wildlife Agencies in each state as part of their mandate to protect human health and fishery resources for recreational, commercial and subsistence use. Contributions from the following people are greatly appreciated: Laurie Connell, University of Maine; Raymonde RaLonde, University of Alaska Sea Grant; Frank Cox and Judy Dowell, Washington State Department of Health; Matthew Hunter, Oregon Department of Fish and Wildlife; Deb Cannon, Oregon Department of Agriculture; Gregg Langlois, California Department of Health Services. Funding for database construction and map production was provided by the National Ocean Service, NOAA, through the Environmental Services Data and Information (ESDIM) program, propject 01-414F.

References

Bates, S.S., Bird, C.J., deFreitas, A.S.W., Foxall, R., Gilgan, M., Hanic, L.A., Johnson, G.R., McCulloch, A.W., Odense, P., Pocklington, R., Quilliam, M.A., Sim, P.G., Smith, J.C., Subba Rao, D.V., Todd, E.C.D., Walter, J.A., and Wright, J.L.C. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can. J. Fish. Aquat. Sci. 46: 1203-1215.

Bell, G.R. 1961. Penetration of spines from a marine diatom into the gill tissue of lingcod *Ophiodon elongatus*. Nature 192: 279-280.

Buck, K.R., Uttal-Cooke, L., Pilskaln, C.H., Roelke, D.L., Villac, M.C., Fryxell, G.A., Cifuentes, L., and Chavez, F.P. 1992. Autecology of the diatom *Pseudonitzschia australis* Frenguelli, a domoic acid producer, from Monterey Bay, California. Mar. Ecol. Prog. Ser. 84: 293-302.

Bursa, A. 1963. Phytoplankton in coastal waters of the Arctic Ocean at Point Barrow, Alaska. Arctic 16:239-262.

Cox, F. 2001. The marine toxin problem in Washington State. *In* R. RaLonde (Ed.) Harmful Algal Blooms on the Northern America West Coast. University of Alaska Sea Grant. AK-SG-01-05, Fairbanks, AK, p. 35-37.

Frenette, B., McNair, M., and Savikko, H. 1997. Catch and production in Alaska's commercial fisheries. Alaska Department of Fish and Game, Special Publication 11, Juneau, AK.

Fritz L., Quilliam, M.A., Walter, J.A., Wright, J.C.L., Beale, A.M., and Work, T.M. 1992. An outbreak of domoic acid poisoning attributed to the pennate diatom *Pseudonitzschia australis*. J. Phycol. 28: 439-442.

Fryxell, G.A., Villac, M.C., and Shapiro, L.P. 1997. The occurrence of the toxic diatom genus *Pseudo-nitzschia* (Bacillariophyceae) on the West Coast of the USA, 1920-1996: a review. Phycologia 36: 419-437.

Garrison, D.L., Conrad, S.M., Eilers, P.P., and Waldron, E.M. 1992. Confirmation of domoic acid production by *Pseudonitzschia australis* (Bacillariophyceae) cultures. J. Phycol. 28: 604-607.

Gessner, B.D. and Schloss, M.S. 1996. A population-based study of paralytic shellfish poisoning in Alaska. Alaska Medicine 38(2): 54-58.

Horner, R., Dick, L.S., and Shiels, W.E. 1973. Phytoplankton studies. *In* D.W. Hood, W.E. Shiels, and E.J. Kelley (Eds.) Environmental Studies of Port Valdez. Institute of Marine Science, University of Alaska, Occasional Publication No. 3. Fairbanks, pp. 281-294.

Horner R.A., Postel, J.R., and Rensel, J.E. 1991. Noxious phytoplankton blooms and marine salmon culture in Puget Sound, Washington. *In* J.R. Forbes (Ed.) Pacific Coast Research on Toxic Marine Algae. Can. Tech. Rep. Hydrogr. Ocean Sci. 135:59-61.

Hughes, E.H., Nelson, R.W., and Nelson, R. 1997. Initial assessments of the distribution, abundance, and quality of subtidal clams in the S.E. Bering Sea. NOAA, NMFS, Northwest and Alaska Fisheries Science Center Processed Report. Seattle, WA, 42 pp.

Langlois, G. 2001. Marine biotoxin monitoring in California, 1927-1999. *In* R. RaLonde (Ed.) Harmful Algal Blooms on the Northern America West Coast. University of Alaska Sea Grant. AK-SG-01-05, Fairbanks, AK, pp. 31-34.

Lefebvre, K.A., Powell, C.L., Busman, M., Doucette, G.J., Moeller, P.D.R., Silver, J.B., Miller, P.E., Hughes, M.P., Singaram, S., Silver, M.W., and Tjeerdema, R.S. 1999. Detection of domoic acid in northern anchovies and California sea lions associated with an unusual mortality event. Natural Toxins 7: 85-92.

Meyer, K.F., Sommer, H., and Schoenholz, P. 1928. Mussel poisoning. J. Preventative Medicine 2:365-394.

Nevé, R.A., and Reichardt, P. B. 1984. Alaska's shellfish industry. *In* P. Raagelis (Ed.) Seafood toxins. ACS Symp. Ser. 262, pp. 53-58.

Nosho, T. 1999. *In* Western Regional Aquaculture Center, Waterlines, Vol. 9(1). Winter-Spring 1999, p. 3.

Price, D.W., Kizer, K.W., and Hansgen, K.H. 1991. California's paralytic shellfish poisoning prevention program, 1927-89. J. Shellfish Res. 10(1): 119-145.

RaLonde, R. 1996. Paralytic Shellfish Poisoning: The Alaska Problem, Vol. 8(2). University of Alaska Sea Grant, Fairbanks, AK.

Scholin, C.A., Gulland, F., Doucette, G.J., Benson, S., Busman, M., Chavez, F.P., Cordaro, J., DeLong, R., De Vogelaere, A., Harvey, J., Haulena, M., Lefebvre, K., Lipscomb, T., Loscutoff, S., Lowenstine, L.J., Martin, R. I., Miller, P.E., McLellan, W.A., Moeller, P.D.R., Powell, C.L., Rowles, T., Silvagnl, P., Silver, M., Spraker, T., Trainer, V., and Van Dolah, F.M. 2000. Mortality of sea lions along the central California coast linked to a toxic diatom bloom. Nature 403: 80-84.

Schandelmeier, L. and Alexander, V. 1981. An analysis of the influence of ice on spring phytoplankton populaton structure in the Southeast Bering Sea. Limnol. Oceanogr. 26 (5): 935-943.

Scholin, C.A. and Anderson, D.M. 1998. Detection and quantification of HAB species using antibody and DNA probes: progress to date and future research objectives. *In* B. Reguera, J. Blanco, M.L. Fernández, and T. Wyatt (Eds.) Harmful Algae. Xunta de Galicia and the IOC of UNESCO, Paris, pp. 253-257.

Taylor, F.J.R. and Horner, R.A. 1994. Red tides and other problems with harmful algal blooms in Pacific Northwest coastal waters. *In* Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Fish. Aquat. Sci. Tech. Rep. 1948, pp. 175-186.

Torrey, H.B. 1902. An unusual occurrence of Dinoflagellata on the California coast. Am. Nat. 36: 187-192.

Trainer, V.L., Adams, N.G., and Wekell, J.C. 2001. Domoic acid-producing *Pseudo-nitzschia* species off the U.S. West Coast associated with toxification events. *In* G.M. Hallegraef (Ed.) Proceedings of the IX International HAB Conference, Tasmania, Australia, pp. 46-48.

United States Department of the Interior. 1968. The potential of Alaska's fishery resources. Newsletter to Alaska Fishermen and Processors. No. 9, Sept. 13, Juneau, AK.

Villac, M.C., Roelke, D.L., Chavez, F.P., Cifuentes, L.A., and Fryxell, G.A. 1993. *Pseudonitzschia australis* Frenguelli and related species from the west coast of the U.S.A.: occurrence and domoic acid production. J. Shellfish. Res. 12: 457-465.

Work, T.M., Beale, A.M., Fritz, L., Quilliam, M.A., Silver, M.W., Buck, K.R., and Wright, J.L.C. 1993. Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. *In* T.J. Smayda and Y. Shimizu (Eds.) Toxic Phytoplankton Blooms in the Sea. Elsevier Science Publ. B.V., Amsterdam, pp. 643-650.

Appendix US

Harmful algal blooms on the U.S. west coast

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On the U.S. west coast, the toxin-producing algal species are the dinoflagellate in the genus *Alexandrium* that cause paralytic shellfish poisoning (PSP), the dinoflagellate in the genus *Gambierdiscus* that causes ciguatera fish poisoning, and diatoms in the genus *Pseudo-nitzschia* that produce domoic acid and cause domoic acid poisoning (DAP), also known as amnesic shellfish poisoning (ASP). Other harmful species, including the raphidophyte, *Heterosigma akashiwo,* and the diatoms from the genus *Chaetocerus*, kill fish at aquaculture sites, but are not harmful to humans. Water discolorations (red tides) caused by noxious phytoplankton also occur throughout the area.

Only about 25 of the more than 5000 known phytoplankton species produce toxins or directly cause fish mortalities, while another 20-30 species are responsible for other problems, including water discolorations, along the U.S. west coast (Table 19).

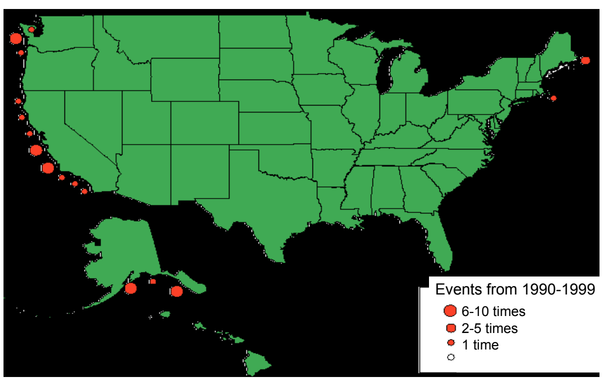

Fig. 35 ASP events in the U.S.A.

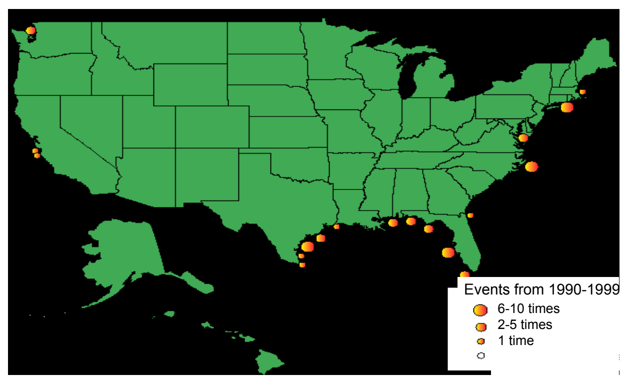

Fig. 36 PSP events in the U.S.A.

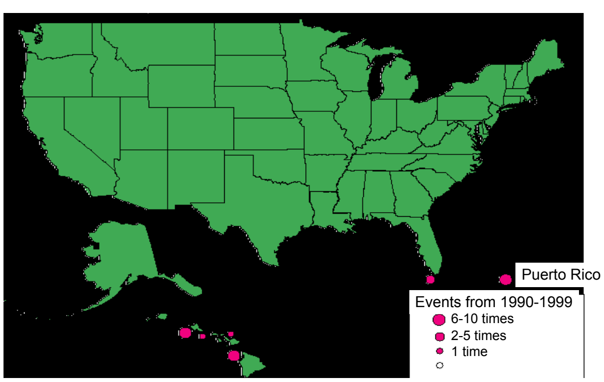

Fig. 37 Ciguatera fish poisoning *Gambierdiscus toxicus* in the U.S.A.

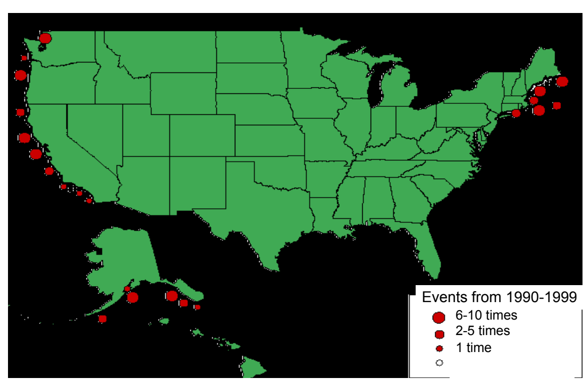

Fig. 38 Animal and plant mortalities in the U.S.A.

Table 19 Toxic and nuisance algal species reported from the west coast of U.S. (from Horner *et al.* 1997).

1.	Dinoflagellate species that produce saxitoxins that cause paralytic shellfish poisoning (PSP)	*Alexandrium acatenella* *Alexandrium catenella* *Alexandrium fundyense* *Alexandrium hiranoi* *Alexandrium ostenfeldii* *Alexandrium tamarense*
2.	Dinoflagellate species that produce okadaic acid that causes diarrhetic shellfish poisoning (DSP). DSP has not yet been measured in shellfish on the west coast, but the causative organisms are common	*Dinophysis acuminata* *Dinophysis acuta* *Dinophysis fortii* *Dinophysis norvegica*
3.	Diatoms that produce domoic acid that causes domoic acid poisoning, also known as amnesic shellfish poisoning (ASP)	*Pseudo-nitzschia australis* *Pseudo-nitzschia multiseries* *Pseudo-nitzschia pseudodelicatissima* *Pseudo-nitzschia pungens* *Pseudo-nitzschia seriata*
4.	Species associated with fish kills, but not know to be harmful to humans	*Diatoms* *Chaetoceros concavicornis* *Chaetoceros convolutes* *Chaetoceros danicus* *Raphidophyte* *Heterosigma akashiwo*
5.	Species that cause water discolorations. Blooms of these species may kill kish or invertebrates due to oxygen depletion may change or disrupt food-web dynamics or produce noxious compound	*Dinoflagellates* *Ceratium dens* *Ceratium divaricatum* *Ceratium furca* *Ceratium fusus* *Gymnodinium sanguineum* *Gymnodinium flavum* *Lingulodinium poydrum* *Noctiluca scintillans* *Prorocentrum micans* *Protoneridium*

Maps of the United States show the frequency of occurrence of each type of toxic syndrome (from the WHOI web site, http://www.redtide.whoi.edu/hab/) common on the U.S. west coast (Figures 35-38). Although some ASP has been measured in shellfish along the U.S. east coast, it is primarily a west coast problem (detected in shellfish and Dungeness crab). Record levels (297 ppm) of domoic acid were measured in razor clams in the fall of 1998.

Paralytic shellfish poisoning is found on both the U.S. east and west coasts, however, the highest levels of PSP have been measured in shellfish on the U.S. west coast. For example, levels of PSP measured at 13,700 μg/100g in mussels resulted in the hospitalization of 3 people and the illness of at least 9 people in Washington State during the summer of 2000. The highest PSP concentration measured in Alaskan shellfish from 1982-1999 was 20,606 μg/100 g in blue mussels off Kodiak Island. Each year, the harvesting of shellfish from restricted areas results in the illness of people in Alaska. During the years 1973-1995, 70 people were sickened due to PSP in Alaska; during 1995-2000, at least 51 people became ill. Due to under-reporting of illnesses, or misdiagnosis, the numbers of people sickened in Alaska due to PSP are likely 10-30 times higher. The first documented case of PSP in North America occurred in 1793 when five members of Captain George Vancouver's crew became ill and one died after eating mussels (Quayle 1969).

Ciguatera fish poisoning is the most significant HAB problem in Hawaii, Puerto Rico, and Florida. Incidences of ciguatera poisoning in the eastern Pacific appear to be very low, and represent a small risk to both human health and the economy. However, ciguatera poisoning is an emerging risk outside the tropics because of importation of tropical seafood to areas such as the continental United States.

Animal mortalities due to toxic and harmful algae occur routinely on the U.S. west coast. Domoic acid poisoning in Monterey Bay, California, in 1991, resulted in the death of seabirds (pelicans and cormorants). These birds fed on anchovies that had eaten toxic *P. australis*. More recently, in 1998 and again in 2000, sea lions and sea otters have suffered from seizures due to domoic acid poisoning. Several of these mammals also died due to their ingestion of toxic sardines and anchovies. Unexplained mortalities of marine mammals in the Monterey Bay region due to seizures and other neurological problems over the past decades, indicate that domoic acid poisoning of mammals may be a relatively common occurrence.

Farmed fish have also been known to succumb due to injury caused by harmful algae. The diatoms *Chaetoceros convolutus* and *C. concavicornis* have caused the death of finfish reared in net pens since at least 1961 (Bell 1961). Fish death is likely due to suffocation from excess mucus production by the gills. The death of pen-reared salmon has also been associated with the raphidophyte flagellate *H. akashiwo* since 1976. It has been reported that *Heterosigma* produces superoxide and hydroxyl radicals (Yang *et al.* 1995) resulting in fish deaths.

References

Horner, R.A., Garrison, D.L., and F.G. Plumley. 1997. Limnol. Oceanogr. 42: 1076-1088.

Quayle, D.B. 1969. Fish. Res. Bd. Can. Bull. 168.

Bell, G.R. 1961. Nature 192: 279-280

Yang, C.Z., Albright, L.J, and A.N. Yousif. 1995. Dis. Aquat. Org. 23:101-108.

Comprehensive references pertaining to research and management interests in the Western United States

Adams, N.G., Lesoing, M., and Trainer, V.L. 2000. Environmental conditions associated with domoic acid in razor clams on the Washington coast. J. Shellfish Res. 19: 1007-1015.

Ahmed, F.E. (Ed). 1991. Seafood Safety. National Academy Press, Wash. D.C. 432 pp.

Altwein, D.M., Foster, K., Doose, G., and Newton, R.T. 1995. The detection and distribution of the marine neurotoxin domoic acid on the Pacific Coast of the United States 1991-1993. J. Shellfish Res. 14: 217-222.

Anderson, D.M. (Ed.). 1995. The ecology and oceanography of harmful algal blooms. A national research agenda. Woods Hole Oceanographic Institution, Woods Hole, MA. 66 pp.

Anderson, D.M. 1995. Toxic red tides and harmful algal blooms: a practical challenge in coastal oceanography. Rev. Geophysics, Suppl. U.S. National Report to the Int. Union of Geodesy and Geophysics 1991-1994, pp. 1189-1200.

Anderson, D.M. 1989. Toxic algal blooms and red tides: a global perspective. *In* T. Okaichi, D.M. Anderson, and T. Nemoto (Eds.) Red Tides: Biology, Environmental Science and Toxicology. Elsevier, New York, pp. 11-16.

Anderson, D.M. and White, A.W. 1992. Marine biotoxins at the top of the food chain. Oceanus 35: 55-61.

Anderson, D.M. and Lobel, P.S. 1987. The continuing enigma of ciguatera. Biol. Bull. 172: 89-107.

Anderson, D.M., Kulis, D.M., Sullivan, J.J., Hall, S., and Lee, C. 1990a. Dynamics and physiology of saxitoxin production by the dinoflagellates *Alexandrium* spp. Mar. Biol. 104: 511-524.

Anderson, D.M., Galloway, S.B., and Joseph, J.D. 1993. Marine Biotoxins and Harmful Algae: A National Plan. Woods Hole Oceanographic Institution Tech. Rep. WHOI-93-02. 59 pp.

Annon. 1992. Domoic acid intoxication. Canadian Commun. Dis. Rep. 18: 118-120.

AOAC. 1991. Domoic acid in mussels, liquid chromatographic method, first action. Official methods of action. Association of Official Analytical Chemists, section 991.26.

Apeldoorn van, M.E., van Egmond, H.P, and Speijers, G.J.A. 1999. Amnesic shellfish poisoning: A review. RIVM Rapport 388802019, 53 pp. (in English).

Baden, D.G. and Trainer, V.L. 1993. Mode of Action of Toxins of Seafood Poisoning. In I.R. Falconer (Ed.) Algal Toxins in Seafood and Drinking Water. Academic Press, London, pp. 49-74

Bird, C.J., Boyd, R.K., Brewer, D., Craft, C.A., de Freitas, A.S.W., Dyer, E.W., Embree, D.J., Falk, M., Flack, M.G., Foxall, R.A., Gillis, C., Greenwell, M., Hardstaff, W.R., Jamieson, W.D., Laycock, M.V., Leblanc, P., Lewis, N.I., McCulloch, A.W., McCully, G.K., McInerney-Northcott, M., McInnes, A.G., McLachlan, J.L., Odense, P., O'Neil, D., Pathak, V., Quilliam, M.A., Ragan, M.A., Seto, P.F., Sim, P.G., Tappen, D., Thibault, P., Walter, J.A., and Wright, J.L.C. 1988. Identification of domoic acid as the toxic agent responsible for the P.E.I. contaminated mussel incident. Atlantic Res. Lab. Tech. Rep. 56.

Bird, C.J. and Wright, J.L.C. 1989. The shellfish toxin domoic acid. World Aquacult. 20: 40-41.

Black, E.A. 1990. Forewarned and forearmed with algal blooms. Fish Farmer. Sept/Oct: 36-37.

Blaylock, R. L. 1994. Excitotoxins - the taste that kills. Health Press, Santa Fe, New Mexico. 300 pp.

Boyd, R., Hogge, L., Jamieson, W., McLaren, J., Quilliam, M., Sim, P., Thibault, P., and Wright, J. 1988. The role of mass spectrometry combined with reversed phase HPLC in the identification of an unusual shellfish toxin. Proc. Am. Soc. Mass. Spec. 36: 165.

Buck, K.R., Uttal-Cooke, L., Pilskaln, C.H., Roelke, D.L., Villac, M.C., Fryxell, G.A., Cifuentes, L., and Chavez, F.P. 1992. Autecology of the diatom *Pseudo-nitzschia australis* Frenguelli, a domoic acid producer, from Monterey Bay, California. Mar. Ecol. Prog. Ser. 84: 293-302.

Cangelosi, G.A., Hamlin, A.M., Marin III, R., and Scholin, C.A. 1997. Detection of stable pre-rRNA in toxigenic *Pseudo-nitzschia* species. Appl. Environ. Microbiol. 63: 4859-4865.

Cembella, A.D. (guest ed.). 1993. Issue of "Harmful Algae News" devoted to domoic acid in North America. An IOC Newsletter on toxic algae and algal blooms, Paris, No. 6, 8 p.

Clark, R.F., Williams, S.R., Nordt, S.P., and Manoguerra, A.S. 1999. A review of selected seafood poisonings. Undersea Hyperb. Med. 26: 175-84. (PubMed)

Coale, S., Silver, M., Dovel, S., Kudela, R., and Tjeerdema, R. 2000. Annual bloom cycles of toxic *Pseudo-nitzschia*, cellular domoic acid and macronutrient dynamics in Monterey Bay, California. (Abstract) Symp. Harmful Algae in U.S., Woods Hole, MA.

Couturier, C. 1988. Shellfish toxins aplenty. Bull. Aquaculture Assn. Can. 88-2: 11-27.

Curtis, K.M, Trainer, V.L. and Shumway, S.E. 2000. Paralytic shellfish toxins in geoduck clams (*Panope abrupta*): variability, anatomical distribution, and comparison of two toxin detection methods. J. Shellfish Res. 19(1): 313-319.

Dhoot, J.S., del Rosario, A.R., Appel, B.R., and Tamplin, B.R. 1993. An improved HPLC procedure for domoic acid analysis in seafood. Intern. J. Environ. Anal. Chem. 53: 261-268.

Dhoot, J.S., Appel, B.R., and del Rosario, A.R. 1993. Confirmation of domoic acid in seafood using reverse phase liquid chromatography with ninhydrin post-column derivatization. J. Environ. Anal. Chem. 53: 269-279.

Douglas, D.J. 1991. Axenic cultures of the marine diatom *Nitzschia pungens* f. *multiseries* produce the neurotoxin domoic acid. Appl. Phycol. Forum 8: 10.

Douglas, D.J. and Bates, S.S. 1992. Production of domoic acid, a neurotoxic amino acid, by an axenic culture of the marine diatom *Nitzschia pungens* f. *multiseries* Hasle. Can. J. Fish. Aquat. Sci. 49: 85-90.

Douglas, D.J., Bates, S.S., Bourque, L.A., and Selvin, R. 1993. Domoic acid production by axenic and non-axenic cultures of the pennate diatom *Nitzschia pungens* f. *multiseries*. *In* T.J. Smayda and Y. Shimizu (Eds.) Toxic phytoplankton blooms in the sea. Elsevier Sci. Publ. B.V., Amsterdam, pp. 595-600.

Douglas, D.J., Kenchington, E.R., Bird, C.J., Pocklington, R., Bradford, B., and Silvert, W. 1997. Accumulation of domoic acid by the sea scallop *Placopecten magellanicus* fed cultured cells of toxic *Pseudo-nitzschia multiseries*. Can. J. Fish. Aquat. Sci. 54: 907-913.

Douglas, D.J., Landry, D., and Douglas, S.E. 1994. Genetic relatedness of two toxic and non-toxic isolates of the marine pennate diatom *Pseudo-nitzschia* (Bacillariophyceae): phytogenetic analysis of 18S rRNA sequences. Natural Toxins 2: 166-174.

Douglas, D.J., Ramsey, U.P., Walter, J.A., and Wright, J.L.C. 1992. Biosynthesis of the neurotoxin domoic acid by the marine diatom *Nitzschia pungens* forma *multiseries*, determined with [13 C]-labelled precursors and nuclear magnetic resonance. J. Chem. Soc. Chem. Commun. 1992: 714-716.

Drum, A.S., Siebens, T.L., Crecelium, E.A., and Elston, R.A. 1993. Domoic acid in the Pacific razor clam *Siliqua patula* (Dixon, 1789). J. Shellfish Res. 12:443-450.

Duxbury, M. 2000. Liquid chromatographic determination of Amnesic Shellfish Poison in mussels. J. Chem. Educ. 77: 1319.

Erickson, D. 1992. Demonic [sic] toxin. A new shellfish toxin threatens fisheries. Sci. Am. May, 266: 129-130.

Erickson, G.M. and Nishitani, L. 1985. The possible relationship of El Niño/Southern Oscillation events to interannual variation in *Gonyaulax* populations as shown by records of shellfish toxicity. *In* W.S. Wooster and D.L. Fluharty (Eds.) El Niño North. Niño Effects in the Eastern Subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington, Seattle, pp. 283-290.

Falconer, I.R. (Ed.) 1993. Algal Toxins in Seafood and Drinking Water. Academic Press, London. 224 pp.

Falk, M., Seto, P.F., and Walter, J.A. 1991. Solubility of domoic acid in water and non-aqueous solvents. Can. J. Chem. 69: 1740-1744.

Forbes, J.R. (Ed.). 1991. Pacific coast research on toxic marine algae. Can. Tech. Rep. Hydrogr. Ocean Sci. 135: 76.

Fritz, L., Quilliam, M.A., Wright, J.L.C., Beale, A., and Work, T.M. 1992. An outbreak of domoic acid poisoning attributed to the pennate diatom *Pseudo-nitzschia australis*. J. Phycol. 28: 439-442.

Franks, P.J.S. 1992. Sink or swim: accumulation of biomass at fronts. Mar. Ecol. Prog. Ser. 82: 1-12.

Fritz L., Quilliam, M.A., Walter, J.A., Wright, J.C.L., Beale, A.M., and Work, T.M. 1992. An outbreak of domoic acid poisoning attributed to the pennate diatom *Pseudo-nitzschia australis*. J. Phycol. 28: 439- 442.

Fryxell, G.A., Villac, M.C., and Shapiro, L.P. 1997. The occurrence of the toxic diatom genus *Pseudo-nitzschia* (Bacillariophyceae) on the West Coast of the USA, 1920-1996: a review. Phycologia 36: 419-437.

Garrison D.L., Conrad, S.M., Eilers, P.P., and Waldron, E.M. 1992. Confirmation of domoic acid production by *Pseudo-nitzschia australis* (Bacillariophyceae) cultures. J. Phycol. 28: 604-607.

Glavin, G.B., Pinsky, C., and Bose, R. 1989. Mussel poisoning and excitatory amino acid receptors. Trends Pharmacol. Sci. 10: 15-16.

Grimmelt, B., Nijjar, M.S., Brown, J., MacNair, N., Wagner, S., Johnson, G.R., and Amend, J.F. 1990. Relationship between domoic acid levels in the blue mussel (*Mytilus edulis*) and toxicity in mice. Toxicon 28: 501-508.

Gulland, F. 1999. Unusual marine mammal mortality event – Domoic acid toxicity in California sea lions (*Zalophus californianus*) stranded along the central California coast, May – October 1998. NOAA Technical Memo NMFS-ORP-8, National Marine Fisheries Service, US Dept. of Commerce, Silver Spring, Maryland, 89 p.

Gulland, F., Haulena, M., Lander, M., Lowenstine, L.J., Spraker, T., Lipscomb, T., Van Dolah, F., Doucette, G., Powell, C., Trainer, V., Langlois, G., Lefebvre, K., Scholin, C., Cordaro, J., Rowles, T., McLellan, W., Delong, R. Domoic acid toxicity in California sea lions (*Zalophus californianus*) stranded along the central California coast, May-October, 1998. J. Wildlife Dis.

Hall, S. 1991. Natural toxins. *In* D.R. Ward and C. Hackney (Eds.) Microbiology of marine food products. Van Nostrand Reinhold, New York, pp. 301-330.

Hall, S., Strichartz, G., Moczydlowski, E., Ravindran, A., and Reichardt, P.B. 1990. The saxitoxins: sources, chemistry, and pharmacology. *In* S. Hall and G. Strichartz (Eds.) Marine Toxins: Origin, Structure, and Molecular Pharmacology. Am. Chem. Soc. Symp. Series No. 418. Washington, D.C, pp. 29-65.

Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32:79-99.

Hardstaff, W.R., Jamieson, W.D., Milley, J.E., Quilliam, M.A., and Sim, P.G. 1990. Reference materials for domoic acid, a marine neurotoxin. J. Anal. Chem. 338: 520-525.

Hardy, R.W., Scott, T.M., Hatfield, C.L., Barnett, H.J., Gauglitz, E.J., Jr., Wekell, J.C., and Eklund, M.W. 1995. Domoic acid in rainbow trout (*Oncorhynchus mykiss*) feeds. Aquaculture 131: 253-260.

Hargraves, P.E., Wang, R., Zhang, J., and Shimizu, Y. 1993. Growth characteristics of the diatoms *Pseudo-nitzschia pungens* and *P. fraudulenta* exposed to ultraviolet radiation. Hydrobiol. 269: 207-212.

Hasle, G.R. 1994. *Pseudo-nitzschia* as a genus distinct from *Nitzschia* (Bacillariophyceae). J. Phycol. 30: 1036-1039.

Hasle, G.R. 1995. *Pseudo-nitzschia pungens* and *P. multiseries* (Bacillariophyceae): nomenclatural history, morphology, and distribution. J. Phycol. 31: 428-435.

Hatfield, C.L., Gauglitz, E.J., Jr., Barnett, H.J., Lund, J.K., Wekell, J.C., and Eklund, M. 1995. The fate of domoic acid in Dungeness crab (*Cancer magister*) as a function of processing. J. Shellfish Res. 14: 359-363.

Hatfield, C.L., Wekell, J.C., Gauglitz, E.J. Jr., and Barnett, H.J. 1994. Salt clean-up procedure for the determination of domoic acid by HPLC. Natural Toxins 2: 206-211.

Horner, R.A. 1993. Toxic diatoms - report on a workshop. Hydrobiol. 269: 527.

Horner, R.A., Garrison, D.L., and Plumley, F.G. 1997. Harmful algal blooms and red tide problems on the U.S. west coast. Limnol. Oceanogr. 42: 1076-1088.

Horner, R.A., Hanson, L., Hatfield, C.L., and Newton, J.A. 1996. Domoic acid in Hood Canal, Washington, USA *In* T. Yasumoto, Y. Oshima, and Y. Fukuyo (Eds.) Harmful and toxic algal blooms. Intergov. Oceanogr. Comm., UNESCO, Paris, pp. 127-129.

Horner, R.A., Hickey, B.M., and Postel, J.R. 2000. *Pseudo-nitzschia* blooms and physical oceanography off Washington state, USA. S. Afr. J. Mar. Sci. 22: 299-308.

Horner, R.A., Kusske, M.B., Moynihan, B.P., Skinner, R.N., and Wekell, J.C. 1993. Retention of domoic acid by Pacific razor clams, *Siliqua patula* (Dixon, 1789): preliminary study. J. Shellfish Res. 12: 451-456.

Horner, R.A. and Postel, J.R. 1993. Toxic diatoms in western Washington waters (U.S. west coast). Hydrobiol. 269: 197-205.

Horner R.A., Postel, J.R., and Rensel, J.E. 1991. Noxious phytoplankton blooms and marine salmon culture in Puget Sound, Washington. *In* J.R. Forbes (Ed.) Pacific Coast Research on Toxic Marine Algae. Can. Tech. Rep. Hydrogr. Ocean Sci. 135:59-61.

Hummert, C., Reichelt, M., Luckas M., and Luckas, B. 1997. Automatic HPLC-UV determination of domoic acid in mussels and algae. Chromatographia 45: 284.

Hungerford, J.M. 1993. Seafood toxins and seafood products. J. Assoc. Offic. Anal. Chem. 76: 120-130.

Iverson, F. and Truelove, J. 1994. Toxicology and seafood toxins: domoic acid. Natural Toxins 2: 334-339.

Jellett, J.F. 1993. Phytotoxins and shellfish aquaculture. World Aquacult. 24: 32-43.

Johannessen, J.N. 2000. Stability of domoic acid in saline dosing solutions. J. Assoc. Offic. Anal. Chem. Internat. 83: 411-412. (PubMed)

Juhl, A.R., Trainer, V.L. and Latz, M.I. 2001. Effect of fluid shear and irradiance on population growth and cellular toxin content of the dinoflagellate *Alexandrium fundyense*. Limnol. Oceanogr. 46(4): 758-764.

Kamykowski, D. 1981. The simulation of a southern California red tide using characteristics of a simultaneously measured internal wave field. Ecol. Model. 12: 253-265.

Kawatsu, K., Hamano, Y., and Noguchi, T. 1999. Production and characterization of a monoclonal antibody against domoic acid and its application to enzyme immunoassay. Toxicon 37: 1579-1589.

Kitts, D.D. and Smith, D.S. 1994. A competitive enzyme-linked immunoassay for domoic acid determination in human body fluids. Food Chem. Toxicol. 32: 1147-1154.

Kitts, D.D. and Smith, D.S. 1997. A serological method for the analysis of domoic acid in shellfish extracts and biological fluids. *In* F. Shahidi, Y. Jones, and D.D. Kitts (Eds.) Seafood safety, processing, and biotechnology. Technomic Publ. Co., Inc., Lancaster, PA, p. 17-23.

Kizer, K.W. 1994. Domoic acid poisoning. Western J. Med. 161: 59-60.

Kodama, M., Ogata, T., and Sato, S. 1988. Bacterial production of saxitoxin. Agric. Biol. Chem. 52: 1075-1077.

Lange, C.B., Reid, F.M.H., and Vernet, M. 1994. Temporal distributions of the potentially toxic diatom *Pseudo-nitzschia australis* at a coastal site in southern California. Mar. Ecol. Prog. Ser. 104: 309-312.

Langlois, G.W., Kizer, K.W., Smith, P., Hansgen, K., and Howell, R. 1993. Preliminary results of the California phytoplankton monitoring program. *In* Abstracts, Sixth International Conference on Toxic Marine Phytoplankton, Nantes, France, October 18-22, 1993, pp. 119.

Langlois, G.W., Kizer, L.W., Hansgen, K.H., Howell, R., and Loscutoff, S.M. 1993. A note on domoic acid in California coastal molluscs and crabs. J. Shellfish Res. 12: 467-468.

Lee, W. 1992. What is domoic acid? Seafood Leader 12 (3).

Lefebvre K.A., Silver, M.W., Coale, S.L., and Tjeerdema, R.S. 2002. Domoic acid in planktivorous fish in relation to toxic *Pseudo-nitzschia* cell densities. Mar. Biol. 140(3): 625-631.

Lefebvre, K.A., Dovel, S.L., and Silver, M.W. 2001. Tissue distribution and neurotoxic effects of domoic acid in a prominent vector species, the northern anchovy *Engraulis mordax*. Mar. Biol. 138: 693-700.

Lefebvre, K.A., Powell, C.L., Busman, M., Doucette, G.J., Moeller, P.D.R., Silver, J.B., Miller, P.E., Hughes, M.P., Singaram, S., Silver, M.W., and Tjeerdema, R.S. 1999. Detection of domoic acid in northern anchovies and California sea lions associated with an unusual mortality event. Natural Toxins 7: 85-92.

Lefebvre, K.A., Powell, C.L., Doucette, G.J., Silver, J.B, Miller, P.E., Hughes, M.P, Silver, M.W., and Tjeerdema R.S. Detection of domoic acid in northern anchovies and California sea lions associated with an unusual mortality event. Nat. Toxins (submitted).

Leira, F.J., Vieites, J.M., Botana, L.M., and Vyeites, M.R. 1998. Domoic acid levels of naturally contaminated scallops as affected by canning. J. Food Sci. 63: 1081-1083.

Loscutoff, S.M. and Lowell, R.L. 1992. Domoic acid. J. Assoc. Food Drug Office 56: 28-

Lund, J.K., Barnett, H.J., Hatfield, C.L., Gauglitz, E.J., Wekell, J.C., and Rasco, B. 1997. Domoic acid uptake and depuration in Dungeness crab (*Cancer magister* Dana 1852). J. Shellfish Res. 16: 225-231.

Lund, J.K. 1995. The uptake and depuration of domoic acid in a controlled feeding study of Dungeness crab (*Cancer magister* Dana). M.Sc. Thesis, Univ. of Washington, 118 pp.

MacPhee, D.J., Hanic, L.A., Friesen, D.L., and Sims, D.E. 1992. Morphology of the toxin-producing diatom *Nitzschia pungens* Grunow forma *multiseries* Hasle. Can. J. Fish. Aquat. Sci. 49: 303-311.

Madhyastha, M.S., Novaczek, I., Ablett, R.F., Johnson, G., Nijjar, M.S., and Sims, D.E. 1991. In vitro study of domoic acid uptake by digestive gland tissue of blue mussel (*Mytilus edulis*). Aquat. Toxicol. 20: 73-82.

Maldonado, M.T., Hughes, M., Rue, E., and Wells, M.L. 2002. The effect of Fe and Cu on the growth and domoic acid production of *Pseudo-nitzschia multiseries* and *Pseudo-nitzschia australis*. Limnol. Oceanogr. (In press).

Manhart, J.R., Fryxell, G.A., Villac, C., and Segura, L.Y. 1995. *Pseudo-nitzschia pungens* and *P. multiseries* (Bacillariophyceae): nuclear ribosomal DNAs and species differences. J. Phycol. 31: 421-427.

Mariën, K. 1996. Establishing tolerable Dungeness crab (*Cancer magister*) and razor clam (*Siliqua patula*) domoic acid contaminant levels. Environ. Health Perspectives 104: 1230-1236.

Matter, A.L. 1994. Paralytic shellfish poisoning: toxin accumulation in the marine foodweb, with emphasis on predatory snails. Puget Sound Estuary Program, U.S. EPA 190/R-94-005. 44 pp.

McGinness, K.L., Fryxell, G.A., and McEachran, J.D. 1995. *Pseudo-nitzschia* species found in digestive tracts of northern anchovies (*Engraulis mordax*). Can. J. Zool. 73: 642-647.

Miller, P.E. and Scholin, C.A. 1998. Identification and enumeration of cultured and wild *Pseudo-nitzschia* (Bacillariophyceae) using species-specific LSU rRNA-targeted fluorescent probes and filter-based whole cell hybridization. J. Phycol. 34: 371-382.

Miller, P.E. and Scholin, C.A. 2000. On detection of *Pseudo-nitzschia* (Bacillariophyceae) species using whole cell hybridization: sample fixation and stability. J. Phycol. 36: 238-250.

Miller, P.E. and Scholin, C.A. 1996. Identification of cultured *Pseudo-nitzschia* (Bacillariophyceae) using species-specific LSU rRNA-targeted fluorescent probes. J. Phycol. 32: 646-655.

Mines, D., Stahmer, S., and Shepherd, S.M. 1997. Poisonings: food, fish, shellfish. Emerg. Med. Clin. North. Am. 15: 157-177.

Mos, L. 2001. Domoic acid: a fascinating marine toxin. Environ. Toxicol. Pharmacol. 9: 79-85.

Neve, R.A. and Reichardt, P.B. 1984. Alaska's shellfish industry. *In* E.P. Ragelis (Ed.) Seafood Toxins. Am. Chem. Soc. Symp. Series 262. Washington, D.C., pp. 53-58.

Newsome, H., Truelove, J., Hierlihy, L., and Collins, P. 1991. Determination of domoic acid in serum and urine by immunochemical analysis. Bull. Environ. Contam. Toxicol. 47: 329-334.

Nguyen, A.L., Luong, J.H.T., and Masson, C. 1990. Capillary electrophoresis for detection and quantification of domoic acid in mussels. Analyt. Letr. 23: 1621.

Nijjar, M.S., Grimmelt, B., and Brown, J. 1991. Purification of domoic acid from toxic blue mussels *(Mytilus edulis*) and phytoplankton. J. Chromatogr. 568: 393-406.

Nijjar, M.S., MacKenzie, P.M., and Brown, J.A. 1992. A procedure for large-scale purification of domoic acid from toxic blue mussels (*Mytilus edulis*). Molecular Cellular Biochem. 115: 213-217.

Nishitani, L. and Chew, K. 1988. PSP toxins in the Pacific coastal states: monitoring programs and effects on bivalve industries. J. Shellfish Res. 7: 653-669.

Nisizawa, K. 1978. Marine algae from a viewpoint of pharmaceutical studies. Jap. J. Phycol. 26: 73-78.

Novaczek, I., Madhyastha, M.S., Ablett, R.F., Donald, A., Johnson, G., Nijjar, M.S., and D.E. Sims. 1992. Depuration of domoic acid from live blue mussels *(Mytilus edulis*). Can. J. Fish. Aquat. Sci. 49: 312-318.

Novaczek, I., M.S. Madhyastha, R.F. Ablett, G. Johnson, M.S. Nijjar, and D.E. Sims. 1991. Uptake, disposition and depuration of domoic acid by blue mussels (*Mytilus edulis*). Aquat. Toxicol. 21: 103-118.

Ohfune, Y. and M. Tomita. 1982. Total synthesis of domoic acid. A revision of the original structure. J. Am. Chem. Soc. 104: 3511-3513.

Olney, J.W. 1994. Excitotoxins in foods. Neurotoxicol. 15: 535-544.

Osada, M., L.J. Marks, and J.E. Stewart. 1995. Determination of domoic acid by two different versions of a competitive enzyme-linked immunosorbent assay (ELISA). Bull. Environ. Contam. Toxicol. 54: 797-804.

Paerl, H.W. 1988a. Nuisance phytoplankton blooms in coastal, estuarine and inland waters. Limnol. Oceanogr. 33:823-847.

Peng, Y.G., Taylor, T.B., Finch, R.E., Switzer, R.C., and Ransdell, J.S. 1994. Neuroexcitatory and neurotoxic actions of the amnesic shellfish poison, domoic acid. NeuroReport 5: 981-985.

Pierce, R.H. and Kirkpatrick, G.J. 2001. Innovative techniques for harmful algal toxin analysis. Env. Toxicol. Chem. 20: 107-114.

Pleasance, S., Xie, M., LeBlanc, Y., and Quilliam, M.A. 1990. Analysis of domoic acid and related compounds by mass spectrometry and gas chromatography/mass spectrometry as N-trifluoroacetyl-O-silyl derivatives. Biomed. Environ. Mass Spectrom. 19: 420-427.

Pocklington, R., Milley, J.E., Bates, S.S., Bird, C.J., de Freitas, A.S.W., and Quilliam, M.A. 1990. Trace determination of domoic acid in seawater and phytoplankton by high-performance liquid chromatography of the fluorenylmethoxycarbonyl (FMOC) derivative. Intern. J. Environ. Anal. Chem. 38: 351-368.

Price, R.J., Hansgen, K.H., Langlois, G.W. 1995. Natural marine toxins. California Sea Grant Coll. Program, La Jolla (USA), UCSGEP-95-4, 2 pp.

Price, D.W., Kizer, K.W., and Hansgen, K.H. 1991. California's paralytic shellfish poisoning prevention program, 1927-89. J. Shellfish Res. 10: 119-145.

Quilliam, M.A. 1995. Seafood toxins. J. AOAC Internat. 78: 144-148.

Quilliam, M.A. and Wright, J.L.C. 1989. The amnesic shellfish poisoning mystery. Anal. Chem. 61 (18): 1053A-1060A.

Ramsey, U.P., Douglas, D.J., Walter, J.A., and Wright, J.L.C. 1998. Biosynthesis of domoic acid by the diatom *Pseudo-nitzschia multiseries*. Natural Toxins 6: 137-146.

Ravn, H. 1995. Amnesic Shellfish Poisoning (ASP). HAB Publications Series, IOC Manuals and Guides No. 31, Vol. 1, UNESCO, Paris, 15 p.

Rensel, J.E. 1993. Factors controlling paralytic shellfish poisoning (PSP) in Puget Sound, Washington. J. Shellfish Res. 12: 371-376.

Rensel, J.E., Horner, R.A., and Postel, J.R. 1989. Effects of phytoplankton blooms on salmon aquaculturein Puget Sound, Washington: initial research. Northw. Environ. J. 5: 53-69.

Richardson, K. 1997. Harmful or exceptional phytoplankton blooms in the marine ecosystem. *In* J.H.S. Blaster and A.J. Southward (Eds.) Advances in Marine Biology, Vol. 31. Academic Press Ltd., New York, p. 301-385.

Rines, J.E.B., Donaghay, P.L., Dekshenieks, M.M., Sullivan, J.M., and Twardowski, M.S. 2000a. Thin layers of *Pseudo-nitzschia* in a fjord in the San Juan Islands, Washington USA. ASLO, Copenhagen.

Rines, J.E.B., Sullivan, J.M., Donaghay, P.L., and Dekshenieks, M.M. 2000b. Where are the harmful algae? Thin layers of phytoplankton, and their implications for understanding the dynamics of Harmful Algal Blooms. International Conference on Harmful Algal Blooms, Hobart, Tasmania, Australia.

Ross, N.W. and Bates, S.S. 1996. Electro-immunoblotting characterization of *Pseudo-nitzschia multiseries* and *P. pungens antigens* recognized by antibodies directed against whole cells. J. Appl. Phycol. 8: 51-58.

Rue, E. and Bruland, K.W. 2001. Domoic acid binds iron and copper: a possible role for the toxin produced by the marine diatom *Pseudo-nitzschia*. Mar. Chem. 76: 127-134.

Sayce, K. and Horner, R. A. 1996. *Pseudo-nitzschia* spp. in Willapa Bay, Washington, 1992 and 1993. *In* T. Yasumoto, Y. Oshima, and Y. Fukuyo (Eds.) Harmful and toxic algal blooms, Intergov. Oceanogr. Comm., UNESCO, Paris, p. 131-134.

Scarratt, D.J., Gilgan, M.W., Pocklington, R., and Castell, J.D. 1991. Detoxification of bivalve molluscs naturally contaminated with domoic acid. *In* W.S. Otwell, G.E. Rodrick, and R.E. Martin (Eds.) Molluscan shellfish depuration. CRC Press, Boca Raton, p. 239-245.

Scholin, C.A. 1998. Development of nucleic acid probe-based diagnostics for identifying and enumerating harmful algal bloom species. *In* D.M. Anderson, A.D. Cembella, and G.M. Hallegraeff (Eds.). Physiological ecology of harmful algal blooms. Springer-Verlag, Heidelberg, p. 337-349.

Scholin, C.A. and Anderson, D.M. 1998. Detection and quantification of HAB species using antibody and DNA probes: progress to date and future research objectives. *In* B. Reguera, J. Blanco, M.L. Fernández, and T. Wyatt (Eds.) Harmful algae. Xunta de Galicia and the IOC of UNESCO, Paris, p. 253-257.

Scholin, C.A., Buck, K.R., Britschgi, T., Cangelosi, G., and Chavez, F.P. 1996. Identification of *Pseudo-nitzschia australis* (Bacillariophyceae) using rRNA-targeted probes in whole cell and sandwich hybridization formats. Phycologia 35: 190-197.

Scholin, C.A., Gulland, F., Doucette, G.J., Benson, S., Busman, M., Chavez, F.P., Cordaro, J., DeLong, R., De Vogelaere, A., Harvey, J., Haulena, M., Lefebvre, K., Lipscomb, T., Loscutoff, S., Lowenstine, L.J., Martin, R.I., Miller, P.E., McLellan, W.A., Moeller, P.D.R., Powell, C.L., Rowles, T., Silvagnl, P., Silver, M., Spraker, T., Trainer, V., and Van Dolah, F.M. 2000. Mortality of sea lions along the central California coast linked to a toxic diatom bloom. Nature 403: 80-84.

Scholin, C.A., Marin III, R., Miller, P.E., Doucette, G.J., Powell, C.L., Haydock, P., Howard, J., and Ray, J. 1999. DNA probes and a receptor-binding assay for detection of *Pseudo-nitzschia* (Bacillariophyceae) species and domoic acid activity in cultured and natural samples. J. Phycol. 25: 1356-1367.

Scholin, C., Miller, P., Buck, K., and Chavez, F. 1997. Detection and quantification of Pseudo-nitzschia australis in cultured and natural populations using LSU rRNA-targeted probes. Limnol. Oceanogr. 42: 1265-1272.

Scholin, C.A., Miller, P., Buck, K., Chavez, F., Cangelosi, G., Haydock, P., Howard, J., and Harris, P. 1996. DNA probe-based detection of harmful algal species using *Pseudo-nitzschia* species as models. *In* T. Yasumoto, Y. Oshima, and Y. Fukuyo (Eds.) Harmful and toxic algal blooms, Intergov. Oceanogr. Comm., UNESCO, Paris, p. 439-442.

Scholin, C.A., Villac, M.C., Buck, K.R., Krupp, K.M., Powers, D.A., Fryxell, G.A., and Chavez, F.P. 1994. Ribosomal DNA sequences discriminate among toxic and non-toxic *Pseudo-nitzschia* species. Natural Toxins 2: 152-165.

Shimizu, Y. 1993. Microalgal metabolites. Chemical Reviews. 93: 1685-1698.

Shumway, S.E. (Ed.). 1988. Toxic algal blooms: hazards to shellfish industry. J. Shellfish Res. 7:587-705.

Shumway, S.E. 1989. Toxic algae: a serious threat to shellfish aquaculture. World Aquacult. 20: 65-74.

Shumway, S.E. 1990. A review of the effects of algal blooms on shellfish and aquaculture. J. World Aquacult. Soc. 21: 65-104.

Shumway, S.E. 1992. Mussels and public health. *In* E. Gosling (Ed.) The mussel *Mytilus*: ecology, physiology, genetics and culture. Elsevier, New York, p. 511-542.

Shumway, S.E. and Cembella, A.D. 1992. Toxic algal blooms: potential hazards to scallop culture and fisheries. Bull. Aquacult. Assoc. Can. 92-4: 59-68.

Silvert, W. and Subba Rao, D.V. 1992. Dynamic model of the flux of domoic acid, a neurotoxin, through a *Mytilus edulis* population. Can. J. Fish. Aquat. Sci. 49: 400-405.

Smith, G.J., Ladizinsky, N., and Miller, P.E. 2001. Amino acid profiles in species and strains of *Pseudo-nitzschia* from Monterey Bay, California: insights into the metabolic role(s) of domoic acid. *In* G.M. Hallegraeff, S.I. Blackburn, C.J. Bolch, and R.J. Lewis (Eds.) Harmful Algal Blooms 2000. Intergovernmental Oceanographic Commission of UNESCO, Paris, p. 323-326.

Stehr, C.M., Connell, L., Baugh, K.A., Bill, B.D., Adams, N.G., and Trainer, V.L. 2002. Morphological, toxicological, and genetic differences among *Pseudo-nitzschia* (Bacillariophyceae) species in inland embayments and outer coastal waters of Washington State, USA. J. Phycol. 38: 1-11.

Stewart, J.E., Marks, L.J., Gilgan, M.W., Pfeiffer, E., and Zwicker, B.M. 1998. Microbial utilization of the neurotoxin domoic acid: blue mussels (*Mytilus edulis*) and soft shell clams (*Mya arenaria*) as sources of the microorganisms. Can. J. Microbiol. 44: 456-464.

Todd, E. 1990. Amnesic shellfish poisoning - a new seafood toxin syndrome. *In* E. Granéli, B. Sundström, L. Edler, and D.M. Anderson (Eds.) Toxic marine phytoplankton. Elsevier Sci. Publ. Co., Inc., New York, p. 504-508.

Todd, E.C.D. 1993. Amnesic shellfish poisoning - a review. J. Food Protection 56: 69-83.

Todd, E.C.D. 1993. Domoic acid and amnesic shellfish poisoning - a review. J. Food Protection 56: 69-83.

Trainer, V.L., Adams, N.G., Bill, B.D., Anulacion, B.F., and Wekell, J.C. 1998. Concentration and dispersal of a *Pseudo-nitzschia* bloom in Penn Cove, Washington, USA. Natural Toxins 6: 113-126.

Trainer, V.L., Adams, N.G., Bill, B.D., Stehr, C.M., Wekell, J.C., Moeller, P., Busman, M., and Woodruff, D. 2000. Domoic acid production near California coastal upwelling zones, June 1998. Limnol. Oceanogr. 45(8): 401-440.

Trainer, V.L. 2002. Marine Mammals as Sentinels of Environmental Biotoxins. *In* Handbook of Neurotoxicology, volume 1, (Massaro, E.J. [Ed.]), Humana Press, pp. 349-362.

Trainer, V.L., Adams, N.G., and Wekell, J.C. Domoic acid-producing Pseudo-nitzschia species off the U.S. West Coast associated with toxification events. *In* G.M. Hallegraef, (ed) Proceedings of the IX International HAB Conference, Tasmania, Australia (In press).

Trainer, V.L., and Poli, M.A. 2000. Assays for Dinoflagellate Toxins, Specifically Brevetoxin, Ciguatoxin, and Saxitoxin. *In* H. Rochat and M.-F. Martin-Eauclaire (Eds.) Animal Toxins. Facts and Protocols Birkhauser, Berlin, pp. 1-19.

Trainer, V.L., Adams, N.G., Bill, B.D., Stehr, C.M., Wekell, J.C., Moeller, P. Busman, M, and Woodruff, D. 2000. Domoic acid production near California upwelling zones, June 1998. Limnol. Oceanogr. 45: 401-440.

Trainer, V.L., and Baden, D.G. 1999. High Affinity Binding of Toxins to Marine Mammal Brain. Aquatic Toxicol. 46: 139-148.

Trainer, V.L., Adams, N.G., Bill, B.D., Anulacion, B.F., and Wekell, J. C. 1998. Concentration and Dispersal of a *Pseudo-nitzschia* Bloom in Penn Cove, Washington, U.S.A. Natural Toxins 6: 1-13.

Trainer, V.L., Adams, N.G., Bill, B.D., Anulacion, B.F., and Wekell, J.C. 1998. A *Pseudo-nitzschia* bloom in Penn Cove, Washington during the summer 1997. Puget Sound Research '98. From Basic Science to Resource Management. Puget Sound Water Quality Authority, PO Box 40900, Olympia, WA 98504.

Trainer, V.L., Wekell, J.C., Horner, R.A., Hatfield, C.L., and Stein, J.E. 1998. Domoic Acid Production by *Pseudo-nitzschia pungens. In* B. Reguera, J. Blanco, M.L. Fernandez, and T. Wyatt (Eds.) Harmful Microalgae IOC of UNESCO, pp. 235-237.

Trainer, V.L. and Baden, D.G. 1991. Enzyme Immunoassay for Detection of Florida Red Tide Brevetoxins. Toxicon 29(11): 1387-1394.

Van Dolah, F.M., Finley, B.L., Doucette, G.J., Moeller, P.D., and Ramsdell, J.S. 1994. Development of rapid and sensitive high throughput pharmacologic assays for marine phycotoxins. Natural Toxins 2: 189-196.

Van Dolah, F.M., Leighfield, T.A., Haynes, B.L., Hampson, D.R., and Ramsdell, J.S. 1997. A microplate receptor assay for the amnesic shellfish poisoning toxin, domoic acid, utilizing a cloned glutamate receptor. Anal. Biochem. 245: 102-105.

Van Dolah, F.M., Zevotek, N.A., Finley, E.L., Doucette, G.J., P.D. Moeller, and Ramsdell, J.S. 1995. A high throughput acid receptor binding assay utilizing microplate scintillation technology. *In* P. Lassus, G. Arzul, E. Erard, P. Gentien, and C. Marcaillou-Le Baut (Eds.) Harmful marine algal blooms. Lavoisier Sci. Publ., Paris, pp. 365-370.

van Egmond, H.P., G.J.A. Speyers, and H.J. van den Top. 1992. Current situation on worldwide regulations for marine phycotoxins. J. Natural Toxins 1: 67-85.

Villac, M.C. 1996. Synecology of the genus *Pseudo-nitzschia* H. Peragallo from Monterey Bay, California, U.S.A. Ph.D. Thesis, Texas A&M University, College Station, TX. 258 p.

Villac, M.C. and Fryxell, G.A. 1998. *Pseudo-nitzschia pungens* var. *cingulata* var. *nov.* (Bacillariophyceae) based on field and culture observations. Phycologia 37: 269-274.

Villac, M.C., Roelke, D.L., Chavez, F.P., Cifuentes, L.A., and Fryxell, G.A. 1993. *Pseudo-nitzschia australis* Frenguelli and related species from the west coast of the U.S.A.: occurrence and domoic acid production. J. Shellfish Res. 12: 457-465.

Villac, M.C., Roelke, D.L., Villareal, T.A., and Fryxell, G.A. 1993. Comparison of two domoic acid-producing diatoms - a review. Hydrobiol. 269: 213-224.

Waldichuk, M. 1989. Amnesic shellfish poison. Mar. Pollut. Bull. 20: 359-360.

Walz, P.M., Garrison, D.L., Graham, W.M., Cattey, M.A., Theerdema, R.S., and Silver, M.W. 1994. Domoic acid producing diatom blooms in Monterey Bay, California: 1991-1993. Natural Toxins 2: 271-279.

Watters, M.R. 1995. Organic neurotoxins in seafoods. Clinical Neurology Neurosurgery 97: 119-124.

Wekell, J.C., Gauglitz, E.J., Jr., Barnett, H.J., Hatfield, C.L., and Eklund, M. 1994. The occurrence of domoic acid in razor clams (*Siliqua patula*), Dungeness crab (*Cancer magister*), and anchovies (*Engraulis mordax*). J. Shellfish Res. 13: 587-593.

Wekell, J.C., Gauglitz, E.J., Jr., Barnett, H.J., Hatfield, C.L., Simons, D., and Ayres, D. 1994. Occurrence of domoic acid in Washington state razor clams (*Siliqua patula*) during 1991-1993. Natural Toxins 2: 197-205.

Wekell, J.C., Horner, R.A., Postel, J.R., Hatfield, C.L., Ross, A.M., and Trainer, V.L. 1998. In situ domoic acid levels in *Pseudo-nitzschia* cells off the Washington state coast in July 1996. *In* B. Reguera, J. Blanco, M.L. Fernández, and T. Wyatt (Eds.) Harmful algae. Xunta de Galicia and the IOC of UNESCO, Paris, p. 235-126.

Wekell, J.C., Lorenzana, R.M, Hogan, M., and Barnett, H. 1996. Survey of paralytic shellfish poison and domoic acid in Puget Sound predatory gastropods. J. Shellfish Res. 15: 231- 236.

Wekell, J.C., Gauglitz, E.J. Jr., Barnett, H.J., Hatfield, C.L., Simons, D., and Ayres, D. 1994. Occurrence of domoic acid in Washington state razor clams (*Siliqua patula*) during 1991-1993. Nat. Toxins 2: 197-205.

Wells, M.L., Trick, C., Maldonado, M., and Rue, E. 2002. Iron Regulation of Domoic Acid Production by Toxigenic *Pseudo-nitzschia* spp. Nature. (Submitted).

Whyte, J.N.C., Ginther, N.G., and Townsend, L.D. 1995. Formation of domoic acid and fatty acids in *Pseudo-nitzschia pungens* f. *multiseries* with scale of culture. J. Appl. Phycol. 7: 199-205.

Whyte, J.N.C., Jones, T.O., Ginther, N.G., and Townsend, L.D. 1996. Physiological effects and retention of domoic acid in the oyster, *Crassostrea gigas*, fed the toxic alga *Pseudo-nitzschia pungens* f. *multiseries*. Bull. Aquacult. Assoc. Can. 96-: 73-75.

Windust, A. 1992. The response of bacteria, microalgae, and zooplankton to the diatom *Nitzschia pungens* forma *multiseries*, and its toxic metabolite domoic acid. M.Sc. Thesis, Dalhousie University, Halifax, Nova Scotia, Canada. 107 p.

Wohlgeschaffen, G.D. 1991. Uptake and loss of the neurotoxin domoic acid by mussels (*Mytilus edulis*) and scallops (*Placopecten magellanicus* Gmelin). M.Sc. Thesis, Dalhousie University, Halifax, Nova Scotia, Canada. 84 p.

Wohlgeschaffen, G.D., Mann, K.H., Subba Rao, D.V., and Pocklington, R. 1992. Dynamics of the phycotoxin domoic acid: accumulation and excretion in two commercially important bivalves. J. Appl. Phycol. 4: 297-310.

Wood, A.M. and Shapiro, L. (Eds.). 1993. Domoic acid: final report of the workshop, Oregon Institute of Marine Biology, February 21-23, 1992. Oregon Sea Grant, ORESU-W-92-003.

Wood, A.M., Shapiro, L., and Bates, S.S. (Eds.). 1994. Domoic acid: final report of the workshop, Oregon Institute of Marine Biology, February 21-23, 1992. Oregon Sea Grant, ORESU-W-94-001 (second edition).

Wood, A.M., Apelian, N., and Shapiro, L. 1993. Novel toxic phytoplankton: a component of global change? *In* R. Guerrero and C. Pedrós-Alió (Eds.) Trends in microbial ecology. Spanish Society for Microbiology, p. 479-482.

Work, T.M., Barr, B., Beale, A.M., Fritz, L., Quilliam, M.A., and Wright, J.L.C. 1993. Epidemiology of domoic acid poisoning in brown pelicans (*Pelecanus occidentalis*) and Brandt's cormorants (*Phalacrocorax penicillatus*) in California. J. Zoo Wildlife Medicine 24: 54-62.

Work, T.M., Beale, A.M., Fritz, L., Quilliam, M.A., Silver, M.W., Buck, K.R., and Wright, J.L.C. 1993. Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. *In* T.J. Smayda and Y. Shimizu (eds) Toxic Phytoplankton Blooms in the Sea. Elsevier Science Publ. B.V., Amsterdam. pp. 643-650.

Worms, J., Bates, S.S., Smith, J.C., Cormier, P., Léger, C., and Pauley, K. 1990. Domoic acid, a neurotoxin produced by the pennate diatom *Nitzschia pungens* forma *multiseries*: an overview of some recent ecological and physiological observations. *In* J.M. Fremy (Ed.) Proceedings of the international symposium on marine biotoxins. CNEVA Pub. Series, Maisons-Alfort, Paris, France, pp. 35-42.

Wright, J.L.C. 1989. Domoic acid, a new shellfish toxin: the Canadian experience. J. Shellfish Res. 8: 444.

Wright, J.L.C. 1990. Toxin research at the NRC Atlantic Research Laboratory. Can. Chem. News 42: 18-22.

Wright, J.L.C. 1995. Dealing with seafood toxins: present approaches and future options. Food Res. Internat. 28: 347-358.

Wright, J.L.C. 1998. Domoic acid - ten years after (guest editorial). Natural Toxins 6: 91-92.

Wright, J.L.C., Falk, M., McInnes, A.G., and Walter, J.A. 1990. Identification of isodomoic acid D and two new geometrical isomers of domoic acid in toxic mussels. Can. J. Chem. 68: 22-25.

Wright, J.L.C. and Quilliam, M.A. 1995. Methods for domoic acid, the amnesic shellfish poisons. *In* G.M. Hallegraeff, D.M. Anderson, and A.D. Cembella (Eds.) IOC manual on harmful marine algae, IOC manuals and guides 33. UNESCO, Paris, pp. 97-113.

Wright, R.O. 1995. Amnesic Shellfish Poisoning. Clin. Toxicol. Rev. 17: 1-2.

Yang, C.Z., Yousif, A.M., Perkins, T., and Albright, L.J. 1993. The mode of action of the toxic phytoplankter, *Heterosigma akashiwo* on juvenile sockeye salmon (*Oncorhynchus nerka*). *In* Abstracts, Sixth International Conference on Toxic Marine Phytoplankton, Nantes, France, October 18-22, 1993, p. 277.

Yao, Y, Nelson, W.H., Hargraves, P., and Zhang, J. 1997. UV resonance raman study of domoic acid, a marine neurotoxic amino acid. Appl. Spectroscopy 51: 785-791.

Yasumoto, T., Nakajima, I., Chunque, E., and Adachi, R. 1977. Finding of a dinoflagellate as a likely culprit of ciguatera. Bull. Jpn. Soc. Sci. Fish. 43: 1021-1026.

Zitko, V. 1992. Domoic acid-containing toxic mussels produce neurotoxicity in neuronal cultures through a synergism between excitatory amino acids. Brain Res. 577: 41-48.