PICES Scientific Report No. 23
2002

Harmful algal blooms in the PICES region of the North Pacific

Edited by
F.J.R. “Max” Taylor and Vera L. Trainer

August 2002
Secretariat / Publisher
North Pacific Marine Science Organization (PICES)
c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2
E-mail: secretariat@pices.int Home Page: http://www.pices.int

TABLE OF CONTENTS

Foreword

This publication by PICES Working Group 15 brings together reviews of the state of knowledge of harmful algal blooms (HABs) in the six PICES member countries of the North Pacific (Canada, Japan, People's Republic of China, the Republic of Korea, Russia and the United States of America) plus Mexico, up to 2001. Both HABs harming humans due to the consumption of contaminated marine products and those harming marine life are involved; both have major economic and social impacts. The reports summarize the impacts and provide insights into the understanding of the ecology of HABs in northern Pacific countries. All nations report severe HAB problems, often due to the same species of algae. These problems appear to be chronic in some countries, and worsening in others; the severity of HABs will likely continue into the foreseeable future. The need and potential value of co-operation in this and other similarly-affected regions is emphasized in this report.

Background and objectives

This report constitutes the first publication of PICES Working Group 15 (WG 15) on Ecology of harmful algal blooms (HABs) in the North Pacific. PICES, the intergovernmental North Pacific Marine Science Organization, derives its nickname from "Pacific ICES", the 10-year-old North Pacific counterpart to the 100 year-old ICES (International Council for the Exploration of the Sea) in the North Atlantic. The current member countries of PICES are Canada, Japan, People's Republic of China, Republic of Korea, Russia and the United States.

HAB is the internationally preferred collective name for harmful phenomena, also known variously as "red tides", "brown tides", and by similar names which may, confusingly, include harmless blooms or blooms without visible manifestations. They have freshwater counterparts but only the marine forms are considered here. The subjects harmed by HABs are either humans or marine fauna. WG 15 was formed as an initiative of both the Marine Environmental Quality (MEQ) and Biological Oceanography (BIO) Committees at the Eighth Annual Meeting of PICES in Vladivostok in 1998. It was established in recognition of dramatically increasing reports of HABs, not only in the North Pacific but also in the coastal regions of the world as a whole. Its goals are to promote the exchange of information and cooperation between the PICES member countries to assist in coping with HABs. A similar working group has been in existence under various guises in ICES for more than a decade, the North Atlantic being similarly afflicted with various types of HABs, including most of those mentioned here.

The membership and terms of reference for WG 15 are shown in Appendices A and B. As a first priority, the Working Group agreed that the state of knowledge on HABs and their impacts in each of the member countries needed to be reviewed to serve as a baseline for determination of regional needs. Other goals were to encourage regional communications, collaborative studies, standardization of methodologies, data sharing and, possibly, training initiatives. The interim activities of WG 15 are summarized in 2000-2001 Annual reports (Appendix C) and in Workshop report on Taxonomy and identification of HAB species and data management (Appendix D).

This is the first group to establish linkages among HAB studies in the six PICES member countries but it is not the first Pacific-based international organization to investigate HABs. In Southeast Asia, a HAB component was a significant part of a seven-year Cooperative Program in Marine Science, a project sponsored by ASEAN-Canada. The program included within-country training workshops for all the ASEAN countries: Malaysia (including Sabah and Sarawak), Indonesia, Brunei, the Philippines, Singapore, Thailand and Vietnam (which joined shortly before the program concluded). A communication network, based in the Philippines, was left in place after the program ended. WESTPAC, another regional scientific organization under IOC, has sponsored meetings and training courses on HABs in the western Pacific, and DANIDA and APEC have also focused on Pacific HABs mostly in Southeast Asia. IOC has a semi-permanent office dealing with global HABs that is located in Denmark. Most recently IOC-UNESCO has established an international program concerned with promoting the study of the ecology of HABs on a global scale, termed GEOHAB. At present most of the activity has been at the national level, most notably ECOHAB in the United States, but with national programs formed or forming in several other PICES member countries.

Our goal in preparing this report has been to provide a useful and practical guide to HAB-related problems, literature and related research/monitoring efforts in northern Pacific nations. For example, the literature relating to each country deliberately includes obscure local literature that might otherwise be missed by outsiders. The national reports provide a basis for future annual incident updates similar to those of the ICES working group. The activities of WG 15 have also brought to light discrepancies in approach and methodologies in the reporting and study of HAB data by the member countries (see

Summary and conclusions). Although there are some differences in detail among PICES member countries, this work has emphasized that all PICES countries suffer from common problems and challenges due to HABs. In many ways, HABs have created a bridge of understanding among nations that share bodies of water and coastlines. These nations are, in fact, more similar to one another than a single nation with multi-ocean coastlines such as Canada, Russia or the United States.

This commonality should help to unite HAB researchers in PICES nations in the future, motivating many international collaborative efforts that strive to better understand the ecology and oceanography of North Pacific and global HABs.

F.J.R. “Max” Taylor and Vera L. Trainer

Section I

Western North Pacific

Red tides and other harmful algal blooms in Japan

Yasuwo Fukuyo[1], Ichiro Imai[2], Masaaki Kodama[3] and Kyoichi Tamai[4]

1 Asian Natural Environmental Science Center, the University of Tokyo, Yayoi 1-1-1, Bunkyo-ku, Tokyo, Japan 113-8657. E-mail: ufukuyo@mail.ecc.u-tokyo.ac.jp

2 Graduate School of Agriculture, Kyoto University, Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto, Japan 606-8502. E-mail: imai1ro@kais.kyoto-u.ac.jp

3 School of Fisheries Sciences, Kitasato University, Okiraiazautou 160-4, Sanriku-cho, Kesen-gun, Iwate, Japan 022-0101. E-mail: kodama@kitasato-u.ac.jp

4 National Research Institute of Fisheries and Environment of Inland Sea, Fisheries Research Agency, Maruishi 2-17-5, Ohno-cho, Saeki-gun, Hiroshima, Japan 739-0452. E-mail: tamaik@nnf.affrc.go.jp

History of HAB investigations in Japan

In Japan, one of the old historical books entitled "The History of Great Japan" (Dai Nippon Shi), edited more than 300 years ago, described 16 cases of red tide, seven in freshwater and the rest in the marine environment. The oldest was an occurrence in 731 AD. A case that occurred in 1234 AD was reported to cause fish mass mortality and human fatalities after eating fishes. The first scientific study on red tides was made by Nishikawa in 1900 on *Noctiluca scintillans*. From 1900 to 1950 the number of reports on red tides was about 10-25 per decade, and after 1950 it gradually increased. In 1970s, the number jumped drastically to more than 200 cases per year along with the development of heavy industry in coastal terrestrial zone and fish aquaculture industry in marine embayments. Fish mass mortality cases with serious economic loss also increased. After 1970, effort and large budgets were devoted to the elucidation of the biology and ecology of red tide organisms and their blooming mechanisms, modeling and mitigation methods.

Two types of harmful algal blooms (HABs) are known in Japan. The first one is a noxious algal bloom associated with the mass mortality of marine organisms, especially fish in aquaculture cages and shellfish hanging from rafts. Most of the noxious blooms cause water discoloration, *i.e.* red tides, but less than 20% of the red tides, as the term is used here, cause harmful effects. Most management and scientific research efforts have been devoted to the harmful ones, but successive occurrences of different harmful species such as *Chattonella*, *Gymnodinium* and *Heterocapsa* along with changing environmental oceanographic conditions, make people concerned, feeling that the fight against red tides is endless.

The second type of HAB is a toxic algal bloom causing contamination of shellfish, either PSP (paralytic shellfish poisoning) or DSP (diarrhetic shellfish poisoning). The amount of toxin in shellfish and the cell number of toxic dinoflagellates are monitored regularly by local governments. Closures of aquaculture areas for the harvesting and marketing of shellfish occur depending on the amount of toxin, not the toxic plankton concentration. Therefore not all blooms of toxic plankton are recorded as HAB occurrences. Toxic plankton blooms with toxin contamination lower than the permitted level are not recorded as HAB occurrences.

In some fishing villages in northern Japan, warning about possible toxin contamination might be passed on from ancestors and known among elderly local fishermen. There are several traditional folk tales such as "Do not eat shellfish during snow water runoff into the sea", *i.e.* it warns that shellfish may become inedible in early spring. After modern aquaculture developed, fishermen tried to sell their products year round but closure of marketing happens often in the spring. Thus we notice the wisdom from the experience that led to the folk tale. Perhaps this indicates that toxin contamination of shellfish has repeatedly occurred almost every year over a long time, leading to many tragedies among the local people.

The first recorded cases that were undoubtedly PSP and DSP occurred in 1948 and 1976, respectively. In the early 1970s, shellfish aquaculture techniques were more fully developed and the aquaculture industry spread into various areas, mainly along the coast of northern Japan. But at the same time several cases of human poisoning (PSP and DSP) were also reported.

The Fisheries Agency together with the Ministry of Health and Welfare set guidelines for monitoring and marketing regulation. After implementation of the official monitoring program there was no poisoning by marine products sold in market.

Red tides that harm marine life

The number of algal bloom occurrences in the western part of Japan (Seto Inland Sea, Kyushu area, Tosa Bay and Kumano-nada: for locations see Figure 1) is shown in Figure 2. In the Seto Inland Sea red tide observations were very rare in the 1950s. Then, they dramatically increased and reached a peak of about 300 per year in the mid-1970s. After this period, they gradually decreased and recently remained stable. The number is now around 100 per year. This is thought to be mainly due to governmental regulations to control eutrophication based on laws such as the law concerning special measures for conservation of the environment of the Seto Inland Sea ("Seto Inland Sea Law") enforced in 1973. On the other hand, in the other three areas, the number of red tide events seems not to have decreased in last two decades. The sighting ranges per annum are 60 to 110 in Kyushu area, 3 to 16 in Tosa Bay, and 0 to 9 in Kumano-nada.

The number of red tides which have actually caused fisheries damage in Japan is shown in Figure 3. In last three decades, it seems to have been relatively stable. The numbers range from 20 to 50 per annum.

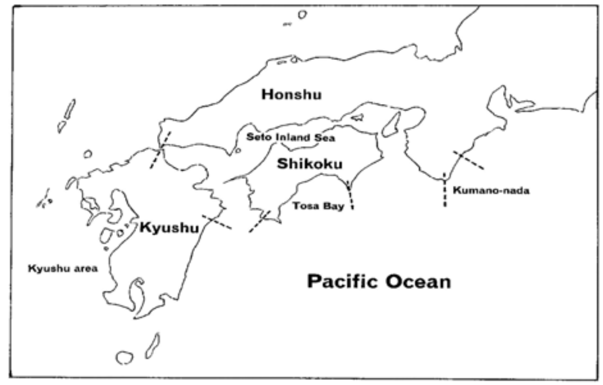


Fig. 1 Map of western Japan.

Figure 4 indicates the economic loss caused by red tides in Japan. Maximum economic loss was recorded in the summer of 1972. In that year the raphidoflagellate *Chattonella* red tide caused severe damage to cultured yellowtail in the eastern part of the Seto Inland Sea. The loss was about seven billion yen (about US$70 million). Since then, the loss per year has decreased but, even in the 1990s, severe fisheries damage was sometimes recorded.

Table 1 demonstrates the major red tide species in Japan and the number of fisheries damage events due to these species. The most hazardous species are *Chattonella marina*, *C. antiqua* and dinoflagellate *Gymnodinium mikimotoi*. These three species mainly kill finfish and have frequently caused very severe fisheries damage of more than 100 million yen (about one million US$). The dinoflagellate *Heterocapsa circularisquama* recorded for the first time from a small, semi-enclosed bay connected to Tosa Bay in 1988 was newly added to the list of hazardous species. This species only shows a harmful effect on shellfish, particularly on bivalves such as edible oysters, pearl oysters, short-necked clams and so on. Very severe fisheries damage caused by this species were occurred four times in last decade. In addition, the dinoflagellates *Cocholodinium polykrikoides* and *Gonyaulax polygramma* and raphidoflagellate *Heterosigma akashiwo* are also hazardous species in Japan.

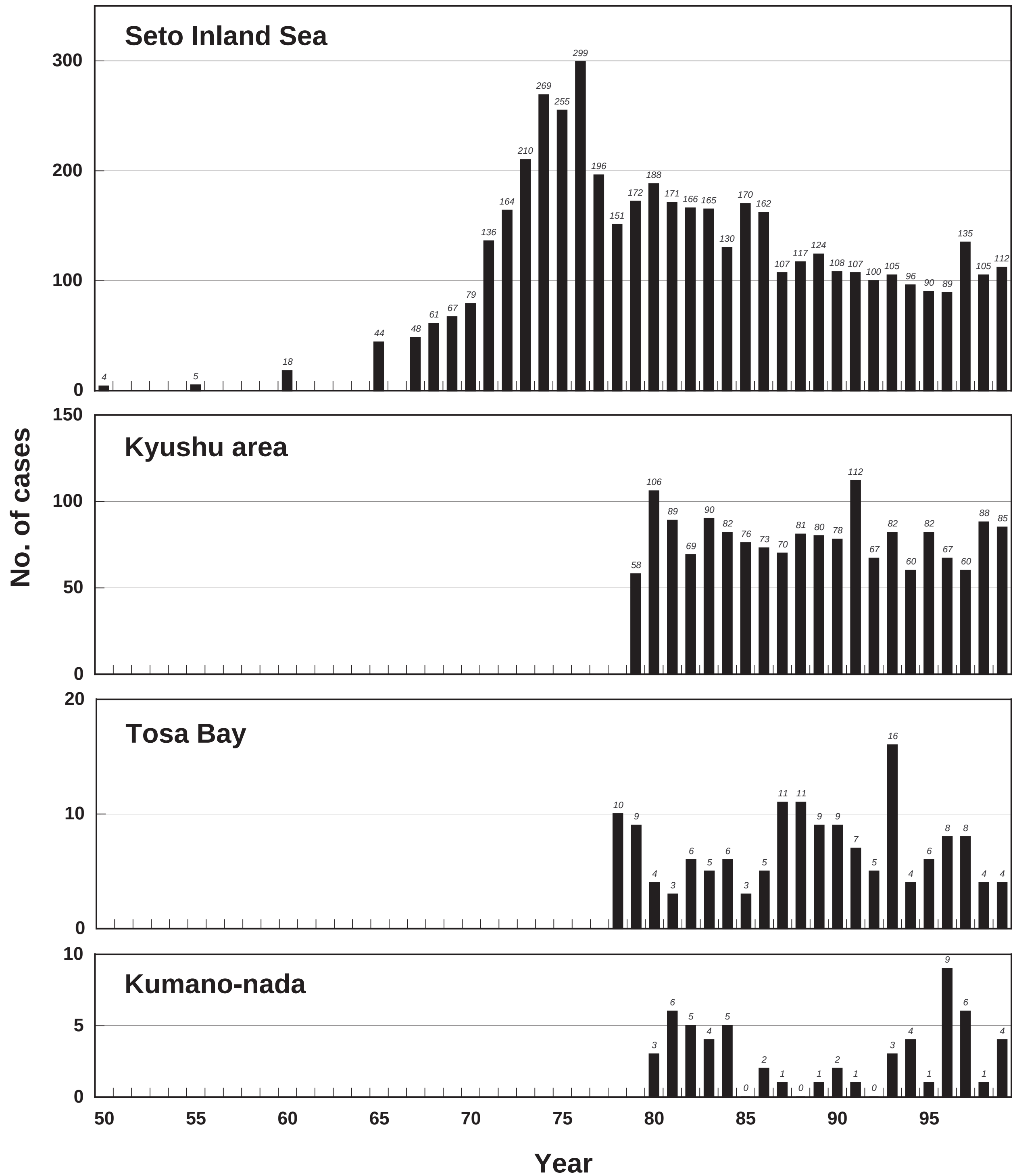


Fig. 2 Number of red tide occurrences per year. ND indicates no data. Refer to Figure 1 for names of area (Fisheries Agency 1973, 1999, 2000b).

Table 1 Major red tide species and the number of fisheries damaged by these species in Japan.

Causative organism (genus)	More than 100 million yen					10 ~ 100 million yen					Species name
	Seto Inland Sea ('70 ~ '98)	Kyushu area ('79 ~ '98)	Tosa Bay ('78 ~ '98)	Kumano-nada ('80 ~ '98)	Total	Seto Inland Sea ('70 ~ '98)	Kyushu area ('79 ~ '98)	Tosa Bay ('78 ~ '98)	Kumano-nada ('80 ~ '98)	Total	
Dinophyceae											
Prorocentrum	0	0	0	0	0	3(2)	1(0)	0	0	4(2)	*P. dentatum* etc.
Cochlodinium	0	0	0	0	0	0	12(1)	0	0	12(1)	*C. polykrikoides* etc.
Gymnodinium	16(2)	2(0)	1(0)	1(0)	20(2)	20(3)	9(1)	2(2)	0	31(6)	*G. mikimotoi* etc.
Polykrikos	0	0	0	0	0	1(1)	1(0)	0	0	2(1)	*Polykrikos* sp.
Noctilca	0	0	0	0	0	4(0)	0	0	0	4(0)	*N. scintilans* etc.
Ceratium	0	0	0	0	0	1(1)	1(0)	0	0	2(1)	*C. fusus* etc.
Alexandrium	0	0	0	0	0	0	1(0)	0	0	1(0)	*A. catenella*
Gonyaulax	2(0)	0	0	0	2(0)	0	0	0	0	0	*G. polygramma*
Heterocapsa	3(0)	1(0)	0	0	4(0)	1(0)	1(0)	0	0	2(0)	*H. circularisquama*
Raphidophyceae											
Chattonella	13(2)	5(0)	0	0	18(2)	11(1)	9(0)	2(1)	0	22(2)	*C. marina*, *C. antiqua* etc.
Heterosigma	0	1(0)	1(0)	0	2(0)	7(3)	0	2(1)	0	9(4)	*H. akashiwo*
Chrysophyceae											
Distephanus	0	1(0)	0	0	1(0)	0	0	0	0	0	*D. speculum*

A dollar corresponds to 108 yen (Aug. 2000).
Figure in parentheses shows the number of the cases that more than 2 species caused a red tide (complex red tide).

(Fisheries agency 1999a, 2000a)

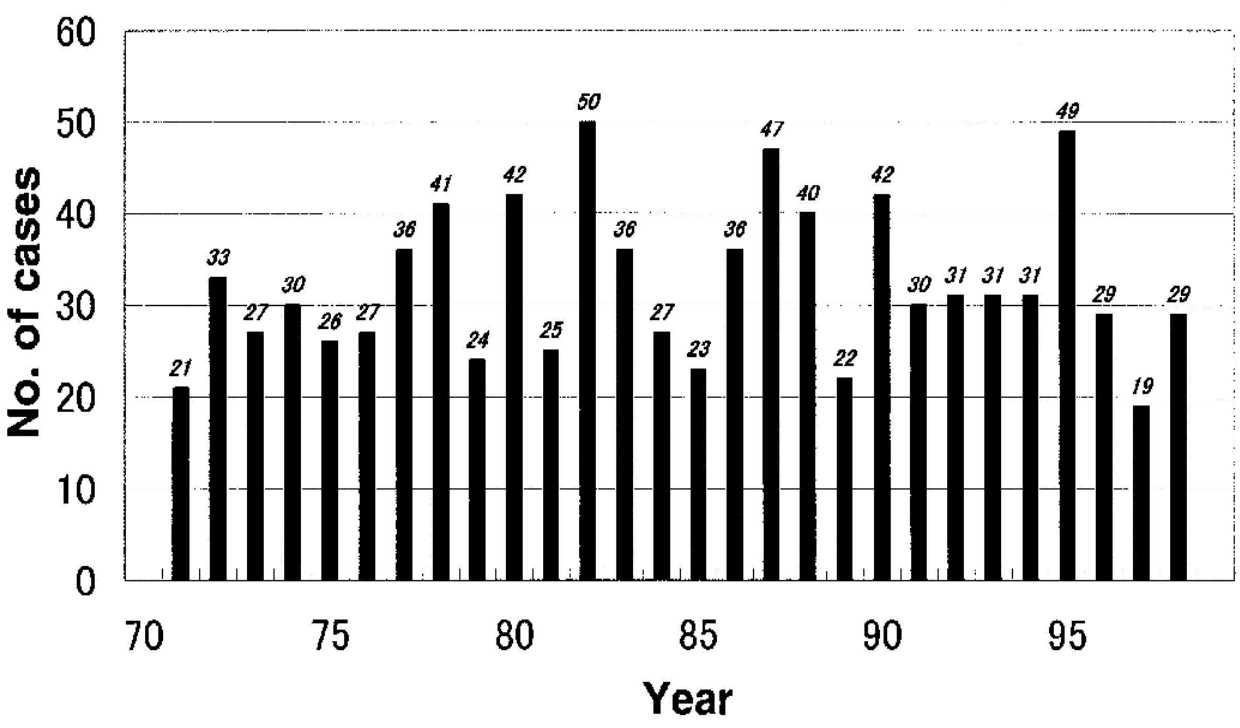


Fig. 3 Number of red tides causing fisheries damage in Japan (Fisheries Agency 1996b).

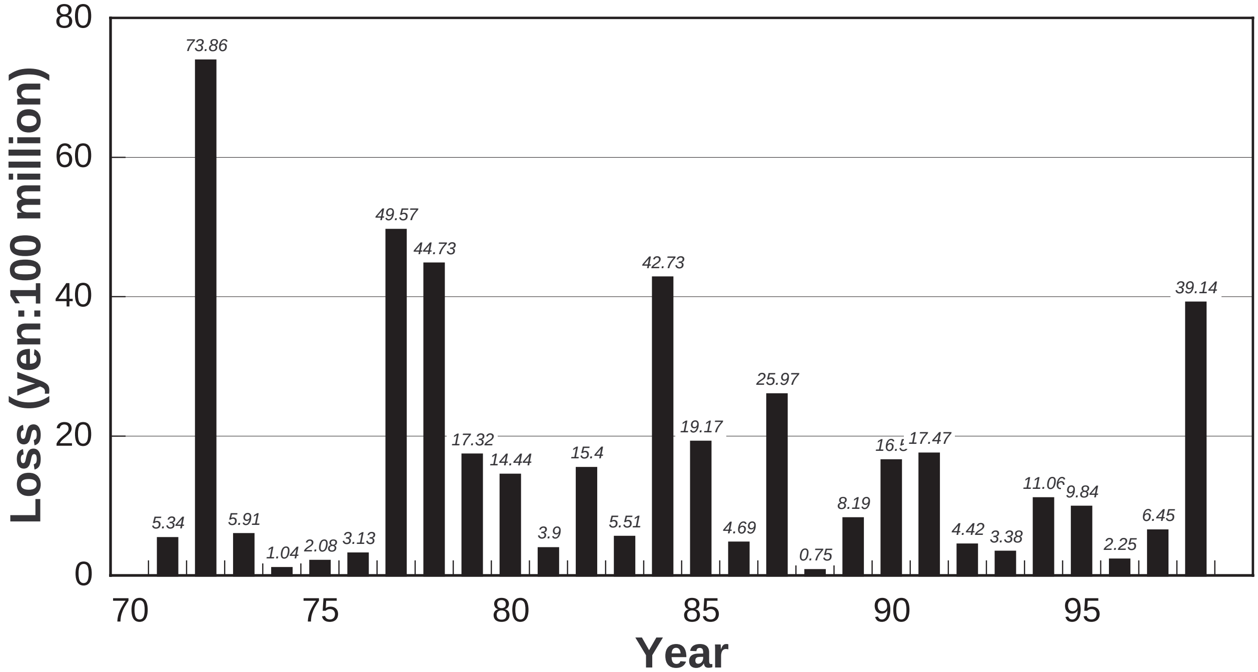


Fig. 4 Economic loss caused by red tide in Japan (Fisheries Agency 1999b).

Plankton blooms toxic to humans

Almost all microalgae responsible for various types of fish and shellfish poisoning of humans, such as PSP, DSP, ASP (amnesic shellfish poisoning), NSP (neurotoxic shellfish poisoning) and ciguatera (ciguatera fish poisoning), are present in Japanese coastal waters. Among them, PSP and DSP toxin contaminations in marine shellfish and filter feeders have been monitored officially since 1995 at 67 sea areas and 173 sampling stations

The official monitoring program started in 1978 in northern Japan and some other areas where shellfish aquaculture operated. Several trials to reduce toxins in shellfish, including the canning of scallops, were operated on a very limited scale. No fully effective countermeasure applicable to variety of affected marine products has been discovered and regular toxin monitoring is the only way to prevent the occurrence of poisoning. Modeling of bloom-forming mechanisms of the causative organisms and toxin accumulation in shellfish has also been tried in several ways in order to create a prediction system, but the current situation is still far from a good system, mostly because of incomplete data acquisition and accumulation. This is the result of low cell number occurrences during blooming of causative plankton and the difficulty in analysis of shellfish physiology.

Among them *A. tamarense* and *A. catenella* appear in wider areas and often cause toxin contamination in scallops, mussels, clams and tunicates. In the first decade after the start of the monitoring program the area affected was mainly in northern Japan, but it gradually expanded to western Japan (Fig. 5). Closures of affected areas are decided by toxin quantification using the mouse bioassay, based on a modified AOAC method. Four MU (Mouse Units) of toxin in 1 gram of edible part of sample is the highest tolerable quarantine level. If the toxicity exceeds the level, closure of the area for harvesting the sample species is declared and three consecutive weeks of lower toxicity than that level is necessary to lift the closure. This means that it takes a minimum 21 days to re-open the market. The economic damage due to PSP toxin contamination is measured by the duration of closure. This monitoring and management system has been working successfully, and no PSP cases have

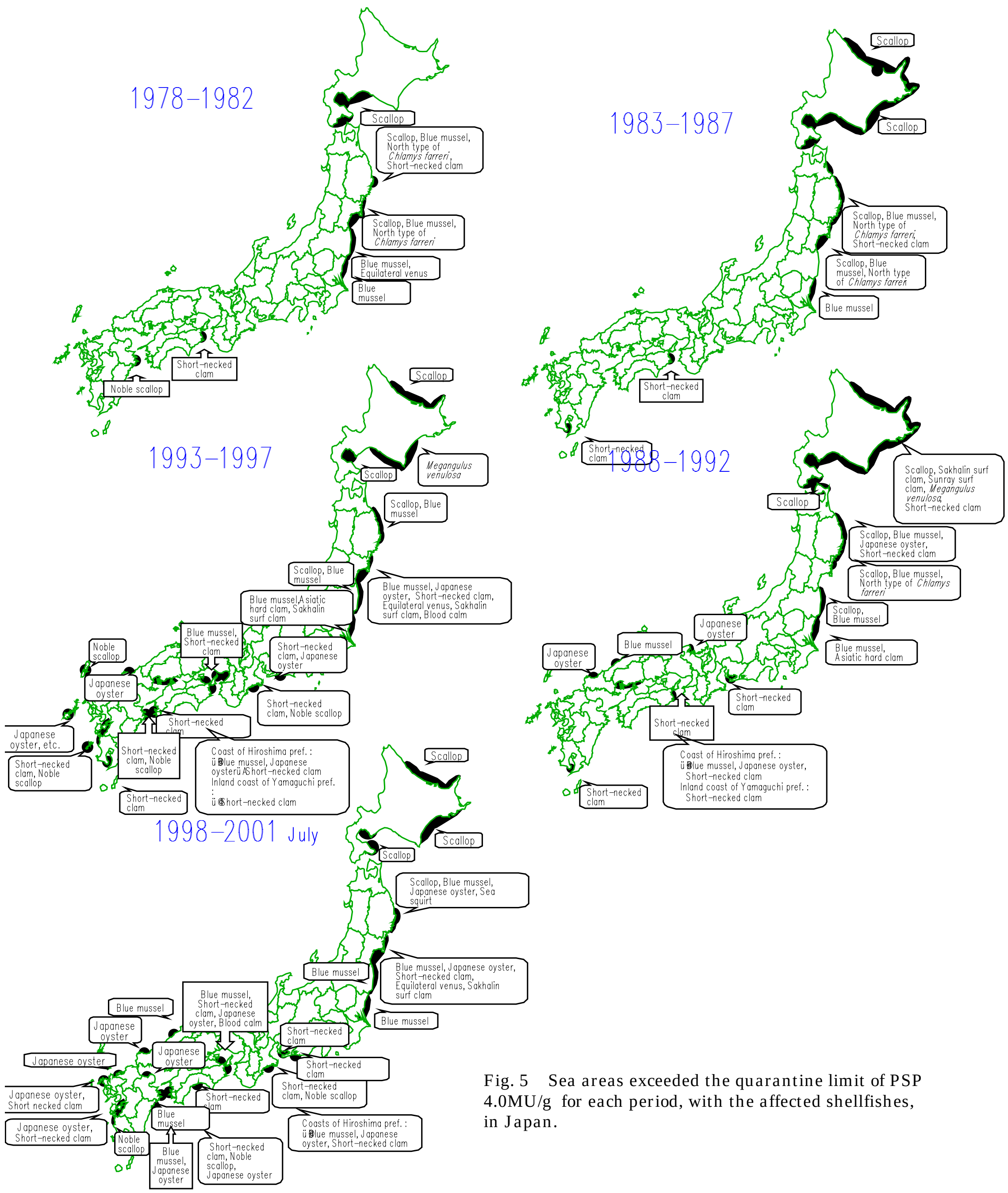


Fig. 5 Sea area exceeded the quarantine limit of PSP 4.0 MU/g for each period with the affected shellfishes in Japan.

occurred so far from eating shellfish sold in market, although some accidental cases have been reported from the consumption of shellfish collected by the victims.

DSP causative plankton

Dinoflagellates responsible for DSP contamination in Japanese waters are *Dinophysis fortii* and *D. acuminata*. Some other dinoflagellates such as *D. mitra* and *D. tripos* are also known to produce DSP toxins, but accumulation of toxins produced by these is less than the quarantine level. Closure of the affected area is decided by toxin quantification using mouse bioassay. A level of 0.05 MU in 1 gram of edible part of shellfish toxin is the highest permissive level. The management policy for the closure of aquaculture areas is same as that for PSP. After the operation of the monitoring program, the area affected was mainly in northern Japan (Fig. 6). In western Japan, *D. fortii* mysteriously never causes DSP toxin contamination in shellfish. After the establishment of the monitoring system, no poisoning case has been reported.

Other toxic microalgae

The diatom genus *Pseudo-nitzschia* is one of the commonest phytoplankton in Japanese waters, and about 10 different species bloom successively almost year round. Among them the production of domoic acid, which is responsible for ASP in North America, has been confirmed in *P. multiseries*, *P. delicatissima* and *P. pseudodelicatissima*. However, domoic acid contamination in wild and aquacultured shellfish has not been detected so far, in spite of very intensive surveys conducted by the Japan Fisheries Agency and several universities. Therefore no regular monitoring program is set for ASP toxins.

For NSP and ciguatera, there is no monitoring program, although *Gymnodinium breve* and *Gambierdiscus toxicus*, causative organisms respectively for those types of poisoning, are sometimes found in western Japan, toxin contamination in shellfish and fish has not been detected.

Mitigation

The incidence of fish killing red tides dramatically increased in frequency and scale in Japanese coastal waters, especially in the Seto Inland Sea, during 1960s and 1970s (see above), and huge fishery damages occurred repeatedly. The incidents have decreased thereafter as a long-term trend during the last two decades, but the number of known causative species has increased. The average economic loss associated with these red tides is about one billion Japanese yen per year.

Therefore, there is an urgent and compelling need for bloom mitigation strategies in aquaculture areas. In this section, plans for impact prevention of red tides attempted in the past are summarized, and the possibility of the utilization of diatoms as competitors for nutrients is described. Also the use of pathogenic microbes, such as bacteria and viruses, is introduced as these may be promising tools in reducing the impacts of red tides in the future.

Shellfish poisoning events (PSP and DSP) are also serious problems in Japan, but mitigation methods for these are not considered in this report because the strategies for these toxic blooms are expected to be different from those for red tides.

Plans for counteracting red tides attempted in the past in Japan

Figure 7 illustrates the attempts at counteracting the impact of red tides in the past in Japan (Shirota 1989). The counteraction techniques are roughly divided into two categories, indirect and direct methods. Indirect methods are basically important as prevention of red tide occurrences on a long-term scale. Laws for regulations were established for the conservation of environments in the coastal sea such as the Seto Inland Sea. These laws have been effective in decreasing the direct discharge of polluted waste water into the coastal areas.

.

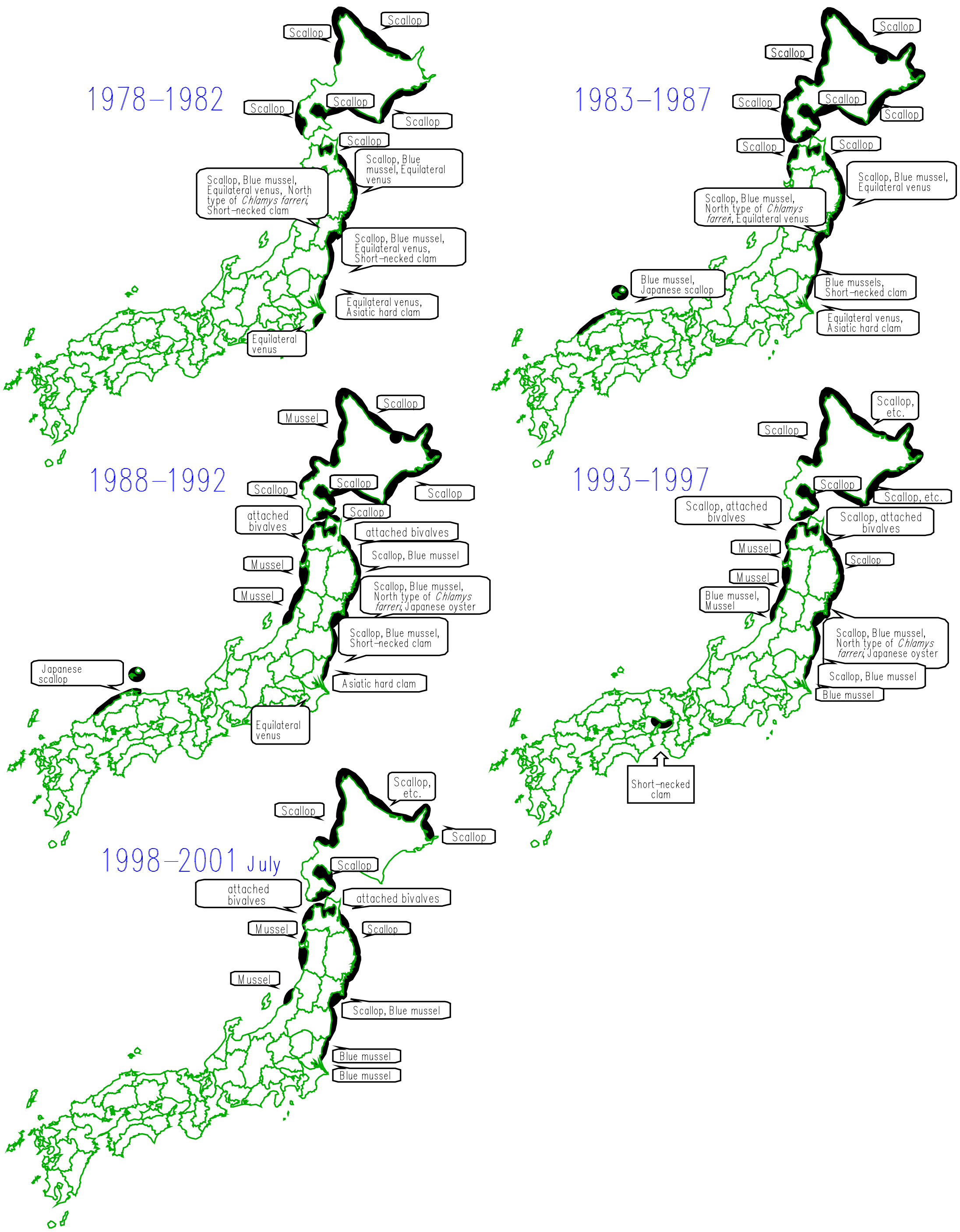


Fig. 6 Sea area exceeded the quarantine limit of DSP 0.05 MU/g for each period with the affected shellfishes in Japan.

The resulting decline of nitrogen and phosphorus concentration in the water and sediments has led to a decrease of incidents of red tides. Developments of fish culture techniques, such as the use of "moist pellets" as a substitute for raw bait, keeping the proper scale and density of fish in aquaculture sites, and transfer of net cages from red tide-prone areas, were effective in reducing the negative impacts of red tides. However, the most prevailing method is to stop feeding cultured fish just before and during red tides. This effectively reduces the mortality of fish in the cages, especially of yellowtail.

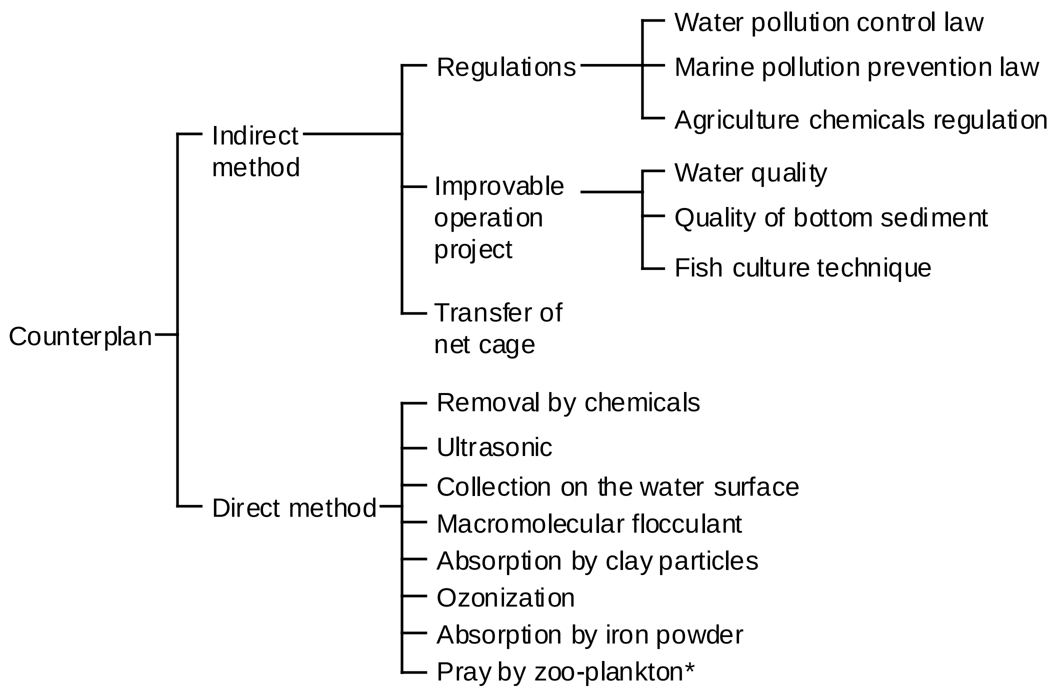


Fig. 7 Counterplans at impact prevention of red tides attempted in the past in Japan (Shirota 1989).

As shown in Figure 7, rather many methods for the direct control of red tides had been attempted before 1985, but no physical and chemical control was successful as a whole. In other words, nature is beyond our direct control. Thereafter, these chemical and physical control options have received little attention. Shirota (1989) suggested that one promising strategy could be to treat red tides with flocculants such as clay, which scavenge particles, including algal cells, from seawater and carry them to bottom sediments. The feasibility of the treatment with clay has also been vigorously investigated in Korea in recent years. Field trials near fish farms have been successful to some extent. However, before this application can be implemented, considerable study is essential to determine the fate and effects of sedimented cells and toxins on benthic animals and the collateral mortality of co-occurring planktonic organisms. Also, the decomposition of sedimented biomass and resulting oxygen depletion needs to be determined (SCOR-IOC 1998).

At present in Japan, treatment with clay is not practically applied because of high costs and the possible bad effects on marine organisms mentioned above.

Biological control of red tides

The biological control of red tides by using copepods and bivalves such as oysters has been examined, but the results were minimal because of the huge scale of red tides (Shirota 1989). Before 1989, microorganisms such as bacteria, viruses, parasites, and harmless phytoplankton such as diatoms, had not been investigated for the application to biological control of red tides except for a few studies on bacteria. These microorganisms appear to be promising control agents against red tides, as they can be abundant in marine ecosystems, proliferate rapidly, and sometimes are host-specific (SCOR-IOC 1998). Basic studies have been conducted on biological control of red tides using microorganisms in Japan during the last decade. Feasibility is discussed in the following sections on diatoms, bacteria, and viruses, and some possible mitigation strategies are proposed.

Prevention of red tides by diatoms

Aiming at controlling red tides due to *Chattonella* spp. (*C. antiqua* and *C. marina*) by using diatoms, a research project sponsored by the Environment Agency of Japan, "Technical development on the ecological control of noxious red tides", was conducted mainly by scientists of the Nansei National Fisheries Research Institute of Fisheries Agency from 1989 to 1993.

It is known empirically that *Chattonella* red tides occur when diatoms are scarce in surface water (Imai *et al*. 1998b). Diatoms (mainly Centrales) can dominate over *Chattonella* spp. due to their higher growth rates. However, diatoms form resting spores under conditions of nutrient limitation, especially of nitrogen, and they rapidly sink to the sea bottom. Accordingly, stratification and resulting exhaustion of nutrients will contribute to the formation of diatom resting spores. A timely mixing event, resulting in nutrient supply to the surface layer, after an appropriate stratification, which causes the nutrient depletion and sinking and/or inactivation of diatoms, is thought to be essential for the occurrence of *Chattonella* red tides.

Chattonella red tides are seeded by the germination of cysts (Imai and Itoh 1987). Diatom resting cells occur at densities of 10^3-10^6 /g (wet sediment) in the coastal sea bottom (Itakura *et al.* 1997). *Chattonella* cysts can germinate in the dark at the sea bottom, but diatom resting cells need light for germination and/or rejuvenation. If a sufficient intensity of light is provided to the diatom resting stage cells on the sea bottom, they are expected to germinate vigorously, and vegetative cells will be supplied to the surface layer (Fig. 8). Growth of diatoms will exhaust nutrients in the surface layer, which will reduce the growth of *Chattonella*. The crucial point of this mitigation strategy (prevention of *Chattonella* red tides) is the timing of irradiation to the sea bottom. The best timing is just after the supply of nutrients to the surface by a mixing event with a low cell density of *Chattonella* in a closed embayment.

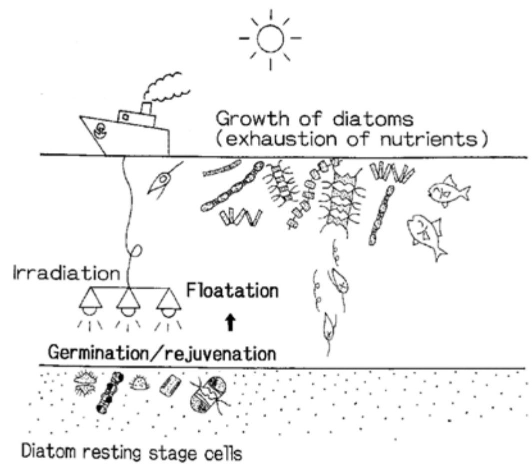


Fig. 8 A possible mitigation strategy of red tides using diatoms. Light is irradiated to the sea bottom in order to accelerate the germination and/or rejuvenation of diatom resting stage cells. Resulting diatom vegetative cells will grow and exhaust nutrients in the surface layer, and suppress the growth of *Chattonella.*

Prevention of red tides by algicidal bacteria

Aiming at controlling red tides by the use of bacteria, several research projects sponsored by the Fisheries Agency were conducted by scientists of several universities and the National Fisheries Research Institute from 1989 to 1999. Temporal fluctuations of algicidal microorganisms acting on the raphidophytes *C. antiqua* and *H. akashiwo,* were studied in northern Hiroshima Bay in the Seto Inland Sea (Imai *et al.* 1998a). The dynamics of *H.*

akashiwo killers revealed a close relationship with that of *H. akashiwo* populations (Fig. 9). *H. akashiwo* killers followed the increase of *H. akashiwo* cells, reaching a maximal level after the beginning of the decline of *H. akashiwo*. They maintained a high level for at least one week after the crash of bloom, and then decreased. *C. antiqua* killers consistently remained at low densities during the period of the *H. akashiwo* red tides. This result clearly indicates that algicidal microorganisms specifically associated with the occurrence and crash of *H. akashiwo* red tides, and contributed to the rapid termination of the red tides in the coastal seas.

Table 2 shows the list of algicidal bacteria isolated from the Japanese coastal seas (Yoshinaga 2000). These bacteria were classified phylogenetically using a database of SSU rDNA. Many algicidal bacteria are new species. The majority of algicidal bacteria are categorized into two groups, γ-proteobacteria (mainly the genera *Alteromonas* and *Pseudoalteromonas*) and a Cytophaga / Flexibacter / Bacteroides (CFB) group (mainly the genus *Cytophaga*). The algicidal bacteria, belonging to CFB group, are generally of the direct attack type, and the γ-proteobacteria are involved in the extracellular production of algicidal matter. SSU rDNA will be used for the development of PCR primers and DNA-probes for FISH (Fluorescence In Situ Hybridization) for specific detection of these algicidal bacteria.

A new aspect of ecology of algicidal bacteria has been the discovery that huge numbers of algicidal microorganisms (mainly bacteria) associate on the surface of macroalgae such as *Ulva* sp. (Chlorophyta) and *Gelidium* sp. (Rhodophyta) (Imai *et al.* in preparation). Maximum numbers of about 10^5 - 10^6 g^{-1} (wet weight) were detected for *Gymnodinium mikimotoi* (Dinophyceae), *Fibrocapsa japonica* (Raphidophyceae), and *H. akashiwo* (Raphidophyceae) (Fig. 10).

Algicidal microorganisms were also abundant in seawater collected at a seaweed bed in Obama Bay and Osaka Bay. Based on these findings, we propose a new prevention strategy of red tides using macroalgae in aquaculture areas (Fig. 11). Co-culturing of *Gelidium* sp. and/or *Ulva* sp. and finfish such as red sea bream or yellowtail is proposed as an effective measure in cage culture. Many algicidal bacteria will be continually released from the surface of macroalgae to seawater, and contribute to reduce cell densities of phytoplankton, including harmful species.

Consequently, these bacteria can probably play an important role in preventing occurrences of noxious red tides. This strategy may be effective in semi-enclosed and small inlets. Feasibility studies will be needed for the practical use of macroalgae in the future. The most excellent merit aspect of this strategy is that macroalgae have no negative image for aquaculture farmers and consumers. Moreover, *Ulva* sp. is actually being utilized as supplementary food for red seabream in some cage cultures in Mie and Ehime Prefectures in Japan

Extermination of red tides by algicidal viruses

Algicidal viruses appear to be promising tools for the reduction or extermination of noxious red tides by virtue of their high host specificity and high replication rate.

In *H. akashiwo* red tides, HaV virus was found and isolated in the final stage of the red tide (Nagasaki *et al.* 1994, Nagasaki and Yamaguchi 1997). Viruses were also found and isolated from the notorious bivalve-killer dinoflagellate *Heterocapsa circularisquama* (Tarutani *et al.* submitted). For the encounter of viruses and host algal cells, relatively high cell densities of red tide organisms are thought to be essential.

Hence, viruses cannot be used as a tool for the prevention of red tides but as an effective tool for the extermination of red tides. As viruses have an extremely high replication rate, they can be utilized as a trump card after the failure of the prevention of red tides by diatoms and algicidal bacteria at earlier stages.

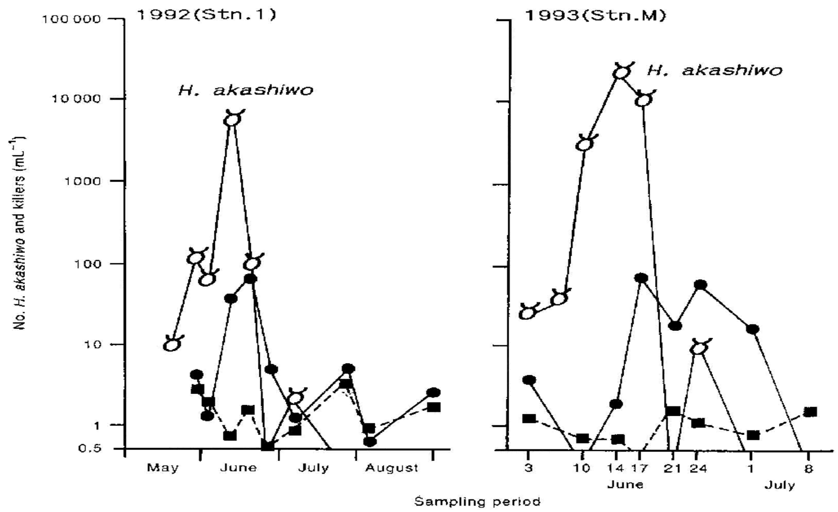


Fig. 9 Fluctuations in densities of *Heterosigma akashiwo* (o), *H. akashiwo* killers (•), and *C. antiqua* killers (■) in the surface waters collected in northern Hiroshima Bay, the Seto Inland Sea (Imai *et al.* 1998a).

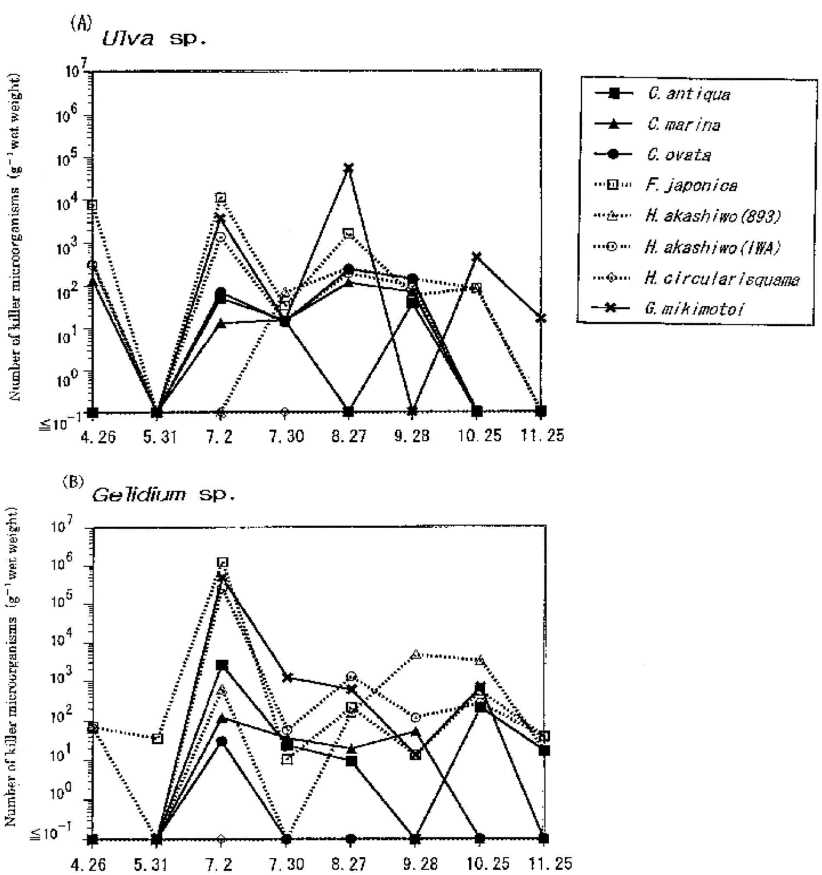


Fig. 10 Seasonal fluctuations in densities of killer microorganisms associated with seaweeds against 8 red tide flagellates (Imai *et al.* in preparation). Algal samples were collected at the station located in macrophitic bed in Osaka Bay.

Table 2 Algicidal microorganisms (mainly bacteria) isolated from the Japanese coastal seas.

Species and strain	Isolated year	Isolated area	Host microalga for isolation	Accession No. in DDBJ	Remarks
Cytophaga sp. /J18/M01	1990	Harima-Nada	*Chattonella antiqua*	AB017046	Direct attack
Alteromonas sp. /S	1991	Hiroshima Bay	*Chattonella antiqua*	AB040464	Extracellular production of algicidal matter
Alteromonas sp. /K	1991	Hiroshima Bay	*Chattonella antiqua*	AB040465	Extracellular production of algicidal matter
Alteromonas sp. /D	1991	Hiroshima Bay	*Chattonella antiqua*	AB040466	Extracellular production of algicidal matter
Pseudoaltermonas sp. /R	1991	Hiroshima Bay	*Chattonella antiqua*	AB040467	Extracellular production of algicidal matter
Alteromonas sp. /GY21	1994	Hiroshima bay	*Heterosigma akashiwo*	AB001335	Extracellular production of algicidal matter
Alteromonas sp. /GY27	1994	Hiroshima Bay	*Heterosigma akashiwo*	AB001334	Extracellular production of algicidal matter
Cytophaga sp. /GY9	1994	Hiroshima Bay	*Heterosigma akashiwo*	AB001332	Extracellular production of algicidal matter
Flavobacterium sp. /5N-3	1989	Uranouchi Inlet, Kochi Pref.	*Gymnodinium mikimotoi*	AB017597	Extracellular production of algicidal matter
Alteromonas sp. /E401	1991	Tanabe Bay	*Gymnodinium mikimotoi*	AB004313	Extracellular production of algicidal matter
γ-proteobacterium /EHK-1	1999	Etauhi, Hiroshima bay	*Heterocapsa circularisquama*	AF228694	
Cytophaga sp. /AA8-2	1995	Ago Bay, Mie Pref	*Heterocapsa circularisquama*	AB017047	Direct attack type, the same as Cytophaga sp. J18/M01
Cytophaga sp. /AA8-3	1995	Ago Bay, Mie Pref	*Heterocapsa circularisquama*	AB017048	Direct attack type, the same as Cytophaga sp. J18/M01
Pseudoalteromonas sp. /A25	1994	Ariake Sea, Fukuoka Pref.	*Skeletonema costatum*	AF227237	Extracellular production of algicidal matter, specific to diatoms
Pseudoalteromonas sp. /A28	1994	Ariake Sea	*Skeletonema costatum*	AF227238	Extracellular production (protease) of algicidal matter, specific to diatoms, the same as A27, A29, A30, A42
Cytophaga sp. /A5	1990	Ariake Sea	*Skeletonema costatum*	AB008031	The same as A11, A14, A15, A20
Cytophaga sp. /A11	1990	Ariake Sea	*Skeletonema costatum*	AB008032	The same as A5, A14, A15, A20
Cytophaga sp. /A14	1990	Ariake Sea	*Skeletonema costatum*	AB008033	The same as A5, A11, A15, A20
Cytophaga sp. /A15	1990	Ariake Sea	*Skeletonema costatum*	AB008034	The same as A5, A11, A14, A20
Cytophaga sp. /A20	1990	Ariake Sea	*Skeletonema costatum*	AB008035	The same as A5, A11, A14, A15
Cytophaga sp. /A38	1994	Ariake Sea	*Skeletonema costatum*	AB008036	
Cytophaga sp. /A12	1992	Ariake Sea	*Skeletonema costatum*	AB008037	The same as A32, A35, A41
Cytophaga sp. /A32	1992	Ariake Sea	*Skeletonema costatum*	AB008038	The same as A12, A35, A41
Cytophaga sp. /A35	1992	Ariake Sea	*Skeletonema costatum*	AB008039	The same as A12, A32, A41
Cytophaga sp. /A41	1992	Ariake Sea	*Skeletonema costatum*	AB008040	The same as A12, A32, A35
Flavobacterium sp. /A16	1992	Ariake Sea	*Skeletonema costatum*	AB008041	
Flavobacterium sp. /A17	1992	Ariake Sea	*Skeletonema costatum*	AB008042	
Flavobacterium sp. /A43	1994	Ariake Sea	*Skeletonema costatum*	AB008043	
Flexibacter sp. /A37	1994	Ariake Sea	*Skeletonema costatum*	AB008044	
Flexibacter sp. /A45	1994	Ariake Sea	*Skeletonema costatum*	AB008045	
Cytophaga sp. /A23	1994	Ariake Sea	*Skeletonema costatum*	AB008046	
Saprospira /SS90-1	1990	Shrimp culture pond, Kagoshima Pref.	*Chaetoceros ceratosporum*	unavailable	Filamentous, multicellular, carotenoid, cell lysis by direct contact
Saprospira /SS91-40	1991	Shrimp culture pond, Kagoshima Pref.	*Chaetoceros ceratosporum*	unavailable	Filamentous, multicellular, carotenoid, cell lysis by direct contact
Saprospira /SS92-11	1992	Kagoshima Bay	*Chaetoceros ceratosporum*	unavailable	Filamentous, multicellular, carotenoid, cell lysis by direct contact
Saprospira /SS95-4	1995	Kagoshima Bay	*Chaetoceros ceratosporum*	unavailable	Filamentous, multicellular, carotenoid, cell lysis by direct contact
Labyrinthula /L93-3	1993	Seagrass, Kagoshima Bay	*Chaetoceros ceratosporum*	unavailable	Eucaryotes, cell lysis by direct contact
Labyrinthula /L95-1	1995	Seaweed, Kagoshima Bay	*Chaetoceros ceratosporum*	unavailable	Eucaryotes, cell lysis by direct contact

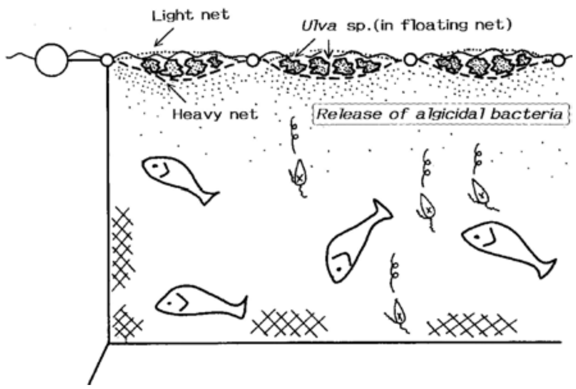


Fig. 11 A possible prevention strategy of red tide by using macroalgae in aquaculture areas. Co-culture of macroalgae and finfish is proposed in the same cage.

Diatoms have not yet been tried for the prevention of harmful red tides. Uncertainties about host specificity, pathogen stability, and environmental impacts such as negative effects of these microorganisms on higher organisms, must be examined before the practical utilization of microorganisms as tools for the prevention and control of noxious red tide occurrences.

References

Fisheries Agency. 1973. Information on the occurrence of red tide in the Seto Inland Sea. Seto Inland Sea Fisheries Coordination Office, Annual Report 1972 (in Japanese).

Fisheries Agency. 1999a. Information on the occurrence of red tide in Kyushu area. Kyushu Fisheries Coordination Office, Annual Report 1998 (in Japanese).

Fisheries Agency. 1999b. Report on accidental fisheries damages. Annual Report 1998 (in Japanese)

Fisheries Agency. 2000a. Information on the occurrence of red tide in the Seto Inland Sea Fisheries Damages-. Seto Inland Sea Fisheries Coordination Office, Supplemental Report (in Japanese).

Fisheries Agency. 2000b. Information on the occurrence of red tide in the Seto Inland Sea. Seto Inland Sea Fisheries Coordination Office, Annual Report 1999 (in Japanese).

Imai, I. and Itoh, K. 1987. Annual life cycle of *Chattonella* spp., causative flagellates of noxious red tides in the Inland Sea of Japan. Mar. Biol. 94: 287-292.

Imai, I., Kim, M.C., Nagasaki, K., Itakura, S., and Ishida, Y. 1998a. Relationships between dynamics of red tide-causing raphidophycean flagellates and algicidal micro-organisms in the coastal sea of Japan. Phycol. Res. 46: 139-146.

Imai, I., Yamaguchi, M., and Watanabe, M. 1998b. Ecophysiology, life cycle, and bloom dynamics of *Chattonella* in the Seto Inland Sea, Japan. *In* Anderson, D.M., A.D. Cembella and G.M. Hallegraeff (Eds.) Physiological Ecology of Harmful Algal Blooms. Springer-Verlag, Berlin, pp. 95-112.

Itakura, S., Imai, I., and Itoh, K. 1997. "Seed bank" of coastal planktonic diatoms in bottom sediments of Hiroshima Bay, Seto Inland Sea, Japan. Mar. Biol. 128: 497-508.

Nagasaki, K., Ando, M., Itakura, S., Imai, I., and Ishida, Y. 1994. Viral mortality in the final stage of *Heterosigma akashiwo* (Raphidophyceae) red tide. J. Plankton Res. 16: 1595-1599.

Nagasaki, K. and Yamaguchi, M. 1997. Isolation of a virus infectious to the harmful bloom causing microalga, *Heterosigma akashiwo*. Aquat. Microb. Ecol. 13: 135-140.

SCOR-IOC. 1998. The global ecology and oceanography of harmful algal blooms - A plan for coordinated scientific research and co-operation to develop international capabilities for assessment, prediction and mitigation. Report from a joint IOC/SCOR Workshop, Havreholm, Denmark, p. 43.

Shirota, A. 1989. Red tide problem and countermeasures (2). Int. J. Aq. Fish. Technol. 1: 195-223.

Tarutani, K., Nagasaki, K., Itakura, S., and Yamaguchi, M. Isolation of a virus infecting the novel shellfish-killing dinoflagellate *Heterocapsa circularisquama*. Aquat. Microb. Ecol. (submitted).

Yoshinaga, I. 2000. Molecular taxonomy of algicidal bacteria. *In* Fisheries Agency Report of technical development in utilization of marine microorganisms for preventing harmful red tides. Tokyo (in Japanese), (in press).

A national report on harmful algal blooms in China

Tian Yan, Ming-Jiang Zhou and Jing-Zhong Zou

Institute of Oceanology, Chinese Academy of Sciences, Qingdao, 266071, People`s Republic of China.

E-mail: tianyan@ms.qdio.ac.cn

Introduction

Harmful algal blooms (HABs) have been spreading and increasing along the coast of China in the past two decades, causing damage to the marine environment and posing a threat to human health (Zou 1992; Qi *et al.* 1993; Tseng *et al.* 1993; Zhu *et al.* 1995). Because HABs are globally distributed and are integral parts of marine and brackish-water ecosystems, the central research problem can be addressed comprehensively and effectively only through international, interdisciplinary, and comparative research on important questions about the dynamics of HABs within their oceanographic and ecological systems (GEOHAB 1998). Several international organizations, including IOC (Intergovernmental Oceanographic Commission), PICES (North Pacific Marine Science Organization), APEC (Asian-Pacific Economic Cooperation) have set up programs or workshops on HABs. To foster international cooperative research on HABs, it is important for marine and health scientists and agencies to document and understand HAB occurrences in each country in order to find common issues. In this paper, we will give an overview of HAB history, causative HAB species, algal toxin distribution and poisoning events, and introduce HAB research activities and recent progress in HAB monitoring and mitigation in China.

HAB occurrence in China

The first documented HAB event in China, which was caused by *Noctiluca scintillans* and *Skeletonema costatum* in Zhejiang coast in 1933, killed marine organisms such as razor clams and other shellfish species. This event was recorded by H. Fei (Fei 1952). A summary of the early HABs in China is shown in Table 3. The Chinese government and concerned scientists started to pay greater attention to HABs after the especially devastating *Prorocentrum minimum* bloom in the Bohai Sea, in August 1977. This event covered an area of 560 km^2 and lasted 20 days, causing a mass mortality of fish, resulting in great losses to the local fishery (Hua 1989). With increased awareness of the issue and economic development along the coast of China, HAB numbers have increased dramatically each year. Figure 12 shows coastal seas in China where HABs can occur. Figure 13 demonstrates the increase in number of HAB occurrences during recent decades. It is clear that HABs have been increasing rapidly along the Chinese coast since the 1970s, and that they occur more frequently along the south coast than along the north coast. Thus, at least 322 documented HAB events have occurred from 1952-1998 in Mainland China. An average of more than 10M RMB (1.2M US$) economic loss related to HAB occurrences has been suffered each year. The main areas of HAB occurrences are the Bohai Sea, Changjiang Estuary and the South China Sea. The HAB seasons are apparently delayed from the south to the north coast, which peak in March- May in the South China Sea, June-August in the East China Sea, and July-September in Bohai Sea and Yellow Sea.

Table 4 lists 27 major and recent HAB events in China (event locations are also shown in Figure 12). These HAB events have resulted in great damage to local fisheries, the mariculture industry, and/or human health. In each of three successive years from 1998, large HAB events on the scale of several thousand square kilometers, occurred in the Bohai Sea, East China Sea or South China Sea. This increase in HAB frequency, scale and economic loss in China is drawing great attention from the government and the public.

Fig. 12 Sites of major HAB occurrences and sites of shellfish sampling for toxin analysis in the coastal seas of China. Sites are described in more detail in Table 4.

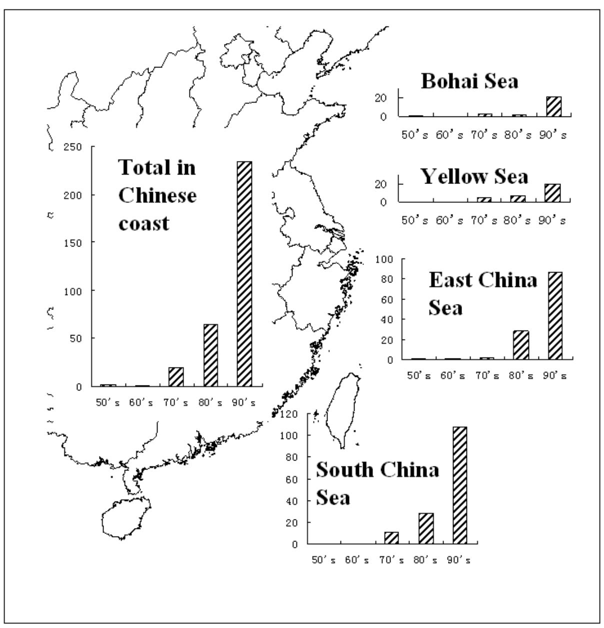


Fig. 13 HAB events reported in the coastal seas of China during each decade from 1952-1998.

As one of the areas of most frequent HAB occurrence, Hong Kong first began its reporting of HAB events in the early 1970s. In 1983, Lam and Ho (1989) pointed out that the increasing frequency of HABs and related fish-killing events in Hong Kong were thought to be correlated with increased urbanization of that region. From 1980-1997, 496 HAB events were recorded in Hong Kong waters (AFD 1997). According to the record, the area of most frequent HAB occurrence in Hong Kong was at Tolo Harbour (which experienced more than 70% of the total HAB events), Mirs Bay and Port shelter (which are all located at north-east of Hong Kong). In Hong Kong, 70% of the HABs occurred between December and May.

In Taiwan, *Alexandrium minutum* has been a main causative HAB species. Blooms of this species were first recorded in a crab culture pond in Pintoung County in November 1986. Since the late 1980s, blooms of this species have caused mass mortality of cultured fish and grass prawn and PSP contamination of shellfish, as well as frequent intoxication of humans in Taiwan (Zhou 1999; Su *et al.* 1993). The species was classified as *Gonyaulax tamarensis*, also known as *A. tamarense* in the early literature (Zhou 1999).

Toxin distribution and poisoning events in China

Several studies on PSP (Paralytic Shellfish Poisoning) toxins in shellfish and its causative organisms have been focused in Guangdong, Hong Kong, Taiwan, and in southern coast regions of China (Lam *et al.* 1989b; Lin *et al.* 1994; Anderson *et al.* 1996; Zhou 1999; Jiang *et al.* 2000). In Hong Kong, PSP toxins were first detected in shellfish samples in Tolo Harbour in 1985 (Lam *et al.* 1989b). PSP toxins in marine products from Hong Kong showed two peaks with the main peak occurring in the spring and the other in fall (Chan and Young 1999). However, not until a recent investigation of PSP and DSP (Diarrhetic Shellfish Poisoning) toxins along the Chinese coast (sample sites are shown in Figure 12), was it found that these toxins were distributed widely along both the northern and southern coasts of China (Zhou *et al.* 1999). This investigation also indicated that DSP toxins were more frequently detected than PSP toxins. The frequency of occurrence and levels of PSP toxins along the southern coast were higher than those along the northern coast. In March 1990, extremely high PSP toxicity (>20,000 MU/kg) was detected in shellfish samples collected in Tai Tam Bay, southeast of Hong Kong, due to a bloom of *A. catenella* (Ho and Hodgkiss 1993). The highest level of DSP (10 μg/g) in China was found in blue mussel collected on October 2, 1998, in Liaodong Bay (Juhua Island) during a bloom of *Ceratium furca* and *Dinophysis fortii* (Zhao 2000). The distribution of PSP and DSP toxins along the Chinese coast is shown in Table 5.

Table 3 Early record of HAB events in China.

Year	Site	Species	Reference
1933	Zhenhai to Taizhou-Shipu along Zhejiang Coast	*Noctiluca scintillans* *Skeletonema costatum*	Fei, 1952
1952	Yellow River Estuary, 1460 km^2	*Noctiluca scintillans*	Fei, 1952
1962	Pingtan Island sea area along Fujian Coast	*Trichodesmium* sp.	Zhou, 1962
1971	Hong Kong coast	*Noctiluca scintillans*	Morton & Twentyman, 1971
1972	Exterior sea area of Changjiang Estuary	*Trichodesmium* sp.	Chen, 1972

Table 4 Main HAB events in the last 20 years in China. The number in parentheses under Area indicates its location in Figure 12.

Sea	Area	Time	Extent	Species	Damage/ Loss
Bohai Sea	(1) Huanghua coast, Hebei	Aug.-Sept., 1989	1300 km^2	*Gymnodinium* sp.	Economic loss was about 200M RMB (25M US$)
	(2) Bohai Sea	Sept.-Oct., 1998	5000 km^2	*Ceratium furca*	Economic loss 500M RMB
	(2) Sishili Bay, Yantai	Aug.-Sept., 1998	100 km^2	*Gymnodinium sanguineum*	large amount of marine organisms, 30M RMB loss
	(2) Bohai Sea	July, 1999	6300 km^2	*Noctiluca scintillans*	
	(3) Liaodong Bay	July, 2000	350-850 km^2		About 100M Jellyfish died
	(4) Liaoning Coast	Aug., 2000	1000 km^2		
East China Sea	(5) Exterior sea area of Changjiang Estuary	June–July, 1987	1000 km^2	*Skeletonema costatum*	Marine ecosystem was affected seriously
		June, 1988	1400 km^2	*Noctiluca scintillans*	Marine ecosystem was damaged seriously
		July, 1989	1700 km^2	*Noctiluca scintillans*	Marine ecosystem was damaged seriously
	(6) Gouqi sea area of Zhejiang	Aug., 1987	large area	*Noctiluca scintillans*	A large amount of bay scallop and abalone, also mussels died
	(7) East coast of Zhejiang	May, 1990	7000 km^2		fish, shrimp, and shellfish affected
	(8) Weitou Bay to Quanzhou Bay in Fujian	mid June, 1990		*Cochlodinium* sp.	Large amount of fish and clams died. 600M RMB
	(9) Changjiang Estuary and Hangzhou Bay	1998	Large area		

Sea	Area	Time	Extent	Species	Damage/ Loss
	(11) Zhoushan Area, Zhejiang	May, 2000	7000 km^2	*Prorocentrum* sp.	
South China Sea	(12) Inland bay of Zhanjiang Harbour, Guangdong	May 1980		*Guinardia flaccida*	fish died, resulting in reduction of fish mariculture output
	(13) Tolo Harbour in Hong Kong	Sept., 1980			Resulted in the death of fish and invertebrates, and also affected tourism in this area
	(14) Sansha sea area of Mindong, Fujian	Sept., 1981		*Noctiluca scintillans*	Cultured oysters and kelp were influenced
	(15) Dapeng Bay and Daya Bay, Guangdong	April, 1983		*Rhizosolenia Alata* f. *Gracillima*	A large loss of fish, shrimp, and shellfish. In one county alone, Gaoyang, 75 tons fish died.
	(13) Hong Kong sea area	summer, 1987		*A. polygramma*	Large sea area, dead fish reached 120 tons and economical loss was 24 thousands Pounds
	(13) Hong Kong sea area	March, 1989		*A. catenella*	Market sales of shellfish were suspended for two weeks
	(16) Tainan county, Taiwan	June, 1989		*A. minutum*	Mass mortality of grass prawn
	(17) Chiayi county, Taiwan	Feb., 1991		*A. minutum*	136 human poisonings, 2 deaths
	(15) Yantian Sea area of Dapeng Bay	March 20, 1991		*Chattonella marina*	Large amount of fish and fish fry were killed
	(14) + (15) Quanzhou Bay in Fujian to Shanwei in Guangdong	Nov.-Dec., 1997	some thousand km^2	*Phaeocystis pouchetii*	180M RMB
	(13)+(15) Hong Kong and Guangdong Waters	March-April, 1998	Large area	*Gymnodinium* sp.	Fish fry and cultured fish affected, economic loss reached 100M HK$
	(15) Daya Bay, Guangdong	August, 2000	20 km^2	*Scrippsiella trochoidea Peridinium quinquecorne*	Fish death, economic loss About 1M RMB.

Table 5 PSP and DSP distribution along the Chinese coast. Sampling sites are indicated in Figure 12.

Sampling site	PSP	DSP	Sampling site	PSP	DPS
Tianjin (TJ)	-	+	Zhoushan(ZS)	+	+
Yantai (YT)	+	+	Shengzhen(SZ)	-	+
Qingdao (QD)	-	+	Guangdong	+	
Rizhao (RZ)	-	-	Hong Kong	+	+
Lianyungang (LYG)	+	+	Taiwan	+	

\+ detected - not detected

Table 6 summarizes records of shellfish poisoning events in China, in which more than 1,800 people were affected and 31 people died (Zhou, M. *et al.* 1999; Zhou, H. *et al.* 1999). Several illnesses are suspected to have been due to the consumption of DSP toxin-contaminated marine products in 1995 (Qian and Liang 1995). Ciguatera Fish Poisoning (CFP) is also a frequent algal toxin problem in the Hong Kong area. More than 200 documented CFP poisoning events have occurred in Hong Kong since 1989, resulting in more than 1,000 people being intoxicated. Although most of these CFP incidents were due to the consumption of imported coral reef fish, the causative HAB species *Gambierdiscus toxicus* has also been found recently in local waters (Lu and Hodgkiss 1999). Similar to Hong Kong, PSP and CFP toxins are the most frequently measured algal toxins in shellfish in Taiwan (Zhou, H. *et al.* 1999). A summary of PSP, DSP, CFP events, animal and plant mortalities over the past decade (1990-2000) appears in Appendix CH.

Causative HAB organisms

Table 7 summarizes 148 HAB species that have been found in China thus far, of which 44 have caused HAB events. Among these 44 species, 28 are known to be toxic (Qi *et al.* 1993; Zou 1992; Zhu *et al.* 1997). The most common species include *Noctiluca scintillans*, *Prorocentrum minimum*, *P. mians*, *Alexandrium tamarense*, *Gonyaulax polyedra*, *Skeletonema costatum*, *Mesodinium rubrum*, *Trichodesmium* sp., and *Chattonella marina*. Twenty two species of dinoflagellate cysts have been found in samples collected from the East and South China Seas, including cysts from *A. tamarense*, *Cochlodinium sp.*, *Diplopelta parva*, *Gonyaulax grindleyi*, *G. spinifera*, *G. scrippsae*, *Gymnodinium calenatum*, *Gymnodinium sp.*, *Lingulodinium polyedra*, *Pheopolykrikos hartmanii*, *Polykikos kofoidii*, *P. schwartzii*, *Protoperidinium americanum*, *P. cf. avellana*, *P. claudicans*, *P. conicum*, *P. conicoides*, *P. oblongum*, *P. subinerme*, *Pyrophacus steinü*, *Scrippsiella precaria* and *S. trochoidea* (Qi *et al.* 1996). Table 7 shows that more dinoflagellates are distributed along the southern than the northern coast, while harmful diatoms are distributed evenly in both southern and northern coastal waters.

At least 58 HAB species are found in Hong Kong. Here, the main HAB species are *N. scintillans*, *S. costatum*, *G. polygramma*, *P. triestinum*, *P. minimum*, *C. furca*, *M. rubrum*, *G. splendens*, *P. sigmoidens*, *P. triquetra*, and *L. minimus* (AFD 1997). Hong Kong is also considered to be a vulnerable area for importation of foreign HAB species because it is such an internationally important marine transportation center. Several species of dinoflagellate cysts were found in ballast waters arriving from Aukland and California (Zhang and Dickman 1999).

HAB research, management and collaboration in China

HAB research in China covers the following areas: biology and taxonomy; nutrient dynamics and physio-ecological characteristics; life history; toxicity; dynamics of occurrence and disappearance processes; statistical models, and HAB prevention and treatment (Lin 1997; Zhang 1994; Zhu and Li 1995). About 30 projects on HAB and algal toxins have been sponsored by various national or local concerned government bodies in Mainland China since 1978. It is clear that the efforts on HAB research by government agencies and concerned scientists are steadily increasing.

A National Project of HAB in China called CEOHAB (Ecology and Oceanology of HAB in China), was approved in October 2001. The project is called the “973 key project” and has funding of 28 MRMB (3.5 million US$) for the five years, beginning in April 2002. Integrated and multidisciplinary biological, chemical and physical oceanographic research will be initiated in order to understand the mechanism of large-scale HAB events in coastal areas, to provide scientific basis for “prevention, control and treatment of HABs”, and to allow the sustainable development of the marine economy in China.

Table 6 Shellfish poisoning events in China.

Time	Province	Toxin	Poisoned	Died	Shellfish	Algae
1956	Taiwan			1?	Oyster	ND
1967-1979	Zhejiang	PSP	423	23	*Nussarius succinstus*	ND
1986	Taiwan	PSP	50	2	*Soletellina diphos*	*A. minutum*
1986.11	Fujian	PSP?	136	1	*Ruditapes phillipenensis*	*Gymnodinium* sp (?)
1989.2	Guangdong	PSP	5	--	*Pinna pectinata*	ND
1989.11	Fujiang	PSP?	4	1	*Nussarius succinstus*	ND
1991.2	Taiwan	PSP	8	--	*Soletellina diphos*	*A. minutum*
1991.3	Guangdong	PSP?	4	2	*Perna viridis*	ND
1994.6	Zhejiang	PSP?	5	1	*Nussarius succinstus*	ND
1989-1999	Hong Kong	CFP	1000		Coral reef fish	ND
1992	Hong Kong	?	Several		Shellfish from Mirs Bay	ND
1995	Hong Kong	DSP?	Several		Marine products	ND

ND: not detected

Table 7 HAB organisms of coastal China.

Have Formed HAB	Toxic	Species	Distribution: Yellow & Bohai Sea	East China Sea	South China Sea
		Dinophyceae			
	■	*Amphidinium carterae* Hulburt			+
	■	*A. operculatum* Claparede & Lachmann =*A. klebsii* Kofoid & Swezy	+		+
■		*Alexandrium affine* (Inoue & Fukuyo) Balech		+	+
■	■	*A. catenella* (Whedon & Kofoid) Balech			+
		A. cohorticula (Balech) Balech			+
		A. fraterculus (Balech)Balech			+
		A. leei (Balech) Balech			+
■	■	*A. minutum* Halim			+
		A. tropicale Balech=*A. excavata* (Braarud)			+
■	■	*A. tamarense* (Lebour) Balech	+	+	+
		Ceratium breve (Ost. & Schm.) Schroder			+
		C. deflexum (Kofoid) Jorg.			+
		C. furca (Ehrenberg) Claparede & Lachmann	+	+	+
		C. fusus (Ehrenberg) Dujardin	+		+
		C. humile Jorg			+
		C. massiliense (Gourret) Jorgensen			+
		C. trichoceros (Ehrenberg) Kofoid			+
		C. tripos (O. F. Mueller) Nitzsch	+	+	+
		Cochlodinium helicoides Lebour			+
		Cochlodinium sp.			+
■	■	*C. polykrikoides* Margelef			+
	■	*Dinophysis acuminata* Claparede & Lachmann	+	+	+

Have Formed HAB	Toxic	Species	Distribution: Yellow & Bohai Sea	Distribution: East China Sea	Distribution: South China Sea
		D. acuta Ehrenberg	+		
		D. caudata Saville-Kent	+		+
		D. fortii Pavillard	+		+
		D. miatra (Schutt) Abe			+
		D. ratrndatum Claparede & Lachmann			+
		Exuviaella Baltice Lachmann			+
		Gambierdiscus toxicus Adachi & Fukuyo			+
		Gonyaulax digitale (Pouchet) Kofoid	+	+	+
		G. polygramma Stein	+		+
		G. spinifera (Claparede & Lachmann) Diesing	+	+	+
		G. verior Sournia			+
		Gymnodinium breve Davis		+	+
		G. catenatum Graham		+	+
		G. mikimoloi Miyake & Kominami ex Oda =*G. Nagasakiense* Takayama & Adachi		+	+
		G. sanguineum Hirasaka=*G. splendens* Lebour	+	+	+
		G. simplex (Lohmann) Kofoid & Swezy			+
		Gymnodinium sp.	+	+	+
		Gyrodinium aureolum Hulburt			+
		G. dominans Hulburt			+
		G. falcatum Kofold & Swezy			+
		G. fissum (Levander) Kofoid & Swezy	+	+	+
		G. resplendens Hulburt			+
		G. spirale (Bergh) Kofoid & Swezy		+	+
		G. instriatum Freudenthal & Lee			+
		Lingulodinium polyedrum (Stein) Dodge =*Gonyaulax polyedra* Stein		+	+
		Noctiluca scintillans (Macartney) Kofoid & Swezy	+	+	+
		Ostreopsis siamensis Schmidt			+
		Oxyrrhis marina Dujardin			+
		Polykrikos schwartzii Buetschli			+
		Prorocentrum balticum (Lohmann) Locblich , Sherley&Schmidt			+
		P. dentatum Stein	+		+
		P. gracile Schutt			+
		P. lima Dodge		+	+
		P. mexicanum Tafall =*P. rhathymum* Loeblich			+
		P. micans Ehrenberg	+	+	+
		P. minimum (Pavillard) Schiller	+		+
		P. sigmoides Boehm			+
		P. triestinum Schiller	+	+	+
		P. conicum (Gran) Balech	+	+	+
		P. divergens (Ehernberg) Balech	+	+	+
		Protoperidinium depressum (Bailey) Balech	+	+	+
		P. pellucidum Bergh			+
		P. quinquecorne Abe			+
		P. triquetrum Ehrenberg			+
		Pyrodinium bahamense var. *Compressum* (Boehm) Steidinger			+
		Pyrophacus horologium Stein			+
		Pyrophacus horologium v. Steinii Schiller			+
		Pyrocystis fusiiformis Murray			+

Have Formed HAB	Toxic	Species	Yellow & Bohai Sea	East China Sea	South China Sea
		Scrippsiella trochoidea (Stein) Loeblich	+	+	+

Have Formed HAB	Toxic	Species	Distribution		
			Yellow & Bohai Sea	East China Sea	South China Sea
Bacillariphyta					
		Asterionella glacialis (Castracane) F. E. Round	+	+	+
		A. kariana (Grunow) Round	+		
		Bacillaria paxillifera (O. F. Muller) Hendey =*Nitzschia paradoxa* (J. F. Gmelin) Grunow in Cleve & Grunow	+ +	+	+
		Bellerochea malleus (Brightwell) Van Heurck emend. Von Stosch		+	+
		Cerataulina pelagica (Cleve) Hendy =*Cerataulina bergonii* (H. Peragallo) Schuett			+
		Chaetoceros affinis Lauder	+	+	+
		C. atlanticus Cleve			+
		C. compressus Lauder	+	+	
		C. curvisetus Cleve	+	+	+
		C. danicus Cleve	+	+	+
		C. dentiuelus Lauder			+
		C. debilis Cleve	+	+	+
		C. diadema (Ehernberg) Gran	+	+	
		C. didymus Ehrenberg	+	+	+
		C. laciniosus Schutt	+	+	+
		C. lorenzianus Grunow	+	+	+
		C. peruvianus Brightwell	+	+	+
		C. pseudocurvisetus Mangin	+	+	+
		C. siamense Ostenfeld	+	+	
		C. socialis Lauder	+		+
		Coscinodiscus asteromphalus Ehrenberg	+	+	
		C. centralis Ehrenberg	+		
		C. gigas Ehrenberg			+
		C. granii Gough	+	+	+
		C. jonesianus (Greville) Ostenfeld	+		+
		C. radiatus Ehrenberg	+		
		C. wailesii Gran & Angst	+		+
		Cyclotella cryptica Reimann, Lewin & Guillard			+
		Cylindrotheca closterium (Ehrenberg) Lewin& Reimann	+	+	
		C. striata (Kuetzing) Grunow in Cleve & Grunow	+	+	
		Cyclotella sp.	+	+	+
		Ditylum brightwellii (West) Grunow & Van Heurck	+	+	+
		Eucampia zodiacus Ehrenberg	+	+	+
		Guinardia flaccida (Castracane) Peragallo	+	+	+
		Lauderia annulata Cleve=*Lauderia borealis* Gran	+	+	+
		Leptocylindrus danicus Cleve	+	+	+
		L. minimus Gran			+
		Lithodesmium variabile Takano			+
		Melosira nummuloides C. A. Agardh			+
		Nitzschia longissima (Brebisson, in Kuetzing) Ralfs in Pritchard	+	+	+
		Odontella aurita (Lyngbye) C. A. Agardh	+	+	
		O. mobiliensis (Bailey) Grunow	+	+	
		O. sicensis (Greville) Grunow	+	+	
		Paralia sulcata (Ehrenberg) Cleve =*Melosira sulcata* (Ehrenberg) Kuetzing	+	+	+

Have Formed HAB	Toxic	Species	Distribution Yellow & Bohai Sea	 East China Sea	 South China Sea
		Pseudo-nitzschia pungens (Grunow ex Cleve) Hasle =*Nitzschia pungens* Grunow ex Cleve	+	+	+
		P. delicatissima (Cleve) Heiden in Heiden & Kolbe	+	+	
		P. seriata (Cleve) H. Peragallo in H. & M. Peragallo f. Seriata		+	+
		Proboscia alata (Brightwell) Sundstrom =*Rhizosolenia alata* Brightwell	+	+	+
		Pseudosolenia calcar avis (Schultze) Sundstroem =*Rhizosolenia calcar-avis* Schultze	+	+	+
		Guinardia delicatula (Cleve) Hasle =*Rhizosolenia delicatula* Cleve	+	+	+
		Guinardia striata (stolterfoth) Hasle =*Eucampia striata* Stolterfoth =*R. stolterfoth* H. Peragallo	+	+	+
		Dactyliosolen fragilissimus (Bergon) Hasle =*Rhizosolenia fragilissima* Bergon	+	+	+
		Rhizosolenia alata f. Grocillima Cleve	+	+	+
		R. alata f. indica (Peragallo) Ostenfeld	+	+	
		R. hebetata f. semispina (Hensen) Gran	+		+
		R. setigera Brightwell	+	+	+
		R. styliformis Brightwell	+	+	+
		Skeletonema costatum (Greville) Cleve	+	+	+
		Stephanopyxis palmeriana (Greville) Grunow	+	+	+
		Thalassionema nitzschioides (Grunow) Mereschkowsky	+	+	+
		Thalassiosira mala Takano	+	+	+
		T. nordenskioeldii Cleve	+	+	+
		T. pacifica Gran & Angst		+	
		T. rotula Meunier		+	+
		T. subtilis (Ostenfeld) Gran	+	+	+
		Thalassiothrix frauenfeldii (Grunow) Hallegraeff	+		+
		Cyanobacteria			
		Trichodesmium erythraeum Ehrenberg	+	+	+
		T. thiebautii Gomont		+	+
		Chrysophyceae			
		Dictyocha fibula Ehrenberg	+	+	+
		Distephanus speculum (Ehrenberg) Haeckel		+	+
		Ebria tripartita (Schumann) Lemmermann			+
		Phaeocystis poucheti (Hariot) Lagerheim			+
		Raphidophytes			
		Chattonella marina (Subrahmanyan) Hara & Chihara			+
		Chattonella sp.			+
		Heterosigma carterae (Hulburt) Taylor	+	+	+
		Cryptomonadaceae			
		Cryptomonas sp.	+		+
		Chlorophyceae			
		Nephroselmis sp.			+
		Carteria sp.			+
		Protozoa`			
		Mesodinium rubrum Lohmann	+	+	+

In terms of HAB management, environmental monitoring systems were establihsed in China by the State Oceanic Administration and Ministry of Agriculture and Fisheries in 1984 and 1990.

A specific program for HAB monitoring along the Chinese coast, sponsored by the State Oceanic Administration, was initiated in 2001. To address the issue of treatment and mitigation of HABs, a method using modified clay to coagulate HAB organisms has been developed. Development of this process started in the early 1990s, and primarily involves: coagulation of clays with HAB organisms, studies of clay surface modification and preparation methods; kinetic studies of clay particles coagulating HAB organisms, and assessment of environmental impacts of clays on marine ecosystems (Yu *et al.* 1998).

Recently, a China Harmful Algal Bloom WebPage was set up at http://www.china-hab.ac.cn. This C-HAB WebPage contains various sub-areas including FAQ (Frequently Asked Questions), Occurrences, Species, Research, Coordination, Reporting and Links. It is designed to provide basic knowledge to the public, to summarize the main HAB occurrences in China, to describe the main HAB species involved, to introduce research activities in China, and to provide links to related international web sites and projects. Recent HAB occurrences in China will be reported in a timely manner via this web site. The "C-HAB" WebPage has both Chinese and English versions.

Chinese scientists are active in many collaborative international HAB programs, such as IOC (Intergovernmental Oceanographic Commission) Harmful Algal Bloom Program and the APEC (Asian-Pacific Economic Cooperation) Red Tide/Toxic Algae Management project. In addition, the China SCOR (Scientific Committee on Oceanic Research)-IOC HAB workshop was convened in 1992. China is also participating in programs such as GEOHAB (Global Ecology of Harmful Algal Blooms) and PICES Working Group 15 (Ecology of harmful algal blooms in the North Pacific).

Discussion

The seas around China cover a large area of about 3,000,000 km^2. At the present time, however, Mainland China, Hong Kong and Taiwan each utilize different systems for monitoring HABs. Therefore, in the greater China region, there are differences in monitoring methods and frequency as well as in defining HAB events. Such variations might help to explain the big difference in reports of HAB frequency between Mainland China and Hong Kong, in which the number of HABs in Mainland China was 322 from 1952-1998, whereas Hong Kong reported 496 HABs from 1980-1997. During 1980-1998, 67 HAB events were reported from the South China Sea. Among them, 24 took place in both Guangdong and Hong Kong, including the serious "Hong Kong'98" (Hodgkiss *et al.* 2000). Because Hong Kong shares much of the same coastline, e.g., Mirs Bay (Dapeng Bay), with Guangdong Province, and Taiwan likewise shares the Taiwan Strait with Fujian Province, it is crucial for all areas to coordinate their various regional HAB studies. This will allow scientists in the greater China region to better understand HAB mechanisms and to further develop and set up common and efficient HAB alarm systems. It is heartening to see Hong Kong and Mainland China progressing so quickly toward cooperation in this area, through symposia and similar joint projects. China also shares common sea areas with Korea, Japan, Vietnam, Philippines etc. Therefore, international coordination should be strengthened for better understanding of this oceanographic and ecological problem.

For the future study of HABs, China will link its programs more closely with GEOHAB. On the other hand, because China has the largest mariculture operation in the world, we recommend future research efforts on the relationship between mariculture activity and HAB occurrences in key coastal areas, in order to better foster and maintain the sustainable development of both mariculture operations and healthy marine ecosystems along the Chinese coast.

Acknowledgement

We wish to thank Dr. Michael C. Watson (USEPA) for kindly reviewing the manuscript. This study was supported by National Basic Research Project No.2001CB4097, NSFC Projects No. 49906007, 20177023, 39950001, 40076030 and CAS Innovation Project No. KZCX2-206, Direct Project of CAS and Project of Shandong Province Science Committee.

References

AFD (Agriculture and Fisheries Department) 1997. Marine Water Quality in Hong Kong in 1997, Chapter 14, Red tides.

Anderson, D.M., Kulis, D.M., Sheng, Y. Qi, L., Lu, S., and Lin, Y. 1996. Paralytic shellfish poisoning in south China. Toxicon 34: 579-587.

Chan, D. K. O. and Young, M. L. C. 1999. Occurrence of marine neurotoxins in seafood in Hong Kong. 1st conference on Harmful Algae Management and Mitigation, 10-14 May, 1999, Subic Bay, Philippines, p. 8.

Chen, Y. 1972. Analysis of a red tide event of *Trichodesmium* sp. in East China Sea in 1972. Journal of Fisheries of China 6: 181-189. (in Chinese with English abstract)

Fei, H. 1952. The cause of red tides. Science and Art 22: 1-3.

GEOHAB. 1998. Global Ecology and Oceanography of Harmful Algal Blooms, A plan for Co-ordinated Scientific Research and Co-operation to Develop, International Capabilities for Assessment, Prediction and Mitigation, Report from a Joint IOC/SCOR Workshop, Havreholm, Denmark.

Hodgkiss, I. J., Lu, S., and Qi, Y. 2000. The Harmful algal blooms in Hong Kong waters- Where are they from? Abstracts of the 9th International Conference on Harmful Algal Blooms, February 6-11, 2000, Tasmania, Australia. 137pp.

Ho K. C., and Hodgkiss, I.J. 1993. Characteristics of red tides caused by *Alexandrium catenella* (Whedon & Kofoid) Balech in Hong Kong. *In* T.J. Smayda, and Y. Shimizu (Eds.) Toxic Marine Phytoplankton. Elsevier, Amsterdam, pp. 263-268.

Hua, Z. 1989. Red tide in China Coast and its countermeasure. Ocean Bulletin, pp. 1-5. (in Chinese).

Hua, Z. 1994. Red tide disaster. Ocean Press, Beijing. (in Chinese).

Jiang, T., Yin, Y., Luo, Y., Chen, J., and Y. Qi. 2000. Paralytic shellfish toxins in shellfish from Daya and Dapeng Bay. Marine Environmental Science 19(2): 1-5.

Lam, C. W. Y. and Ho, K.C. 1989. Red tides in Tolo Harbor, Hong Kong. *In* T. Okaichi, D.M. Anderson, and T. Nemoto (Eds.) Red tides: Biology, Environmental Science and Toxicology. Elsevier, New York, pp. 49-52.

Lam, C. W. Y., Kodama, M., Chan, D. K. O., Ogata, T., Sato, S., and Ho, K.C. 1989. Paralytic Shellfish Toxicity in shellfish in Hong Kong. *In* T. Okaichi, D.M. Anderson, and T. Nemoto (Ed.) Red tides: Biology, Environmental Science and Toxicology. Elsevier, New York, pp. 455-458.

Lin, Y., Yang, M., Chen, R., Hu, S., and Jin, G. 1994. Study on Paralytic Shellfish Poisoning in shellfish from Guangdong Coast. Oceanology and Limnology Sinica 25: 220-225. (in Chinese with English abstract).

Lin, Y. 1997. A study on eutrophication and red tide research in the offshore area. Science Press, Beijing. (in Chinese with English abstracts).

Lu, S., and Hodgkiss, I. J. 1999. *Gambierdiscus toxicus*, a Ciguateria Fish Poisoning producing species found in Hong Kong waters. 1st conference on Harmful Algae Management and Mitigation, 10-14 May, 1999, Subic Bay, Philippines, pp. 22.

Morton, B., and Twentyman, P.R. 1971. The occurrence and toxicity of a red tide caused by *Noctiluca scintillans* (Macartney) Ehrenb. in the coastal waters of Hong Kong. Environmental Research 4: 544-547.

Qi, Y., Zhang, Z., Hong, Y., Lu, S., Zhu, C., and Li, Y. 1993. Occurrence of red tides on the coasts of China. *In* T.J. Smayda, and Y. Shimizu (Eds.) Toxic Marine Phytoplankton, Elsevier, Amsterdam, pp. 43-46.

Qi, Y., Hong, Y., and Zheng, L. 1996. Dinoflagellate cysts from recent marine sediments of the South and East China seas. Asian Marine Biology 13: 87-103.

Qian, H., and Liang, S. 1999. Study on the red tide in the Pearl River Estuary and its near water. Marine Environment Science 18(3): 69-74. (in Chinese).

Su, H., Chiang, Y., and Liao, I. 1993. Role of temperature, salinity and ammonia on the occurrence of the Taiwanese strain of *Alexandrium tamarense*. *In* T. J. Smayda, and Y. Shimizu (Eds.) Toxic Marine Phytoplankton. Elsevier, Amsterdam, pp. 837-842.

Tseng C. K., Zhou, M. J., and Zou, J. Z. 1993. Toxic phytoplankton studies in China. *In* T. J. Smayda, and Y. Shimizu (Eds.) Toxic Marine Phytoplankton. Elsevier, Amsterdam, pp. 347-452.

Yu, Z. M., Sun, X. X., Song, X. X., and Zhang, B. 1998. Clay surface modification and its coagulation of red tide organism. Chinese Science Bulletin 44(7): 617-620.

Zhang, F., and Dickman, M. D. 1999. Mid-Ocean exchange of container vessel ballast water. 1: Seasonal factors affecting the transport of harmful diatoms and dinoflagellates. Mar. Ecol. Prog. Ser. 176: 243-251.

Zhang, S. 1994. Red tide and its control. Ocean Press, Beijing. (in Chinese).

Zhao, D. 2000. Paper collection of monitoring and assessment on HAB disaster in Bohai Sea. Ocean Press, Beijing. (in Chinese).

Zhou, M. J., Li, J., Luckas, B., Yu, R., Yan, T., Hummert, C., and Kastrup, S. 1999. A recent shellfish toxin investigation in China. Marine Pollution Bulletin 39: 331-334.

Zhou, H. 1999. Manual on microalgal toxin detection in seafood products. Aquaculture Press, Taiwan, pp. 23-28.

Zhou, Z. 1962. Red tide in Fujian. J. Fujian Normal college 4: 75-79. (in Chinese).

Zhu, M., Li, R., Mu, X., and Ji, R. 1997. Harmful algal blooms in China seas. Ocean Research. 19(2): 173-184.

Zhu, M., Li, R., and Wang, F. 1995. Red tide research in China -- selected papers of 2nd symposium of Chinese committee, SCOR/IOC HAB Working Group. Qingdao Press, Qingdao. (in Chinese with English abstracts).

Zou, J. 1992. Red tide organisms and red tide disasters. *In* C.K. Tseng (Ed.) Marine science study and its prospect in China, Qingdao Press, Qingdao, pp. 675-680. (in Chinese).

Appendix CH

SUMMARY SHEET 1

Country Name: **P.R. China**

Country Information: **Contact**

Name: Tian YAN

E-mail: tianyan@ms.qdio.ac.cn

Fax: 86-532-2893088

CFP Events from 1990 to 2000

Location Name	Section No.	Latitude	Longitude	ASP	DSP	PSP	NSP	Ciguatera	Animal/ Plant Mortalities	Comments
Hong Kong	9	114°	22°10'							More than 200 CFP events happened in HK resulted 1,000 people poisoned.(Lv, 1999), Mostly caused by imported fish.

SUMMARY SHEET 2

Country Name: P.R. China

Country Contact Information:

Name: Tian YAN
E-mail: tianyan@ms.qdio.ac.cn
Fax: 86-532-2893088

DSP events from 1990 to 2000

Location Name	Section No.	Latitude	Longitude	ASP	DSP	PSP	NSP	Ciguatera	Animal/Plant Mortalities	Comments
										DSP unit: micro g /100g wt,
East coast of Liaodong Bay	1	120°40'-121°50'	40°-41°		max1000					1998. 9.29-10.2, bivalves (Zhao 2000)
Tianjin	2	117°30'	39°		30.43					1996.9.5, scallop *Chlamys fareri*
Qingdao	4	120°20'	36°		54.29					1997.3.25, *Venerupis philippinarum*
Zhoushan	5	122°	30°		29.71					1996.8.5, scallop *Chlamys farreri* and *Mytilus edulis*
Shenzhen	9	114°	22°40'		22.14					1997.7.3, *Mytilus edulis*
Shenzhen	9	114°	22°40'		84.57					1997.8.3, *Mytilus edulis*
Hong Kong	9	114°	22°10'							1992, several illness from eating shellfishh from Mirs Bay
Hong Kong	9	114°	22°10'							1995, several illness from marine products

SUMMARY SHEET 3

Country Name: **P.R. China**

Country Contact Information:

Name: Tian YAN
E-mail: tianyan@ms.qdio.ac.cn
Fax: 86-532-2893088

Animal and Plant Mortality Events from 1990 to 2000

Location Name	Section No.	Latitude	Longitude	ASP	DSP	PSP	NSP	Ciguatera	Animal/Plant Mortalities	Comments
Liaodong Bay, Bohai Bay and Laizhou Bay	1,2,3	118-121°	37°30'-40°30'						maricultured shrimp and shellfish affacted by *Ceratium furca*	1998.9.16-10.19
and Laizhou Bay										
Tianjin and Huanghua	2	118°10'	38°21'						100 million jellyfish were killed	2000/07/20-21
Yantai	3	121°30'-122°	37°30'-40°30'						scallop, seacucumber, abalone and benthic fish killed by *Gymnodinium sanguineum*	1998.08
East coast of Zhejiang	5	122°	28°25'						fish and shellfish were killed	1990.5
Xiamen	7	118°08'	24°30'						fish killed by chae ….	1997
Weitou Bay to Quanzhou Bay	7	24°3-25°10	118°30-118°50						fish and clam died from *Cochlodinium* sp.	1990 mid June
Xiamen	7	118°08'	24°30'						shrimp killed by *Alexandrium tamarense*	1994
Quanzhou to Shanwei	7, 8	22°50'-25°10'	115°20'-118°50'						fish killed by *Phaeocystis pouchetii*	1997
Raoping	8	117°10'	23°40'						fish killed *Phaeocystis pouchetii*	1999
Dapeng Bay	9	114°10'	22°40'						fish killed by *Chattonella marina*	1991.3.2
Pearl River Estuary, HK,	9	112°-114°20'	21°30'-22°20'						fish killed by *Karenia mikimotoi*	1998.3-4
Daya Bay	9	114°40'	22°30'						fish kill by *Chaetoceros* spp.	

Location Name	Section No.	Latitude	Longitude	ASP	DSP	PSP	NSP	Ciguatera	Animal/Plant Mortalities	Comments
Daya Bay	9	114°40'	22°30'						fish kill by *G. mikimotoi*	1998.5
Shenzhen Bay	9	114°	22°40'						fish kill by *G. intriatum* and *Phaeopolykrikos harmanii*	
Shengzhen-Huiyang	9	114°40'-115°	22°20'						fish killed by *Srippsiella trochoidea*	2000.8.17-20
Daya Bay	9	114°40'	22°30'						fish killl by *Srippsiella trochoidea*, *Peridinium quinquecorne*	2000.9.3-6
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1992/06
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1992/12
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1993/03
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1995/03
Pingdong, Taiwan	10	120°20'	22°30'						cultured *Hiatula* sp.contain toxins	1996/06
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1997/01
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1997/03
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1997/04
Pingdong, Taiwan	10	120°20'	22°30'						cultured-fish were killed by *A. minutum*	1997/02
Kaohsung, Taiwan	10	120°10'	22°30'						cultured-fish were killed by *A. minutum*	1997/05
Kaohsung, Taiwan	10	120°10'	22°30'						cultured-fish were killed by *A. minutum*	1997/04
Kaohsung, Taiwan	10	120°10'	22°30'						cultured-fish were killed by *A. minutum*	1997/05
Kaohsung, Taiwan	10	120°10'	22°30'						cultured-fish were killed by *A. minutum*	1997/12
Kaohsung, Taiwan	10	120°10'	22°30'						cultured-fish were killed by *A. minutum*	1998/01

SUMMARY SHEET 4

Country Name: P.R.China

Country Contact Information:

Name: Tian YAN
E-mail: tianyan@ms.qdio.ac.cn
Fax: 86-532-2893088

PSP Events from 1990 to 2000

Location Name	Section number	Latitude	Longitude	ASP	DSP	PSP	NSP	Ciguatera	Animal/Plant Mortalities	Comments
Yantai	3	121°10'	37°30'			133				1997.9.22, scallop *Chlamys farreri* (Zhou et al. 1999)
Zhejiang	6									1994, five poisoned and one died, *Nussarius succinstus*
TaiTam Bay, HK	9	114°20'	22°10'			max>400,000				1990.3, shellfish (Ho&Hodgkiss 1993)
Mirs Bay, HK	9	114°10'	22°40'			8000 0				1990.4, shellfish (Ho&Hodgkiss 1993)
Dapeng Bay	9	114°10'	22°40'			300				1990, spring, scallop (Lin et al. 1993)
Dapeng Bay	9	114°10'	22°40'			120				1990, autumn, scallop (Lin et al. 1993)
Dapeng Bay	9	114°10'	22°40'			120				1991, spring, scallop and mussel, four were poisoned and two were killed on March 28 (Lin et al. 1993)
Dapeng Bay	9	114°10'	22°40'			100				1991,autum, scallop (Lin et al. 1993)
Daya Bay	9	114°10'	22°30'			514				1991, spring, scallop and mussel (Lin et al. 1993)
Hong Kong	9	114°10'	22°20'			320				1996.9.17, scallop *Chlamys nobilis* (Zhou et al. 1999)
Daya Bay	9	114°10'	22°30'			2340				1999.1, visceral of scallop *Chlamys nobilis* and *Perna viridis* (Jiang et al. 2000)
Dapeng Bay	9	114°10'	22°40'			174				1999.1, visceral of scallop *Chlamys nobilis* (Jiang et al. 2000)
Taiwan	10	120°20'	22°30'			9800/visceral, 600/other tissue				1991.2, *A. minutum*, *Hiatula* sp., eight were poisoned

Harmful algal blooms (red tides): Management and mitigation in the Republic of Korea

Sam Geun Lee, Hak Gyoon Kim, Eon Seob Cho and Chang Kyu Lee
National Fisheries Research and Development Institute (NFRDI), Shirang-ri, Kijang-up, Kijang-gun, Pusan, Republic of Korea 619-900. E-mail: sglee@nfrdi.re.kr

Introduction

Most of the enclosed and semi-enclosed coastal waters of Korea are in a eutrophic state due to the increase of terrestrial and water-born pollutants. The effects of this coastal pollution and eutrophicaton have manifested themselves in three ways, namely as harmful dinoflagellate blooms; seasonal anoxia; and shellfish intoxication. Of these, harmful algal blooms have recently become widespread and persistent, and the accompanying mass fish moralities are the most serious obstacles and risks for the sustainable development of coastal fisheries industries.

Although there are historical records of red tides since the 6th century, the first scientific report on HABs in Korea was published in 1967 (Park and Kim 1967). After then many scientific reports have been published (Cho 1978, 1979, 1981, 1986; Lee *et al*. 1980, 1981, 1982, 1983; Yoo 1982; Han *et al.* 1992; Kim *et al*. 1990, 1993a, 1993b; Park 1980, 1982; Park *et al*. 1988; Lee *et al*. 1992). Since 1981, HABs have mainly occurred on the southern coast in Chinhae Bay and its vicinity. They became more widespread and persistent in 1990s.

As the blooms develop into a harmful phase, such as fish killing, there is an urgent need to monitor the outbreaks and to take appropriate measures for the mitigation of the fisheries damages, especially for aquaculture. HABs will undoubtedly re-occur in the years to come due to abundant benthic cyst populations and eutrophic coastal water. However, it is very hard to accurately forecast the outbreaks of HABs and there are no effective countermeasures to mitigate the fisheries damages. We need to assess the present work on HABs in Korea and establish an efficient scientific agenda for research and mitigation strategies to allow sustainable coastal productivity.

Overview of the spatio-temporal variations of HABs in southern Korean coastal waters

In Figure 14, the number of red tide outbreaks since 1981 is shown. One event is a bloom occurring in an area, caused by one or several species. It is counted as new when the dominant species changes into other species, even if occuring at the same place. Based on the annual total number of red tide outbreaks recorded in the HABs monitoring program, there were 8 events in 1981, including 3 harmful dinoflagellate blooms,

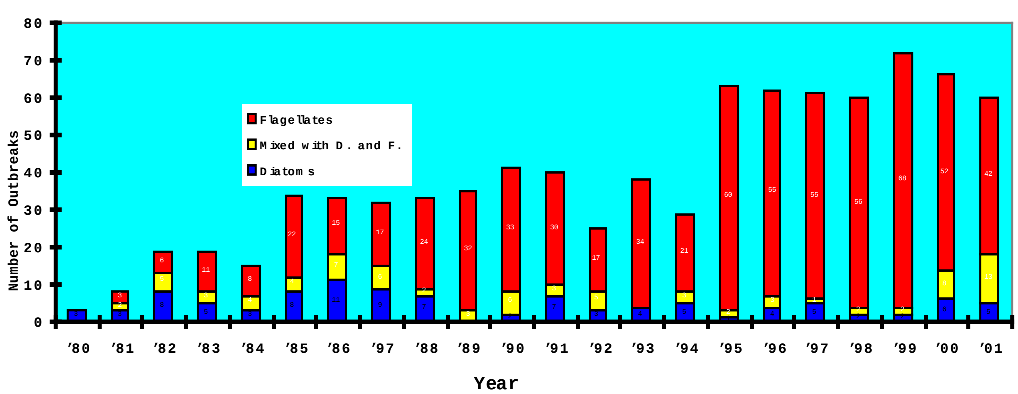


Fig. 14 The outbreak number of red tides in Korean costal waters since 1981. Abbreviations are D for Diatoms and F for Flagellates.

as shown in Figure 14. HABs increased in number to 21 in 1982, the first year of a *Cochlodinium polykrikoides* bloom, reaching 65 in 1995, the biggest and persistent year of *C. polykrikoides* in the last two and half decades. In 1998, it increased to 122 outbreaks. The number of *C. polykrikoides* blooms was 3 in 1982, and increased to 28 events in 1995. The duration of blooms is generally less than one week but since 1984, they have continued sometimes for more than two weeks in enclosed or semi-enclosed bays. These HABs were relatively restricted in geographical distribution in the 1970s. Until the early 1980s, the dinoflagellate blooms occurred mostly in some enclosed or semi-enclosed bays, such as Chinhae and Kosong Bays in the South Sea. But in recent years, they became widespread, extending to Kangnung in the East Sea, to Inchon and Mokpo bordering the Yellow Sea, and Yoja and Kosong Bays in the western part of the South Sea (Fig. 15).

Fig. 15 Spatial distribution of the red tide outbreaks in Korean coastal waters since 1981.

Now the dinoflagellate blooms affect most of the coastal areas, in many cases over large geographic areas and caused by more than one harmful or toxic algal species (Kim *et al*. 1994).

The prevailing phytoplankton groups responsible for the blooms are Dinophyceae and Bacillariophyceae as listed in Table 8. Diatoms were the most common bloom species until the first half of the 1970s. Since then, dinoflagellates such as *Prorocentrum micans*, *P. minimum*, *Heterosigma akashiwo*, *Gymnodinium mikimotoi*, *G. sanguineum* and *Cochlodinium polykrikoides* were found to be the major bloom formers. They exclusively form monospecific blooms of high density in the summer season. Some cyst-forming dinoflagellate species make blooms repeatedly at the same place and same time of the year (Kim *et al*. 1990).

Table 8 List of microalgae responsible for algal blooms in Korean coastal waters.

Division	Class	Order	Red Tide Organisms
Cyanophyta	Cyanophyceae	Chroococcales	*Anabaena flos-aquae* *Anabaena spiroides* *Microcystis aeruginosa*
Cryptophyta	Cryptophyceae	Cryptomonadales	*Chroomonas salina*
Dinophyta	Dinophyceae	Prorocenrales	*Prorocentrum balticum* *Prorocentrum dentatum* *Prorocentrum micans* *Prorocentrum minimum* *Prorocentrum triestinum*
		Gymnodiniales	*Cochlodinium polykrikoides* *Gyrodinium fissum* *Gymnodinium mikimotoi (=G.nagasakiense)* *Gymnodinium sanguineum* *Pheopolykrikos hartmannii*
		Noctilucales	*Noctiluca scintillans*
		Gonyaulacales	*Alexandrium affine* *Alexandrium frateculus* *Alexandrium tamarense* *Ceratium furca* *Ceratium fusus* *Lingulodinium polyedra (=G. polyedra)*
		Peridiniales	*Heterocapsa triquetra* *Scrippsiella trochoidea*
Chrysophyta	Bacillariophyceae	Centrales	*Chaetoceros curvisetus* *Leptocylindrus danicus* *Rhizosolenia alata* *Skeletonema costatum* *Thalassiosira allenii* *Thalassiosira conferta* *Thalassiosira lundiana* *Thalassiosira nordenskioeldii*
		Pennales	*Asterionella sp.* *Cylindrotheca closterium* *Pseudo-nitzschia pungens* *Pseudo-nitzschia australis* *Navicula spp.*
	Raphidophyceae	Raphidomonadales	*Chattonella sp.* *Fibrocapsa japonica* *Heterosigma* akashiwo *(=H. carterae)*
	Chrysophyceae	Dictyochales	*Dictyocha fibula*
Euglenophyta	Euglenophyceae	Eutreptiales	*Eutreptiella gymnastica*
Protozoa Ciliophora	Kinetofrag minophorea	Prostomatida	*Mesodinium rubrum*

Reviewing the annual fluctuations of HABs for the last two decades, four stages can be identified according to species toxicity, spatial distribution, density and duration as follows: the first - before the 1980s, the second stage - from 1981 to 1988, the third - four years from 1989 to 1992, and the last - five years since 1993.

As shown in Table 9, in the first stage the causative species were harmless, and the area was only partially affected by localized algal blooms. Bloom density was approximately 1,000 cells ml^{-1}. The second stage, from 1981 to 1988, was a transition stage from harmless to harmful species. The blooms occurred either in partial areas or sometimes widespread and lasted one or less than two weeks. From the third stage on, harmful species were chiefly responsible for the blooms, and they became widespread in whole coastal South Sea. The density sometimes reached 10,000 cells ml^{-1}, quite lethal to aquatic animals. The duration of algal blooms was less than 3 weeks until 1992, but in 1995, it continued for nearly two months. From 1996 to 1998, the *Cochlodinium* bloom occurred every August and persisted for about one month.

Table 9 Recent HABs in southern Korean coastal waters.

Terms	Before 1980	1981-1988	1989-1992	1993-1997
Species toxicity	Harmless	Harmless/harmful	Harmful	Harmful
Affected area	Partial area	Partial/wide area	Widespread/South Sea	Widespread overall coast
Bloom density (cells/ml)	1000	1000-5000	2000-10000	3000-30000
The longest duration	1 week	1-2 weeks	3 weeks (81)	8 weeks (1995)

Dynamic modeling of harmful *Cochlodinium* blooms

After *C. polykrikoides* blooms caused severe economic loss in 1995, dynamic modeling has been used to study the initiation and subsequent development of the blooms. From our recent work, it was found that *C. polykrikoides* species bloom when the thermocline is absent and water temperature overlying bottom sediment is 20°C or more. The population growth rate of *C. polykrikoides* is high at water temperatures of 24 - 26°C. It has proved that this species grows well in slightly eutrophic water similar to a chemical oxygen demand (COD) of 1 ppm. Warm and slightly eutrophic environment, is optimal for the growth of *C. polykrikoides*, forms in the South Sea in late August or early September when eutrophic coastal water is mixed with warm offshore water. This warm water is the intrusion of the Tsushima Warm Current.

When the *C. polykrikoides* bloom is fully developed, it gradually forms a plume-like patch and grows. Bloom movement and distribution is dependent on the wind direction and tidal currents. The bloom approaches the coast during flood currents when SW winds prevail, and vice versa during neap currents with a NW wind.

In order to build a virtual model for the initiation of *C. polykrikoides* blooms, we need to do in-depth studies to assess the influence of nutrient and COD-related factors on the growth rate, precise dormant period of this species, and temperature sensitivity of excystment and population growth. Furthermore, surface water temperature from NOAA images and chlorophyll-α concentrations from SeaWiFS images are also studied to predict subsequent evolution and horizontal distribution.

HABs management and mitigation strategies

The Korean fisheries economy depends heavily upon the coastal zone for marine products and so it is especially sensitive to constraints from HABs. Resources must be used in the most efficient way and there is a need for sustainable, multiple-use management schemes.

There needs to be reasonable implementation and countermeasures to combat the environmental challenges such as those described above. The best way to minimize the damages is to detect HAB outbreaks at the initial stages and then take urgent action. The present action plan consists of regular monitoring and quick announcements to alert fishermen. Recently, a HAB alarm system and shield curtain for fish cages have been invented and can be commercially acquired. In addition, local self-government authorities sprinkle clay on the surface of the HAB-affected areas. If fisheries damages arise due to HABs, the government grants subsidies and relief bank loans for the sufferers.

Hierarchical and television monitoring and announcement

It is very necessary to forecast the outbreaks of blooms in order to take appropriate measures. Some fish killing dinoflagellates can devastate the farms. Most of the coastal fish farms cannot avoid the HABs due to fixed aquaculture facilities.

Regular coastal monitoring has been carried out since 1981, biweekly or monthly at 70 stations from March to November by the National Fisheries Research and Development Institute (NFRDI) to investigate the status of water quality and HAB outbreaks. Most of the coastal environmental parameters are monitored simultaneously.

When HABs occur, daily observations are made to indicate the subsequent development of HABs in the affected area and neighboring waters likely to be affected. Another 24 watch teams patrol the coast every day to detect red tides from May to October. There were 92 outposts along the coast in 1996. The patrolling periodicity is dependent on the frequency of red tide outbreaks in the last 5 years. They are divided into 3 grades, *i.e.*, daily, weekly and biweekly patrolling outposts. The main target phytoplankton are *C. polykrikoides, G. mikimotoi* and *Gyrodinium* sp.

With respect to the quick-detection and best-save measures, NFRDI is working to build a “remote televisual HAB monitoring network”. This is an image highway network for the telecommunication of microscopic image between local terminal laboratories and the central institute in Pusan. The expert in the central institute can identify phytoplankton species by telecommunicated microscopic image from the local laboratory. This way we can overcome the shortage of identification experts and a limited budget because this framework connects all the laboratories and outposts.

Most of the red tide information is distributed immediately to aquaculturists, fishermen and municipal administrative authorities by facsimile, internet (http://www.nfrdi.re.kr), and automated telephone response system that began service on May 6, 1996.

For the monitoring of shellfish poisoning, toxicological tests are run for PSP and DSP using bioassays and HPLC, and ASP using HPLC. The annual budget for the 1995 national red tide monitoring was about US$250,000 exclusive of the personnel expenses and instrument purchase.

Red tide alert system and alarm facilities

To get early attention from fishermen and aquaculturists, NFRDI deploys an alert system. It consists of notification of “Red Tide Attention”, “Red Tide Alert” and “Lifting of the Warning”. The notices of attention and alert are issued when the density of *C. polykrikoides* exceed 300 cells/ml and 1,000 cells/ml, respectively. To prevent the intake of HABs into the fish culture tanks, practical HAB alarm techniques were invented in 1997. The HAB farm alarm system consists of sensor and alarm apparatus. The sensor can detect chlorophyll, temperature and turbidity. When it detects the possible HAB chlorophyll, it gives an alarm by sound during the day and light at night or both simultaneously. It is possible to stop the seawater supply into the tank automatically.

Mitigation strategies and scattering clays

Mitigation strategies include cage movement to the outside of the affected area, diminution of feed supply, and early harvesting if the bloom develops to fatal levels. Another most important mitigation strategy is the scattering of clay. Clay has a capability to scavenge particles and carry them to bottom sediments. The removal efficiency of flocculent has been qualified in laboratory and field studies near TongYong fish farm using clay in September 1996. The removal efficiency was up to 80% using clay concentrations of 10 g l^{-1}. No big difference was found between the laboratory and field test. In the field, dissolved inorganic nitrogen, chemical oxygen demand and chlorophyll-α concentration decreased slightly after dispersion. However, scattering clays into coastal farms has some impact on marine animals, especially on abalone, with no large effects on flatfish.

References

Cho, C. H. 1978. On the *Gonyaulax* red tide in Jinhae Bay. Bull. Koeran Fish. Soc. 11(2): 111-114 (in Korean).

Cho, C. H. 1979. Mass mortality of oyster due to red tide in Jinhae Bay in 1978. Bull. Korean Fish. Soc. 12(1): 27-33 (in Korean).

Cho, C. H. 1981. On the *Gymnodinium* red tide in Jinhae Bay. Bull. Korean Fish. Soc. 14(4): 227-232.

Cho, C. H. 1986. An occurrence and distribution of phytoplankton in Korean coastal waters, 1930's-1980's. Korean J. Phycol. 1(1): 135-143 (in Korean).

Han, M. S. and Yoo, K. I. 1983. A taxonomical study on the dinoflagellates in Jinhae Bay. 1. Armored and unarmored dinoflagellates. Bulletin of KORDI 5: 37-47 (in Korean).

Han, M. S., Jeon, J. K., and Kim, Y. O. 1992. Occurrence of dinoflagellate *Alexandrium tamarense*, a causative organism of paralytic shellfish poisoning in Chinhae Bay, Korea. J. Plankton Research, 14(11): 1581-1592.

Kim, H. G., Park, J. S., and Lee, S. G. 1990. Coastal algal blooms caused by the cyst-forming dinoflagellates. Bull. Korean Fish. Soc. 23(6): 468-474.

Kim, H. G., Park, J. S., Lee, S. G., and An, K.H. 1993*a*. Population cell volume and carbon content in monospecific dinoflagellate blooms. *In* T.J. Smayda and Y. Shimizu (Eds.) Toxic Phytoplankton Blooms in the Sea. Elsevier, Amsterdam, pp. 769 - 773.

Kim, H. G., Park, J. S., Fukuyo, Y., Takayama, H, An, K. H., and Shim, J. M. 1993b. Noxious dinoflagellate bloom of an undescribed species of *Gyrodinium* in Chungmu coastal waters, Korea. *In* P. Lassus, G. Arzul, E. Erard, P. Gentien, C. Marcaillou (Eds.) Harmful Marine Algal Blooms. Lavoisier, Intercept Limited, Paris, New York, pp. 59-63.

Kim, H. G., Park, J. S., Lee, S. G. *et al*. 1994. Eco-toxicological studies of toxic marine phytoplankto in Korean coastal waters. Special report granted by Ministry of Science and Technology. pp. 153.

Lee, J. S., Jeon, J. K., Han, M. S., Oshima, Y., and Yasumoto, T. 1992. Paralytic shellfish toxins in the mussel *Mytilus edulis* and dinoflagellate *Alexandrium tamarense* from Jinhae Bay, Korea. Bull. Korean Fish. Soc. 25(2): 144-150.

Lee, K. W., Nam, K. S., Huh, H. T. *et al*. 1980. A preliminary investigation on the monitoring system for the red tides in the Jinhae Bay. KORDI, BSPE 00022-43-7, (in Korean).

Lee, K. W., Nam, K. S., Kwak, H. S. *et al*. 1981. A study on the monitoring system for the red tides in Jinhae Bay. KORDI, BSPE 00031-56-7, (in Korean).

Lee, K. W., Nam, K. S., and Kwak, H. S. *et al*. 1982. Studies on the development of red tide and pollution monitoring system in Jinhae Bay. KORDI, BSPE 00041-66-7, (in Korean).

Lee, K. W., Nam, K. S., Kwak, H. S. *et al.* 1983. A study on the monitoring system for red tides. -Jinhae Bay. KORDI, BSPE 00048-80-7, (in Korean).

Park, J. S. 1980. Studies on seasonal changes in population and species composition of phytoplankton and their effects on oysters and local fisheries resources as food organisms and as a cause of red tide in the south coast of Korea. Bull. Fish. Res. Dev. Agency 23, pp.7-157 (in Korean).

Park, J. S. 1982. Studies on the characteristics of red tide and environmental conditions in

Jinhae Bay. Bull. Fish. Res. Dev. Agency 28, pp. 55-88 (in Korean).

Park, J. S., Kim, H. G., and Lee, S. G. 1988. Red tide occurrence and succession of its causative organisms in Jinhae Bay. Bull. Nat. Fish. Res. Dev. Agency 41, pp. 1-26 (in Korean).

Park, J. S. and Kim, J. D. 1967. A study on the red-water, caused at Chinhae Bay. Bull. Fish. Res. Dev. Agency 1, pp. 63-79 (in Korean).

Yoo, K. I. 1982. Taxonomic study on the causative organisms of red tide. Bull. Environmental sciences. Han Yang Univ. 3, pp. 25-31 (in Korean).

Harmful algal blooms on the eastern coast of Russia

Tatiana Y. Orlova, Galina V. Konovalova, Inna V. Stonik, Marina S. Selina, Tatyana V. Morozova and Olga G. Shevchenko
Institute of Marine Biology, Far Eastern Branch of Russian Academy of Sciences, 17 Palchevskogo Street, Vladivostok, Russia 690041. E-mail: orlovat@chat.ru

Introduction

The eastern coast of Russia is a vast zone in the northwestern Pacific Ocean that includes the Sea of Japan, the Sea of Okhotsk and the Bering Sea. This coast covers more than 30 degrees of latitude and extends from the Arctic in the northern Bering Sea to the southern Kuriles and the Sea of Japan. The Far Eastern Seas have a similar relief structure with a shallow northern area and a depression in the southern region. The hydrological conditions in this area are dominated by large-scale ocean circulation with local cyclonic dynamics. The coastline is indented with numerous fjords, inlets, bays, islands and estuaries. The eastern coast of Russia is an important cultural and economic zone with dependence on fishery resources. It is an area that supports active fisheries and the culturing of fish and marine invertebrates (more than 80% of the total production in Russia). Due to decreasing fish catches in international waters of the Pacific Ocean, a restructuring of the fisheries toward coastal fishing and mariculture has occurred. Fish, algal and mollusc farms have been established. Their productivity is still rather low, but it is expected that in the near future the number of farms and their production will increase 2- or 3-fold. However, harmful algae blooms (HABs), a problem in many parts of the Pacific Ocean, threaten the productivity of fisheries in the Far Eastern Seas of Russia.

History

There are few historical records of HABs in the Far Eastern Seas of Russia (Fig. 16; Table 10). The first narrative of a red tide in this area is in the fictional book, *Frigate Pallada* by Goncharov (1857). From the description, we suppose that this red tide was caused by *Noctiluca*. Blooms of *Noctiluca scintillans* in Peter the Great Bay in the Sea of Japan were documented at the beginning of the 20th century (Ostroumov 1924; Tagatz 1933). Gail (1936) observed fatty iridescent patches and bands on the water's surface during the summer of 1928-1931, caused by a bloom of the green alga, *Halosphaera viridis*. Korean fishermen associated these green algal blooms on the sea surface with herring concentrations, and these observations were corroborated not only in the Sea of Japan off the coast of Primorye but also in the Sea of Okhotsk off the coast of Sakhalin Island.

A harmful bloom of the diatoms of the genus *Chaetoceros,* causing the mortality of zooplankton, was described by Kusmorskaya (1947) in the northern Sea of Japan. Herring mortalities during a diatom bloom in this area were reported by Koon (1949). A massive bloom of *Noctiluca* extended over the whole area of Nemuro Strait in Southern Kurills (between the islands of Hokkaido and Kunashir) in May 1948 (Gail 1950). During the 1950s-1960s, investigators studying the seasonal distribution of plankton in the Far Eastern Seas observed a massive spring bloom of diatoms *Thalassiosira* and *Chaetoceros* (Gail 1963; Meshcheryakova 1960; Semina 1959).

The earliest documented case of paralytic shellfish poisoning (PSP) on the eastern coast of Russia was in September 1945, when six crew members of the fishing fleet "Aleut" were poisoned and two of them died after eating mussels collected in Pavla Bay on the western coast of the Bering Sea. Lebedev (1968) describes this phenomenon: "The fishing area between Cape Navarin and Cape Olyutorsky was quite empty at this time of the year, in contrast to preceding years. No life was seen on the sea surface. The entire visible surface of the near shore waters over several miles was covered with brown-red, equally-spaced stripes extending from north to south". A second PSP incident occurred in Petropavlovsk-Kamchatski in mid-August 1973 during a toxic red tide in Avachinskaya Guba Inlet (Kurenkov 1973, 1974).

Table 10 Early record of HAB events in the Far Eastern Seas of Russia.

Date	Locality	Species	Remarks	References
The middle of the 1800s	the Japan Sea (Possyet Bay)	*Noctiluca scintillans* (?)	red tide	Goncharov, 1857
6. VI. 1909; VI-VIII. 1917*	the Japan Sea (Peter the Great Bay)	*Noctiluca scintillans*	red tide	Ostroumov, 1924
VIII. 1926	the Japan Sea (Patrokl Bay)	*Noctiluca scintillans*	red tide	Tagatz, 1933
VI. 1928- 1931	the Japan Sea (Petrov island)	*Halosphaera viridis*	red tide	Gail, 1936
IX. 1945	the Bering Sea (Pavel Bay)	*Alexandrium tamarense*	human poisoning	Lebedev, 1968
summer, 1947	Northern Japan Sea	*Chaetoceros concavicornis*	zooplankton mortality	Kusmorskaya, 1947
16. V. 1948	Kuril Islands (Nemuro Strait)	*Noctiluca scintillans*	red tide	Gail, 1950
summer, 1949	the Japan Sea (Tatarskii Strait)	*Chaetoceros concavicornis*	fish mortality	Koon, 1949
VIII. 1973	Kamchatka (Avachinskaya Guba Inlet)	*Alexandrium tamarense*	human poisoning	Kurenkov, 1974

*Roman numerals correspond to months of the year.

Twelve people, mainly children, were poisoned to varying degrees after they ate a meal of boiled and baked mussels collected in Avachinskaya Bay (Kurenkov 1974); two children died. The presence of saxitoxin in mussels from Avachinskaya Guba Inlet was confirmed in the early 1980s by the Kamchatka Department of the Institute of Marine Biology (V. Sova, pers. comm.). Later it was found that the dinoflagellate, *Alexandrium tamarense*, was the causative organism in this HAB (Konovalova 1989).

Results

Harmful algal blooms in the Far Eastern Seas of Russia are poorly studied. The distribution of HABs across wide areas of the Russian East coast are virtually unknown. Continuous studies of harmful algae have been made only in some localities. A map that shows the Russian coastal waters where (and during which years) harmful algae have been studied is divided into numbered sectors as follows: sector I - Peter the Great Bay in the Sea of Japan, since 1969; sectors II and III - the coastal waters of Sakhalin Island, since 1994; sector IV - planktonic surveys in the coastal waters of Kuril Islands during 1983-1987, sector V - planktonic monitoring in Avachinskaya Guba Inlet off the Pacific coast of Kamchatka during 1987-1990, sectors VI, VII, VIII – a summer 1999 survey of recent dinoflagellate cysts along the western coast of the Bering Sea (Fig. 17, see Appendix RU, Table 14b). Figure 18 shows the frequency of major HAB events in the Far Eastern Seas of Russia between 1980 and 2000 (Appendix RU, Table 14c).

Using improved methods of investigation such as bottle sampling, reverse filtration with nucleopore filters for concentration of living cells, electron microscopy, cyst study and other methods, we have found and described harmful algae previously unknown in this area.

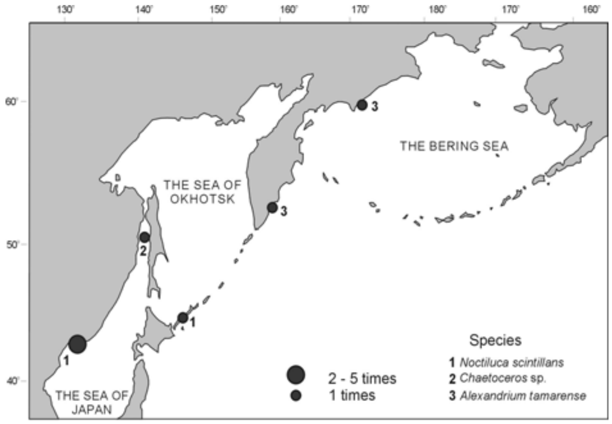


Fig. 16 Harmful algal blooms in the Far Eastern Seas of Russia (1909-1979).

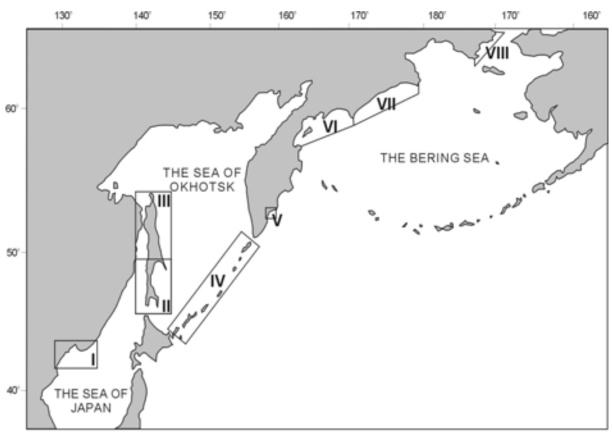


Fig. 17 Russian coastal waters into numbered sectors where harmful algae were studied.

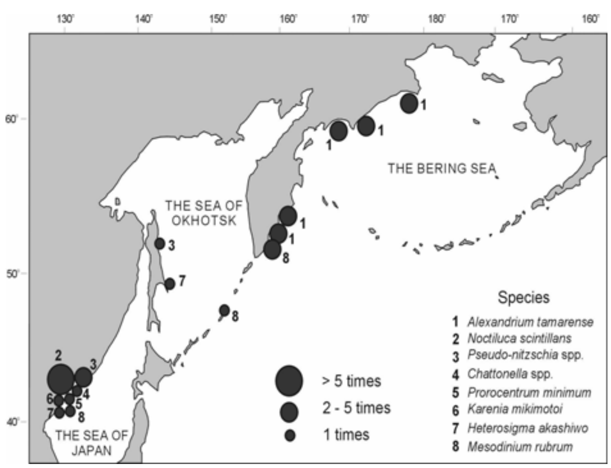


Fig. 18 Harmful algal blooms in the Far Eastern Seas of Russia (1980-2000).

These investigations have revealed that among almost 30 species causing blooms of water in the Far Eastern Seas, 24 species are known to be harmful (Table 11, Fig. 19, for detailed electron micrographs, see Appendix RU, pp. 61-66). Among those species the great majority are planktonic algae belonging to 3 groups of phytoplankton: diatoms, dinoflagellates, and raphidophytes.

Bloom-forming planktonic animals are represented by only one species, an infusorian *Mesodinium rubrum*. This species has caused more than half of all the red tides in the northern part of the Pacific coast of Russia along the eastern coast of Kamchatka and at the northern Kuril Islands (Fig. 18). The first two red tides caused by *M. rubrum* were observed in Avachinskaya Guba Inlet: one in September-October 1983, when water temperatures were 9-11^{o}C, and the other between the end of November and the beginning of December 1984 (water temperature was about 0^{o}C). The concentration of organisms from $3x10^5$-$2x10^6$ cells/liter turned the water a cherry-red color (Orlova *et al.* 1985). In the Sea of Japan, a red tide caused by this species was first recorded in August 1985, in Vostok Bay at water temperature of 21-22^{o}C (Konovalova and Selina 1986). Persistent red tides caused by *M. rubrum* were repeatedly observed in August-September 1985, in Kraternaya Bay, Ushishir Island, Kuril Islands (Propp *et al.* 1989). Planktonic monitoring in Avachinskaya Guba Inlet from 1987-1990 showed that red tides caused by *M. rubrum* were observed here nearly year-round with an interval at the beginning of summer.

Diatoms

Diatoms are the most common bloom-forming algae in the Far Eastern Seas of Russia. More than 20 species of diatoms can cause blooms in the study area (Table 11) and only some of them are known to be harmful. Electron microscopy has revealed the presence of five potentially toxic species of the genus *Pseudo-nitzschia*. *Pseudo-nitzschia pungens* and *P. multiseries* are the most common and widely distributed species in the

Table 11 Harmful algae in the Far Eastern Seas of Russia.

Group	Harmful/toxic* species	Bloom- forming/red tides species
DIATOMS	*Pseudo-nitzschia delicatissima, P. multiseries, P. multistriata, P. pungens, P. pseudodelicatissima*	*Cerataulina dentata, Chaetoceros affinis, C. constrictus, C. debilis, C. decipiens, C. concavicornis, C. convolutus, C. salsugineus, C. socialis, Coscinodiscus wailesii, Eucampia zodiacus, Proboscia alata, Pseudo-nitzschia multiseries, P. pungens, Skeletonema costatum, Rhizosolenia setigera, Thalassionema nitzschioides, Thalassiosira anguste lineata, T. mala, T. nordenskioeldii*
DINOFLAGELLATES	*Alexandrium tamarense, A. pseudogonuaulax, A. ostenfeldii, A. acatenella, A. catenella Amphidinium klebsii, Dinophysis acuminata, D. acuta, D. fortii, D. norvegica, D. rotundata, D. tripos,Karenia brevis, K. mikimotoi, Karlodinium veneficum*	*Alexandrium tamarense, Karenia mikimotoi, Noctiluca scintillans, Prorocentrum minimum*
RAPHIDOPHYTES	*Chattonella globosa, C. marina, Fibrocapsa japonica, Heterosigma akashiwo*	*Chattonella marina, Heterosigma akashiwo*
CILIATES		*Mesodinium rubrum*

*Toxins have not yet been measured in shellfish from Russian waters, but causative organisms are common.

.

Far Eastern Seas of Russia (Table 12; see Appendix RU, pp. 61-62 for electron micrographs and pp. 63-66 for morphometric data of *Pseudo-nitzschia* species; Orlova and Stonik 2001; Stonik *et al.* 2001).

An extensive bloom of both *Pseudo-nitzschia multiseries* and *P. pungens* at 11 million cells l^{-1} was first recorded in Amurskii Bay near Vladivostok in 1992 (Orlova *et al.* 1996). A bloom of *P. pungens* (at numbers up to 2 million cells l^{-1}) was observed in the coastal waters of Sakhalin Island in August 2000 (Fig. 18, Table 12). *P. pseudodelicatissima, P. multistriata* and *P. delicatissima* were found only in the coastal waters of the Sea of Japan. The maximum abundance of hundreds of thousand cells per liter of those species was noted during late summer and autumn.

Raphidophytes

In the past 20 years the first raphidophyte blooms have been observed. These microalgae are *Chattonella globosa*, *C. marina*, *Heterosigma akashiwo*, and *Fibrocapsa japonica* (Table 11). *Heterosigma akashiwo* is the most common of these raphidophytes found in the coastal waters of the Far Eastern Seas of Russia. Short-lived outbreaks of *H. akashiwo* were recorded in Amurskii Bay near Vladivostok and in the coastal waters of Sakhalin Island (Table 12). The distribution of species of the genus *Chattonella* in the Far Eastern Seas is restricted to the northern part of the Sea of Japan. An extensive bloom of *Chattonella* sp., resulting in fish mortality, was first recorded in September 1987 in Amurskii Bay (Simakova *et al.* 1990; Shumilin *et al.* 1994) (Fig. 18). *Chattonella globosa* is abundant (hundreds of thousand cells per liter) in the summer-autumn period in Amurskii Bay (Table 12).

Table 12 Distribution and concentration of harmful algae in the Far Eastern Seas of Russia. Roman numerals in the under ‘Date’ correspond to months of the year.

Species	Sector No. (Fig. 2)	Location	Latitude	Longitude	Date	Conc. (cells l^{-1})
DIATOMS						
P. pseudodelicatissima	I	Amurskii Bay	43^{0}11’N	131^{0}54’ E	XI-1997	2.7 x 10^{6}
P. pungens/ multiseries	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	VI-1992	1.6 x 10^{7}
	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	VI-1993	1 x 10^{6}
	I	Minonosok Bay	42^{0}36’ N	130^{0}51’ E	IX-1997	2.5 x 10^{4}
	I	Amurskii Bay	43^{0}11’ N	131^{0}54’ E	IX-1997	0.6 x 10^{6}
P. pungens	I	Rinda Bay	43^{0}02’ N	131^{0}48’ E	V-2000	1 x 10^{6}
	I	Rinda Bay	43^{0}02’ N	131^{0}48’ E	VIII-2000	1.4 x 10^{6}
	I	Golden Horn Bay	43^{0}06’ N	131^{0}53’ E	VIII-2000	1.5 x 10^{6}
	III	coastal waters of Sakhalin Island	52^{0}51’ N	143^{0}22’ E	VIII-2000	2.1 x 10^{6}
Thalassiosira mala	III	coastal waters of Sakhalin Island	52^{0}51’ N	143^{0}22’ E	IX-2000	5 x 10^{6}
DINOFLAGELLATES						
Alexandrium acatenella	V	Avachinskaya Guba Inlet, Kamchatka	53^{0}00’ N	158^{0}35’ E	VII-VIII-1984	1 x 10^{6}
	III	coastal waters of Sakhalin Island	51^{0}26’ N	143^{0}47’ E	VIII-2000	2 x 10^{4}
	II	Aniva Bay	46^{0}13’ N	143^{0}36’ E	VII-2001	5.2 x 10^{3}
	I	Vostok Bay	42^{0}50’ N	132^{0}46’ E	VIII-2001	2 x 10^{2}
	II	Terpenie Bay	49^{0}13’ N	144^{0}15’ E	VII-2000	1.5 x 10^{4}
A. pseudogonyaulax	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	VII-1999	3 x 10^{4}
	I	Minonosok Bay	42^{0}36’ N	130^{0}51’ E	IX-1999	6.1 x 10^{3}
	II	Terpenie Bay	49^{0}13’ N	144^{0}15’ E	VII-2000	2 x 10^{2}
A. tamarense	V	Avachinskaya Guba Inlet, Kamchatka	53^{0}00’ N	158^{0}35’ E	VII-VIII-1984	1 x 10^{6}
	VI	Olytorskii Bay	58^{0}00’ N	165^{0}00’ E	VII-1986	2 x 10^{6}
	V	Avachinskaya Guba Inlet, Kamchatka	53^{0}00’ N	158^{0}35’ E	VII-1988, 1990	2 x 10^{6}
	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	IX-X-1990	1 x 10^{4}
	I	Minonosok Bay	42^{0}36’ N	130^{0}51’ E	VIII-1999	5.6 x 10^{3}
	III	coastal waters of Sakhalin Island	51^{0}26’ N	143^{0}47’ E	VIII-2000	4 x 10^{2}
	II	Aniva Bay	46^{0}13’ N	143^{0}36’ E	VIII-2000	4 x 10^{4}
	II	Aniva Bay	46^{0}13’ N	143^{0}36’ E	VI-2001	3.5 x 10^{4}
	II	Aniva Bay	46^{0}13’ N	143^{0}36’ E	VII-2001	5.2 x 10^{3}
	I	Vostok Bay	42^{0}50’ N	132^{0}46’ E	VIII-2001	3 x 10^{2}

Species	Sector No. (Fig. 2)	Location	Latitude	Longitude	Date	Conc. (cells l^{-1})
Dinophysis acuminata	I I I I I III I III	Amurskii Bay Minonosok Bay Amurskii Bay Amurskii Bay Amurskii Bay coastal waters of Sakhalin Island Rinda Bay Sakhalinskii Bay	43^{0}15’ N 42^{0}36’ N 43^{0}11’ N 43^{0}11’ N 43^{0}11’ N 52^{0}51’ N 43^{0}02’ N 54^{0}29’ N	131^{0}50’ E 130^{0}51’ E 131^{0}54’ E 131^{0}54’ E 131^{0}54’ E 143^{0}22’ E 131^{0}48’ E 142^{0}03’ E	VII-1992 VI-1997 VIII-1997 VI-1998 VII-1998 VIII-2000 VIII-2000 VIII-2001	8 x 10^4 4 x 10^2 1.5 x 10^4 5 x 10^3 2 x 10^3 5 x 10^2 1.1 x 10^4 5 x 10^2
D. acuta	I II III III	Amurskii Bay Aniva Bay north-eastern coastal waters of Sakhalin Island Sakhalinskii Bay	43^{0}11’ N 46^{0}13’ N 51^{0}26’ N 54^{0}29’ N	131^{0}54’ E 143^{0}36’ E 143^{0}47’ E 142^{0}03’ E	VI-1998 VIII-2000 VIII-2000 VIII-2001	2 x 10^2 2 x 10^2 2 x 10^2 2.1 x 10^3
D. fortii	I	Vostok Bay	42^{0}50’ N	132^{0}46’ E	VIII-2000	3 x 10^3
D. norvegica	II III	Terpenie Bay Sakhalinskii Bay	49^{0}13’ N 54^{0}29’ N	144^{0}15’ E 142^{0}03’ E	VIII-2000 VIII-2001	8 x 10^2 1 x 10^2
D. rotundata	I III	Amurskii Bay Sakhalinskii Bay	43^{0}11’ N 54^{0}29’ N	131^{0}54’ E 142^{0}03’ E	VII-1998 VIII-2001	3 x 10^1 6 x 10^2
Karenia brevis	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	X-1993	3.5 x 10^3
K. mikimotoi	I	Amurskii Bay	43^{0}15’ N	131^{0}50’ E	IX-X-1990	1 x 10^6
Noctiluca scintillans	I I I I I	Peter the Great Bay Peter the Great Bay Peter the Great Bay Peter the Great Bay Peter the Great Bay	43^{0}07’ N 43^{0}07’ N 43^{0}07’ N 43^{0}07’ N 43^{0}07’ N	132^{0}10’ E 132^{0}10’ E 132^{0}10’ E 132^{0}10’ E 132^{0}10’ E	IV-1980 V-1982 VI-1992 VI-1993 IV-VII – -1994-1995	1 x 10^5 1 x 10^6 1 x 10^5 3 x 10^5 3 x 10^5
Prorocentrum *minimum*	I I I I I I	Amurskii Bay Amurskii Bay Amurskii Bay Minonosok Bay Amurskii Bay Minonosok Bay	43^{0}15’ N 43^{0}15’ N 43^{0}15’ N 42^{0}36’ N 43^{0}11’ N 42^{0}36’ N	131^{0}50’ E 131^{0}50’ E 131^{0}50’ E 130^{0}51’ E 131^{0}54’ E 130^{0}51’ E	VII-1991 VIII-1991 VII-1992 VII-1997 VIII-1997 VIII-1999	2.6 x 10^6 8 x 10^6 1.1 x 10^6 2.4 x 10^4 1 x 10^4 4.2 x 10^4
RAPHIDOPHYTES						
Chattonella sp. *Chatonella globosa* *Heterosigma* *akashiwo*	I I I I III	Amurskii Bay Amurskii Bay Amurskii Bay Amurskii Bay north-eastern coastal waters of Sakhalin Island	43^{0}15’ N 43^{0}15’ N 43^{0}15’ N 43^{0}15’ N 49^{0}25’ N	131^{0}50’ E 131^{0}50’ E 131^{0}50’ E 131^{0}50’ E 144^{0}48’ E	IX - 1987 XI-1993 VIII-2000 VI-1995 VIII-2000	10 x 10^6 9 x 10^5 5 x 10^5 5 x 10^6 5 x 10^6

Species	Sector No. (Fig. 2)	Location	Latitude	Longitude	Date	Conc. (cells l^{-1})
Chattonella sp.	I	Amurskii Bay	$43^{0}15'$ N	$131^{0}50'$ E	IX - 1987	10×10^{6}
Chatonella globosa	I	Amurskii Bay	$43^{0}15'$ N	$131^{0}50'$ E	XI-1993	9×10^{5}
	I	Amurskii Bay	$43^{0}15'$ N	$131^{0}50'$ E	VIII-2000	5×10^{5}
Heterosigma akashiwo	I	Amurskii Bay	$43^{0}15'$ N	$131^{0}50'$ E	VI-1995	5×10^{6}
	III	north-eastern coastal waters of Sakhalin Island	$49^{0}25'$ N	$144^{0}48'$ E	VIII-2000	5×10^{6}
CILIATES						
Mesodinium rubrum	V	Avachinskaya Guba Inlet, Kamchatka	$53^{0}00'$ N	$158^{0}35'$ E	IX-X-1983	2×10^{6}
	V	Avachinskaya Guba Inlet, Kamchatka	$53^{0}00'$ N	$158^{0}35'$ E	XI-XII – 1984	2×10^{6}
	I	Vostok Bay	$42^{0}50'$ N	$132^{0}46'$ E	VIII-1985	3×10^{5}
	IV	Kraternaya Bay, Kurill Island	$47^{0}30'$ N	$152^{0}48'$ E	VIII-IX - 1985	1×10^{6}
	V	Avachinskaya Guba Inlet, Kamchatka	$53^{0}00'$ N	$158^{0}35'$ E	VII-IV 1987-1990	3×10^{4}- 1×10^{6}

Dinoflagellates

The greatest number of HABs in the Far Eastern Seas of Russia are caused by dinoflagellates, four of which provoke red tides. *Noctiluca scintillans* is one of the most common species in the investigated area. The distribution of this species is restricted to the southern part of the Pacific coast of Russia (Table 12). In the past 20 years, it has caused most of the visible red tides recorded in this region. An extensive *Noctiluca scintillans* red tide was observed in the spring-summer period in Peter the Great Bay in 1980, 1982, 1992, 1993, 1994 and 1995 (Fig. 18). The density of *N. scintillans* reached hundreds of thousand cells per liter, and the water surface was colored bright red-orange (Vyshkvartsev *et al.* 1982; Zhirmunsky and Konovalova 1982; Ilychev *et al.* 1985).

Dinoflagellates of the genus *Alexandrium* (*A. tamarense*, *A. acatenella*, *A. catenella*, *A. pseudogonyaulax* and *A. ostenfeldi*) have been observed in the Far Eastern Seas of Russia (Table 11, see Appendix RU, pp. 61-62 for electron micrographs of *Alexandrium* species). *A. tamarense* is the most common of these species (Table 12).

A red tide caused by *A. tamarense* and *A. acatenella* at one million cells per liter was recorded in Avachinskaya Inlet in Kamchatka in July and August of 1984. An extensive *A. tamarense* red tide (with numbers up to 2 million cells per liter) was observed in Olyutorsky Bay in the Bering Sea in July 1986 when water temperatures ranged from 12-14^{o} C. This bloom was accompanied by mortalities of cetaceans, fish and birds (Konovalova 1989). In July 1988 and 1990, a red tide of *A. tamarense* covered the entire coast of the Bering Sea, including the northeastern coast of Kamchatka and the estuarine zones. This bloom was especially strong in Kronotsky and Avachinsky Bays and at Cape Lopatka in September 1990 (Konovalova 1989).

Qualitative and semi-quantitative surveys of living dinoflagellate cysts have recently been made along the western coast of the Bering Sea. Sediments were collected from 15 stations in June-October 1999 (Table 13). This is the first survey of recent dinoflagellate cysts on a Russian Pacific coast. Twenty-four types of cysts were identified to species level, representing 8 genera: *Alexandrium, Gonyaulax, Gyrodinium, Polykrikos, Pentapharsodinium, Preperidinium, Protoperidinium and Scrippsiella.* The most common cysts were those of *Gonyaulax grindleyi, G. spinifera, Polykrikos schwartzii, Pentapharsodinium dalei, Protoperidinium americanum, P. conicoides, P. subinerme,* *Scrippsiella crystalina* and *S. trochoidea.* The cysts of the potentially toxic species *A. tamarense* were widely distributed and the dominant type in the study area. The abundance of cysts of *A. tamarense* varied from 13 to 16,761 cysts ml^{-1}. The greatest number of cysts at 25860 cysts ml^{-1} was registered at Station 8 in Pavla Bay (Fig. 20, region VI).

Table 13 Distribution of dinoflagellate cysts along the western coast of the Bering Sea.

Species	Location*														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Alexandrium tamarense	×	×	×	×	×	×	×	×	×		×	×	×	×	×
Gonyaulax grindleyi	×	×	×	×	×	×		×	×		×	×	×	×	
Gonyaulax cf. scrippsae		×		×		×	×								
Gonyaulax spenifera	×	×		×	×	×	×	×	×		×	×	×		
Gyrodinium cf. *instriatum*		×	×												
Pentapharsodinium dalei							×	×	×	×	×	×	×	×	×
Polykrikos kofoidii	×	×	×	×		×	×	×			×				
Polykrikos schwartzii	×		×	×				×							
Preperidinium meunieri		×		×											
Protoperidinium americanum		×	×	×		×	×	×	×		×	×		×	×
Protoperidinium cf. *avellana*		×					×				×				×
Protoperidinium claudicans		×	×												
Protoperidinium conicoides		×		×	×	×			×	×	×	×		×	×
Protoperidinium conicum		×	×					×							
Protoperidinium cf. *denticulatum*	×	×			×	×	×				×	×			×
Protoperidinium leonis						×		×			×				
Protoperidinium minutum		×						×							
Protoperidinium oblongum		×													
Protoperidinium pentagonum		×		×				×						×	×
Protoperidinium cf. *punctulatum*						×		×							
Protoperidinium subinerme		×	×					×		×	×			×	
Scrippsiella crystallina	×	×	×	×	×	×			×	×					×
Scrippsiella lachrymosa	×	×		×											
Scrippsiella trochoidea	×	×	×	×		×	×	×	×	×	×	×	×	×	
Scrippsiella sp. 1			×	×		×	×					×	×		

* 1. Karaginskii Island; 2. Ossora; 3. Glybokaya Bay; 4. Lavrova Bay; 5. Tylenie Ozero Bay; 6. Mys Osynoy; 7. Kamni Chasovie Island; 8. Pavla Bay; 9. Rossina Bay; 10. Tkachen Bay; 11. Konovak Cape; 12. Penkingen Bay; 13. Deznev Cape; 14. Kakano Cape; 15. Lavrentiya Bay; 16 Chaluskina Strait.

Five species of the genus *Dinophysis* were common and widely distributed in the Far Eastern Seas of Russia (Table 11, Fig. 19). The abundance of these species have exceeded the reportedly harmful level of 200-500 cells per liter in the coastal waters of the Far Eastern Seas of Russia in the summer-autumn period (Table 12). Dinophysis acuminata is one of the most abundant species with numbers reaching thousands of cells per liter in Peter the Great Bay in summer.

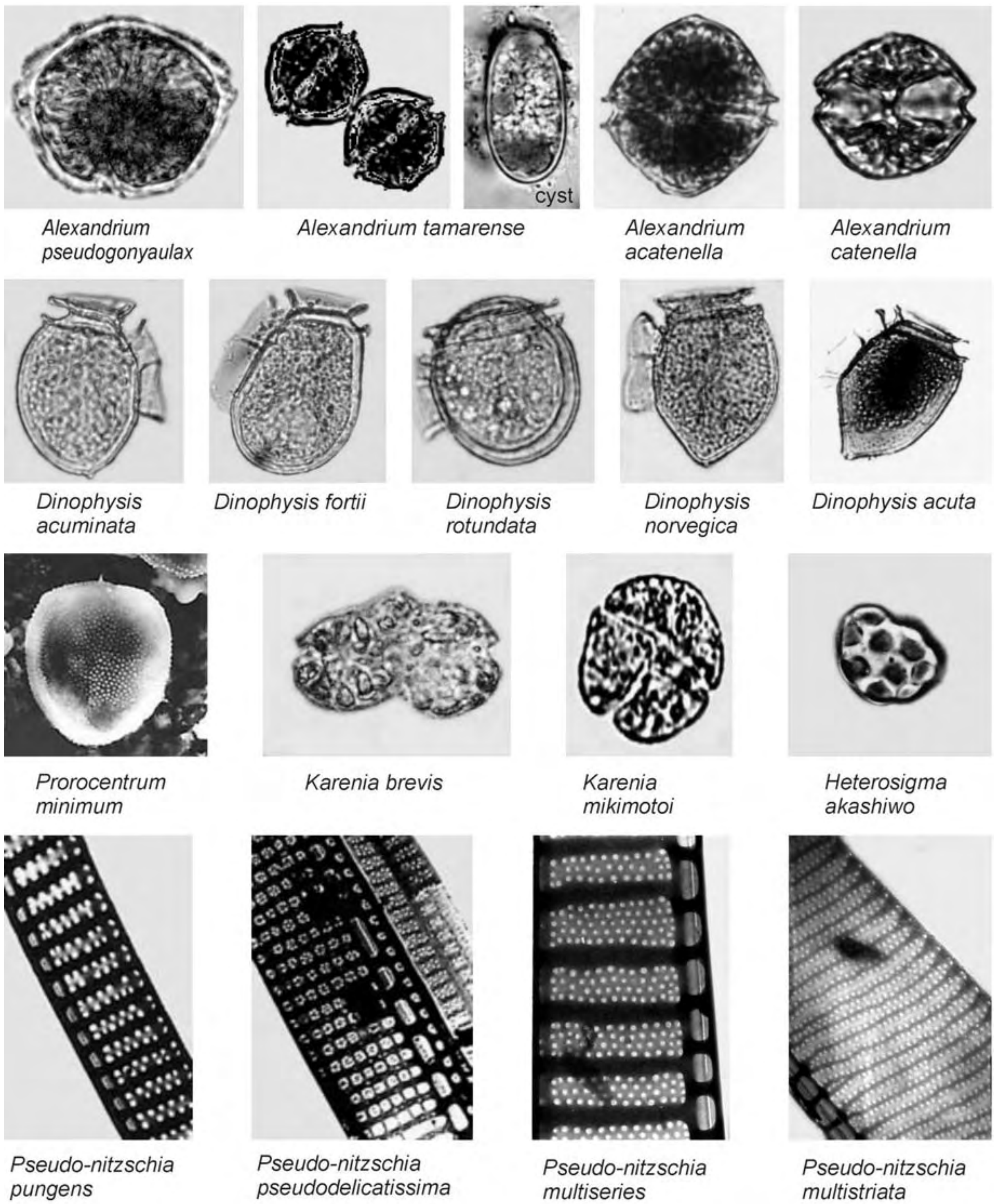


Fig. 19 Species found in the Far Eastern Seas of Russia and known to be harmful elsewhere.

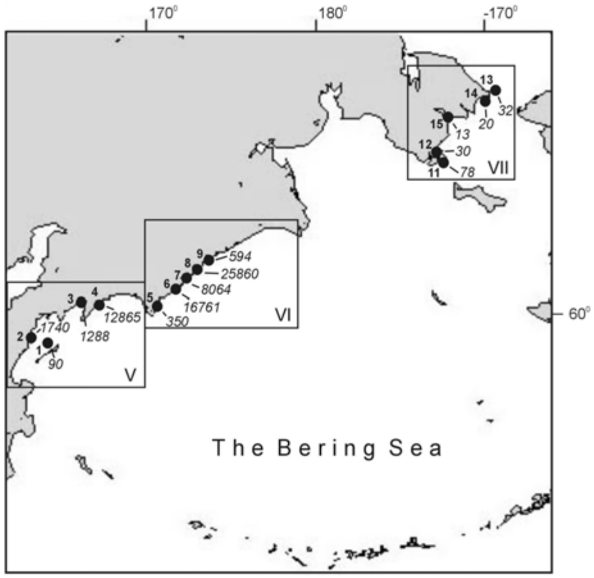


Fig. 20 The abundance of *Alexandrium tamarense* cysts per milliliter of sediment at 15 stations on the west coast of the Bering Sea (sectors V-VIII).

During the past 20 years, new species of *Karenia* have been observed in the Far Eastern Seas of Russia. *Karenia brevis* (synonym *Gymnodinium breve*) has been found in low numbers in the coastal waters of the Sea of Japan and Sakhalin Island (Table 12). Short-term outbreaks of *K. mikimotoi* (synonym *G. mikimotoi*) at one million cells per liter were recorded in Amursky Bay in September and October of 1987, 1989 and 1990 (Selina *et al.* 1992; Fig. 18).

Conclusion

There is a great disparity in the amount of information about HABs available for the Far Eastern Seas of Russia. The most complete record of numbers and seasonal dynamics of harmful algae, as well as HAB events can be found for the coastal waters of Primorye and Kamchatka rather than for other areas on the Russian east coast. Some regions still remain blank spots on the HAB map.

Long-term observations in the northern Sea of Japan and planktonic surveys on the coasts of the Sea of Okhotsk, the Bering Sea, and the Pacific coast of Kamhatka, show that there has been an apparent increase in the frequency, intensity and geographical distribution of HABs in Russian coastal waters during the last two decades. Routine phytoplankton monitoring in Peter the Great Bay (Sea of Japan) has revealed that a peak of HAB activity occurred between the end of the 1980s and the beginning of the 1990s.

In this area, the appearance and massive blooms of new species of raphidophytes and naked dinoflagellates were observed during this period. It is obvious that the distribution of those microalgae is widespread. The most serious problem in identification is that fixed cells are generally indistinguishable. The decrease in the apparent intensity of HABs in the mid-and late-1990s does not suggest that any positive changes in the coastal ecosystem have occurred. Every year we have observed recurrent blooms of nontoxic species (*Skeletonema*, *Chaetoceros*, *Thalassionema* and others) at millions of cells per liter in the hypereutrophic coastal waters during the summer and autumn periods. The majority of harmful species that are known in this area can produce cysts (hypnozygotes in *Alexandrium* spp.) and resting cells (*Pseudo-nitzschia* spp.). Transport of resting cells or cysts by currents or ballast waters may bring new species to new locations where they remain dormant until conditions are right for germination. Most of the blooms of harmful species have occurred in coastal waters subjected to the most powerful anthropogenic influence. In our opinion, complex factors that provide the most favorable conditions for outbreaks of harmful algae exist in those areas. The major factors are high levels of mineral and dissolved organic substances, as well as the vertical stability of the water layers, associated with the substantial freshening and warming of the surface waters during the summer period.

In this report, we have reviewed the available data pertaining to harmful algae on the coasts of the Russian Far East. The information reviewed here indicates that in the last two decades there has been an apparent increase in the frequency, intensity and distribution of harmful algal blooms in Russian coastal waters. The algae that cause the most concern are the genera *Alexandrium*, *Pseudo-nitzschia* and *Dinophysis*, known for their toxigenicity and ability to cause paralytic, amnesic and diarrhetic shellfish poisonings.

Recommendations for the future

The Russian Federation lags far behind other PICES member countries in its approach to the research and management of problems caused by harmful algae and marine biotoxins. The Russian Federation, in contrast to other PICES member countries, does not have a federal HAB monitoring program. It only has small, fragmented research programs carried out by individual investigators, with small budgets, and often without any financial support. We recommend establishing a permanent federal program of HAB monitoring in the Russian coastal waters. The primary goal of this program would be to understand the geographical location and frequency of HAB events in order to protect the human consumers from intoxication and to prevent losses in the aquaculture industry due to harmful algal blooms.

Several of the most important questions for future research in Russia include:

- what is the composition and distribution of harmful algae in the coastal waters of Sakhalin Island and South Kuril Island?
- what is the composition and distribution of dinoflagellate cysts in recent marine sediments in coastal waters of the Sea of Okhotsk?
- what is the distribution of *Alexandrium tamerense* in the Far Eastern Seas of Russia (cyst occurrences, morphology and genetic analysis of populations, toxin analysis)?

References

Gail, G.I. 1936. The distribution of phytoplankton in the upper layer of coastal waters of the north-western part of the Sea of Japan. Vestnik DVF Akademii nauk SSSR. 18: 81 – 107 (in Russian).

Gail, G.I. 1950. Phytoplankton of the Sea of Japan [Opredelitel phitoplanktona Yaponskogo moray]. Izvestiya TINRO, 33: 3 – 177 (in Russian).

Gail, M.M. 1963. Spring phytoplankton of Southeastern Tatar Strait. Izvestiya TINRO 49: 137 – 158 (in Russian).

Goncharov, I. 1857. Frigate Pallada. Moskaw, Hydojestvennaya Literatura (1978) II: 508 pp. (in Russian).

Ilychev, V.I., Anikiev, V.V., Starodubtsev, E.G., Rodionov, N.M., Kulinich, N.M., and Shornikov. A.V. 1985. Observations on the distribution of the red tide in Peter the Great Bay (Sea of Japan). The Soviet Journal of Marine Biology 5: 6-9 (in Russian).

Konovalova, G.V. 1989. Phytoplankton Blooms and Red Tides in Far East Coastal Waters of the USSR. Red Tides, Proc. 1st Int. Symp., New York: Elsevier, pp. 97-100.

Konovalova, G.V., and Selina, M.S. 1986. First report of a red tide caused by the infusorian *Mesodinium rubrum* in the Sea of Japan. The Soviet Journal of Marine Biology 3: 63-63.

Koon, M.S. 1949. Nutrition of Pacific herring in the northern part of Tatar Strait. Izvestiya TINRO 29: 107 - 138 (in Russian).

Kurenkov, I.I. 1973. Red Tide in Avachinskaya Bay in 1973, Report No. 6294818, Archives of Kamchatka division of the Pacific Research Institute for Fisheries and Oceanography. Petropavlovsk-Kamchatski (in Russian).

Kurenkov, I.I. 1974. Red Tide in Avachinskaya Bay. Rybnoe Khozyaistvo 4: 20-21 (in Russian).

Kusmorskaya, A.P. 1947. Observations on the death of Copepoda caused by massive concentrations of diatoms. Dokladi AN SSSR 7(3): 293 – 294 (in Russian).

Lebedev, S.P. 1968. Caution: Red Tides. Rybnoe Khozyaistvo 5: 19 –20 (in Russian).

Meshcheryakova, I.M. 1960. Seasonal changes in plankton in open waters of the Sea of Japan. Izvestiya TINRO 46: 95 - 144 (in Russian).

Orlova T., Konovalova, G.V., and Oshurkov, V.V. 1985. Red tide caused by the bloom of infusorian *Mesodinium rubrum* in Avacha Bay (Kamchatka). The Soviet J. Mar. Biol. 11(6): 342-348.

Orlova T., Zhukova N.V., and Stonik, I.V. 1996. Bloom-forming diatom *Pseudo-nitzschia pungens* in Amurskii Bay (the Sea of Japan): Morphology, Ecology and Biochemistry. *In* Yasumoto, T. *et al.* (Eds.) Harmful and Toxic Algal Blooms. Intergovernmental Oceanographic Commission of UNESCO, pp. 147-151.

Orlova T., and Stonik, I.V. 2001. The species of the Genus *Pseudo-nitzschia* (Bacillariophyta) found in the Far Eastern Seas of Russia.

Russian Journal of Botany [Botanicheskiy Zhurnal] 86(4): 47-52 (in Russian).

Ostroumov A. 1924. *Noctiluca miliaris* in Simbiosis Mit Grunen Algen. Zool / Anzeiger, Bd 58.

Propp, M.V., Propp, L.N., and Tarasov, V.G. 1989. Hydrochemical conditions and daily dynamics of oxygen, chlorophyll "a" and nutrient in Kraternaya Bight. The Soviet J. Mar. Biol. 3: 36-44 (in Russian).

Selina, M.S., Simakova, N.K., and Yasnetskaya, L.V. 1992. *Gymnodidium nagasakiense* Takayama et Adachi (Dinophyta). Algologiya 2 (1): 51-55 (in Russian).

Semina, G.I. 1959. Distribution of phytoplankton in Kronotsky Bay. Trudi Inst. Okeanol. Akad. Nauk SSSR 36: 73-91 (in Russian).

Shumilin, E.N., Kassatkina, A.P., Orlova, T., and Goryachev, N.A. 1994. Trace metals in seston during red tide in estuarine zone of Razdolnaya river. Russian Journal of Marine Biol. 20(4): 286-290.

Simakova, N.V., Orlova, T., and Selina, M.S. 1990. Red tide caused by raphidophytes *Chattonella* sp. in Amurskii Bay, the Sea of Japan. Russian J. Mar. Biology 16(5): 77-79.

Stonik, I. V., Orlova, T., and Schevchenko, O. G. 2001. Species of the Genus *Pseudo-nitzschia* H. Perag. (Bacillariophyta) from the Peter the Great Bay, the Sea of Japan. Russian J. Mar. Biol. 27(4) (in press).

Tagatz, V. 1933. Some data on zooplankton in Patrokl Bay (Peter the Great Bay) in summer 1926. Issledovaniya morei SSSR. 19: 59 – 71 (in Russian).

Vyshkvartsev, D.I., Taratuchin, A. F., and Kharlamenko, V. I. 1982. The 1982 red tide in Peter the Great Bay (Sea of Japan). Soviet J. Mar. Biol. 5: 18-20 (in Russian).

Zhirmunsky, A.V., and Konovalova, G.V. 1982. Red tide in Peter the Great Bay, Sea of Japan. Soviet J. Mar. Biol. 5: 3-6 (in Russian).

Appendix RU

Harmful algal blooms on the eastern coast of Russia in 2000-2001

Tatiana Y. Orlova, Inna V. Stonik, Marina S. Selina, Olga G. Shevchenko and Tatiana V. Morozova

Institute of Marine Biology, Far Eastern Branch of Russian Academy of Sciences, 17 Palchevskogo Street, Vladivostok, Russia 690041. E-mail: orlovat@chat.ru

Abstract

Harmful algae monitoring was carried out during May-October of 2000-2001, on the east coast of Russia both in Primorye and Sakhalin Island. Over the period of study, 13 species known to be harmful were found. These microalgae were the diatoms *Pseudo-nitzschia pungens*, *P. multistriata* and *Thalassiosira mala*; the dinoflagellates *Alexandrium acatenella, A. catenella, A. pseudogonyaulax, A. tamarense, Dinophysis acuminata, D. acuta, D. fortii, D. norvegica* and raphidophyte *Heterosigma akashiwo* and *Chattonella globosa*. Brief outbreaks of *Pseudo-nitzschia pungens* ($1.5x10^6$ cells l^{-1}) were observed in the near-shore zone near Vladivostok. A bloom of *Heterosigma akashiwo* ($5x10^6$ cells l^{-1}) was recorded in coastal waters of Sakhalin Island. Toxins have not yet been measured in shellfish on the east coast of Russia, but the causative organisms are common. Cases of human poisoning were not recorded.

Materials and methods

Harmful algae monitoring was carried out during May-October of 2000-2001 in 3 study areas: (I) in the coastal waters of Primorye in the Sea of Japan, (II) on the southeastern coast of Sakhalin Island, and (III) on the northeastern coast of Sakhalin Island. Samples were collected 1-2 times per month using a 4-liter Molchanov's bathometer from the surface horizon (0.05 m) and near bottom. The material was fixed in Lugol's iodine solution and concentrated using a traditional method of precipitation. The cells were counted in Najott chamber with a volume of 0.05 ml; large or rare species were registered in a chamber with a 1 ml volume.

Results

During these studies 13 species that are known to be harmful were found in the Far Eastern Seas of Russia (Table 14a). They belong to 3 groups of phytoplankton: diatoms (2 species), dinoflagellates (8) and raphidophytes (2).

Diatoms

Pseudo-nitzschia pungens is one of the most widely distributed species in the study area. The blooms of *P. pungens* at 1.5 millions cells l^{-1} were recorded both in May and August 2000, near Vladivostok (Fig. 21). *Pseudo-nitzschia pungens* was common in the coastal waters of Sakhalin Island in August 2000 at $2.1x10^5$ cells l^{-1}. *P. multistriata* was found in the coastal waters of Sakhalin in September 2001, at $1x10^4$ cells l^{-1}.

Raphidophytes

C*hattonella globosa* was common in the coastal waters of Primorye in August 2000, at number $5x10^5$ cells l^{-1}. An extensive bloom of *Heterosigma akashiwo* was recorded in August, 2000 in the coastal waters of Sakhalin Island (Fig. 21).

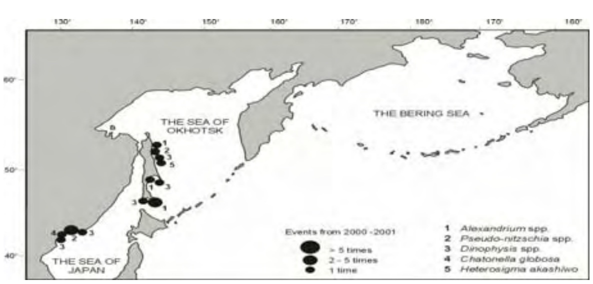


Fig. 21 Harmful algal blooms in the Far Eastern Seas of Russia (2000-2001).

Dinoflagellates

Dinoflagellates of the genus *Alexandrium* (*A. tamarense*, *A. acatenella*, *A. catenella* and *A. pseudogonuaulax*) were observed in the Far Eastern Seas of Russia (Fig. 21). *Alexandrium tamarense* was the most common species. It was abundant in coastal waters of Sakhalin Island, at $4x10^4$ cells l^{-1}.

Dinophysis species are widely distributed in the Far Eastern Sea of Russia but no *Dinophysis* blooms were observed. The abundance of these species exceeded the reportedly harmful level of 200-500 cells l^{-1} in the coastal waters in the summer-autumn period. *Dinophysis acuminata* is one of the most abundant species. Its number reached thousands of cells per liter in the coastal waters of Vladivostok in August 2000.

Major HAB events in each sector of the Far Eastern Seas of Russia are summarized in Table 14b. The frequency of HAB events in 2000-2001 is shown in Figure 22.

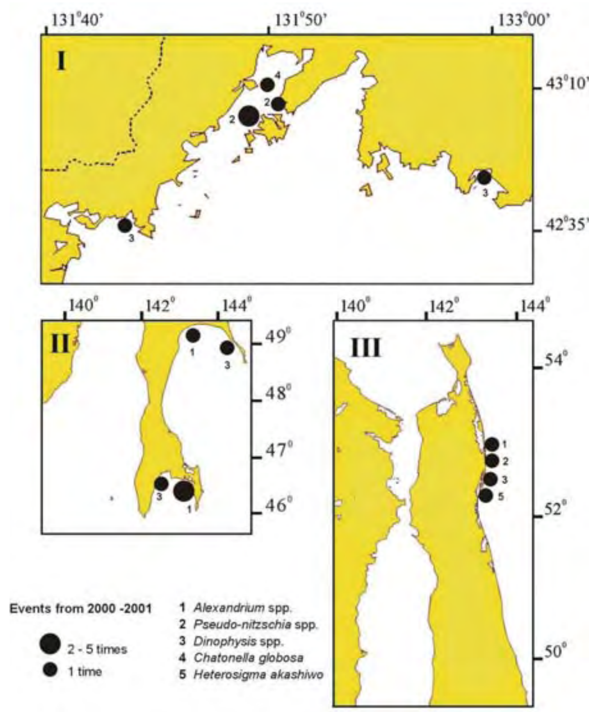
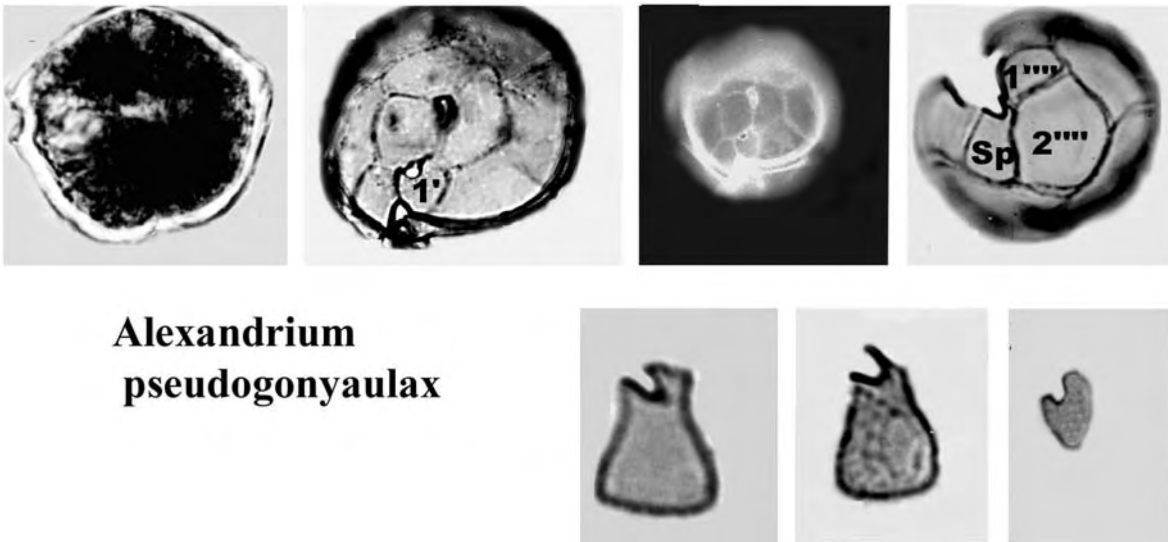


Fig. 22 HAB events in the Far Eastern Seas of Russia in 2000-2001.

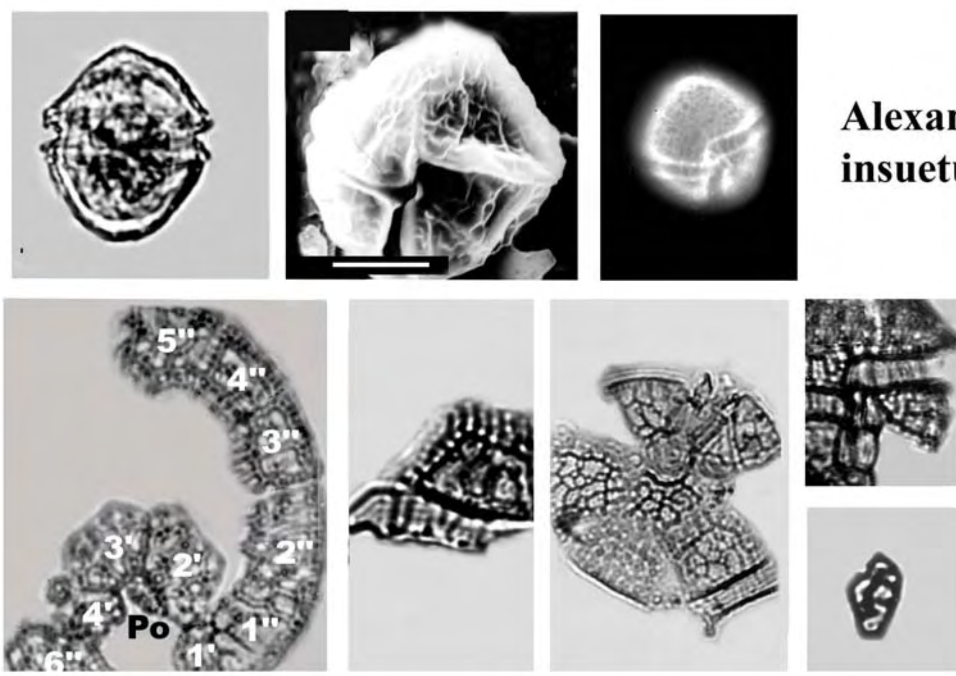
Table 14a Species found on the eastern coast of Russia in 2000-2001, and known to be harmful elsewhere.

1.	Dinoflagellate species found in Russian waters and known to produce saxitoxins that causes paralytic shellfish poisoning (PSP)	*Alexandrium acatenella* *Alexandrium catenella* *Alexandrium tamarense*
2.	Dinoflagellate species that known to produce okadaic acid that causes diarrhetic shellfish poisoning (DSP)	*Dinophysis auminata* *Dinophysis acuta* *Dinophysis fortii* *Dinophysis norvegica*
3.	Diatoms that known to produce domoic acid that causes domoic acid poisoning (ASP)	*Pseudo-nitzschia pungens* *Pseudo-nitzschia multistriata*
4.	Species that known to be harmful and associated with fish kills	*Raphidophyte* *Heterosigma akashiwo* *Chattonella globosa*
5.	Species that cause water discolorations and may kill invertebrates	*Diatoms* *Thalassiosira mala*

Alexandrium spp.from Pacific coast of Russia



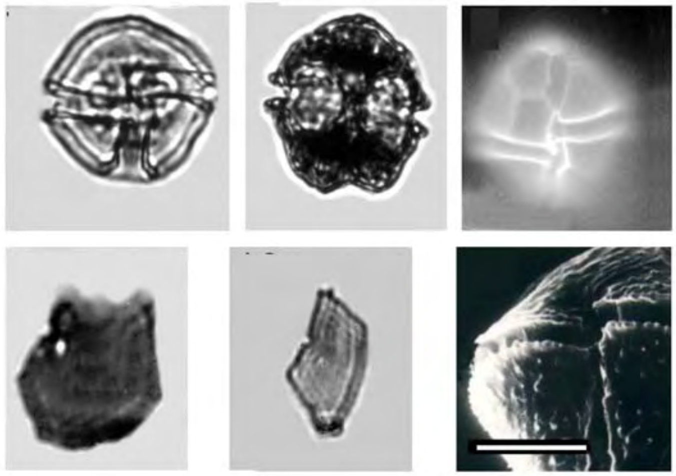
Alexandrium pseudogonyaulax



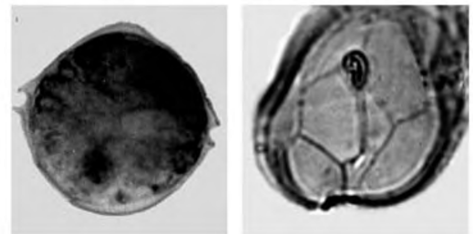
Alexandrium insuetum

Photos by M.S. Selina

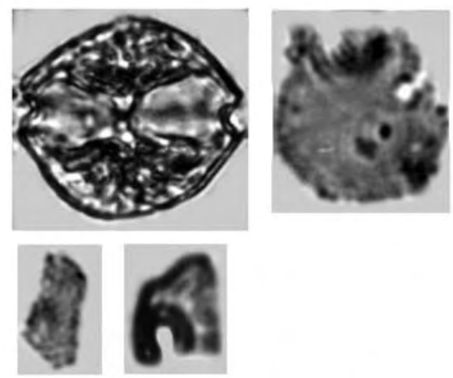
Alexandrium spp. from Pacific coast of Russia



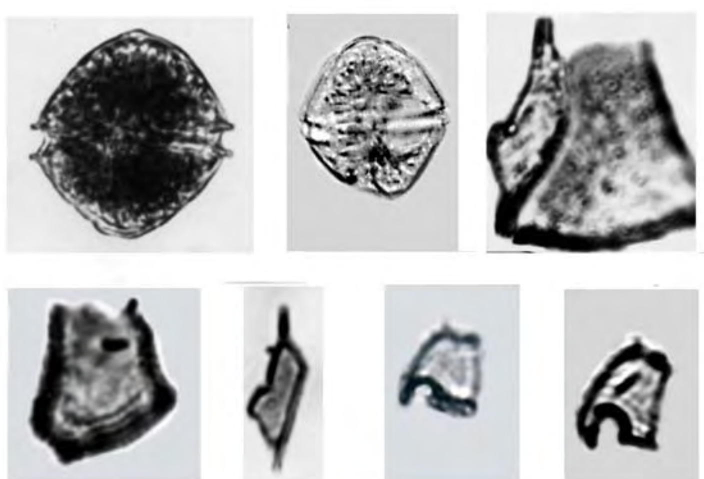
Alexandrium tamarense



Alexandrium ostenfeldi



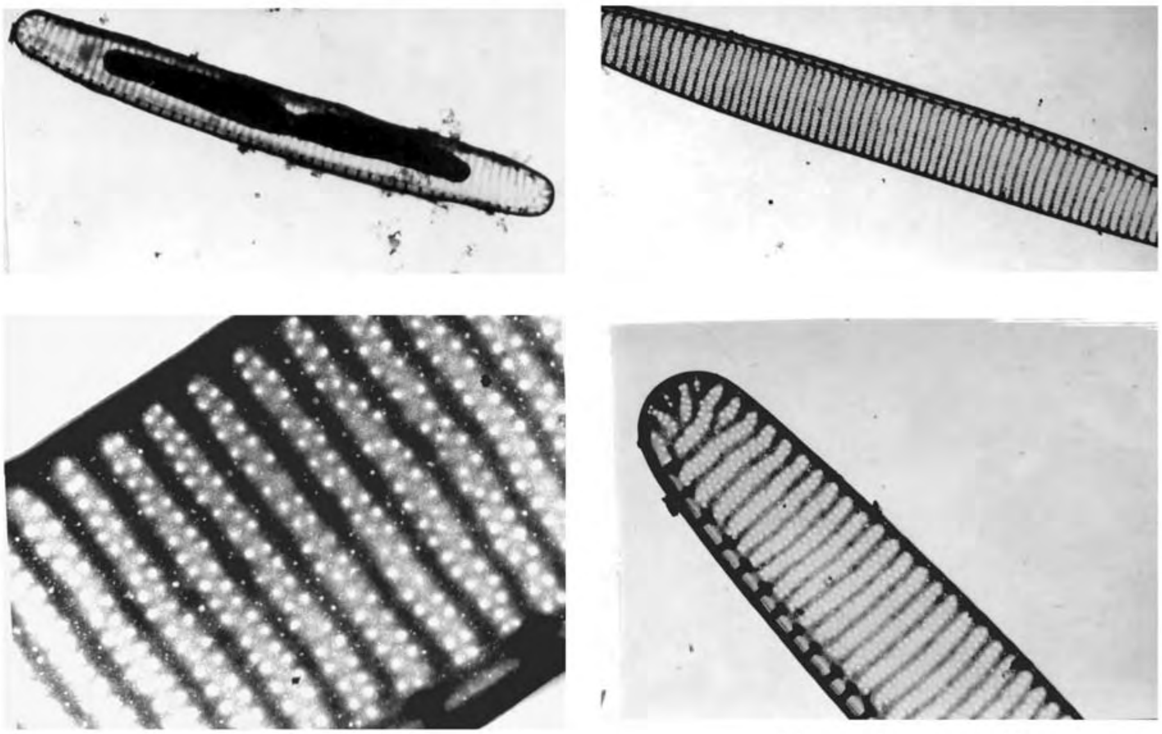
Alexandrium catenella



Alexandrium acatenella

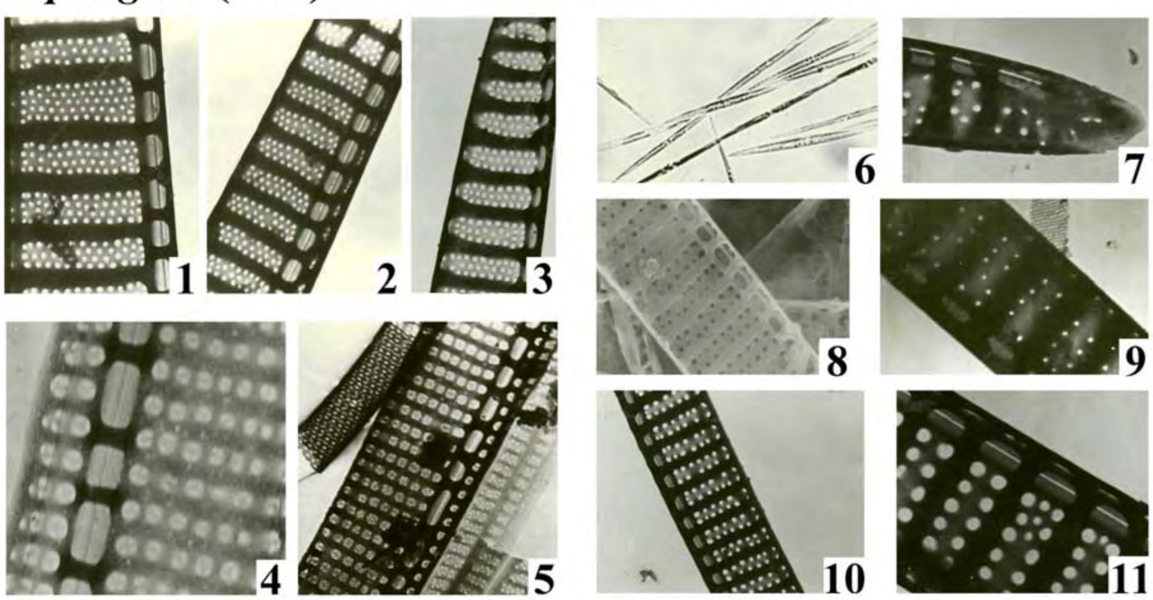
Photos by M.S. Selina

Pseudo-nitzschia americana from Pacific coast of Russia (the Sea of Japan, East coast of Sakhalin Island)



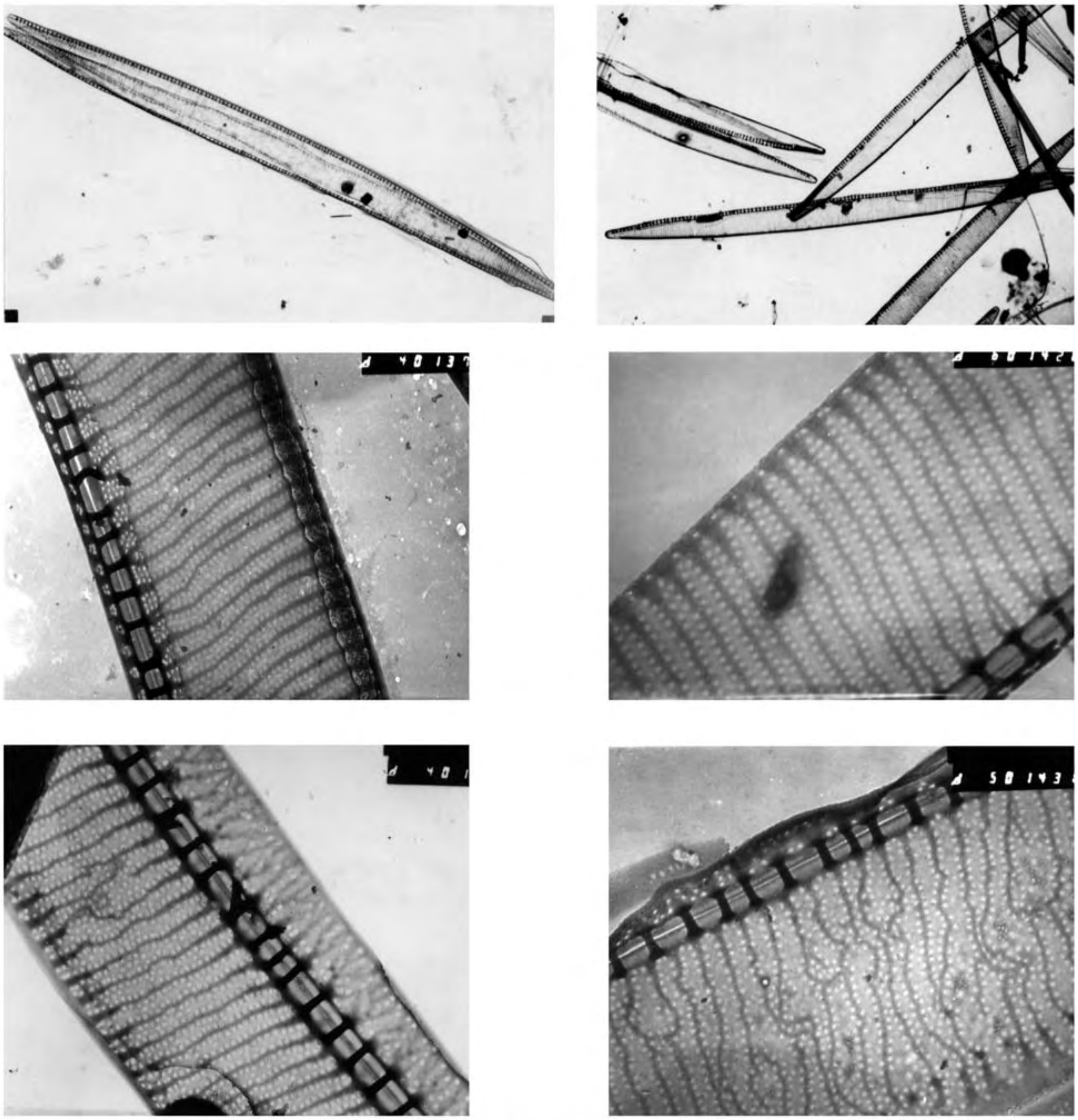
Photos by O.G. Shevchenko

Pseudo-nitzschia multiseries (1-3), *P. pseudodelicatissima* (4-5), *P. pungens* (6-11) from Pacific coast of Russia



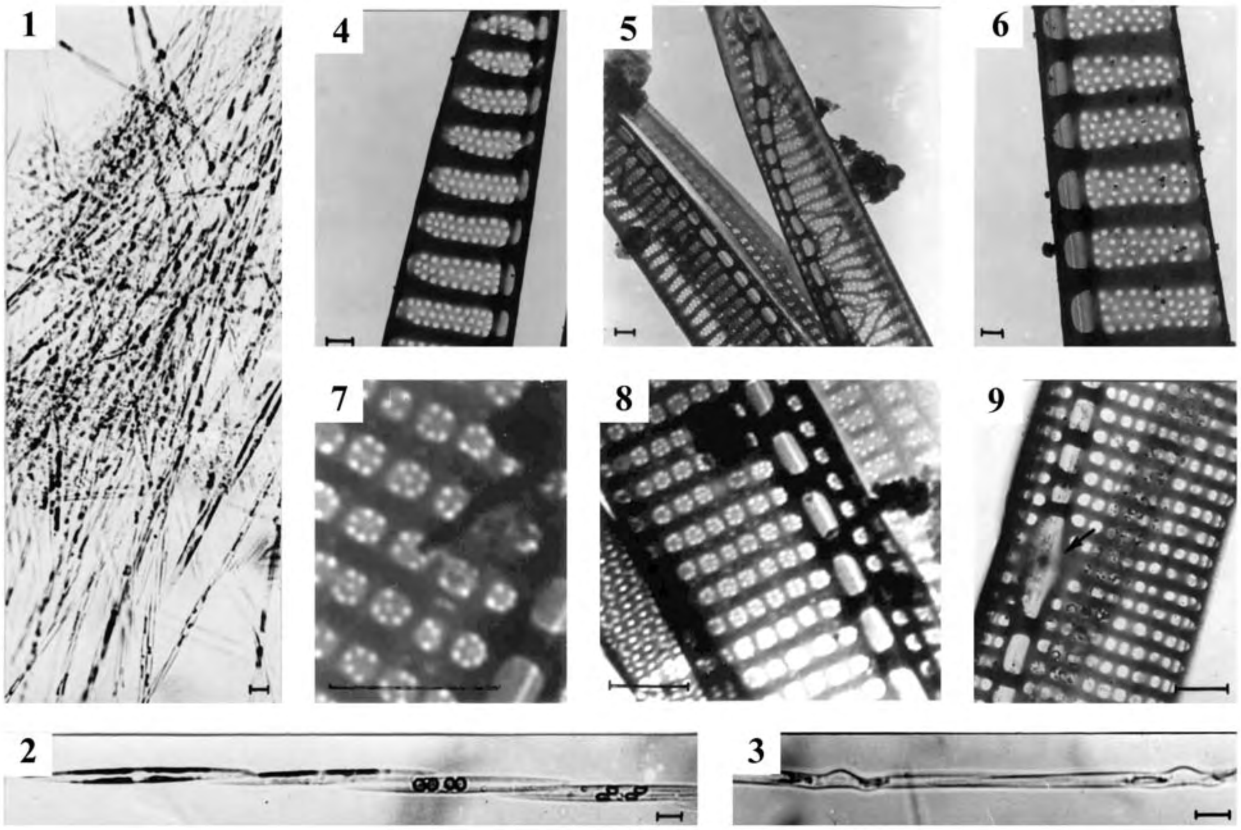
Photos by T.Yu. Orlova and I.V. Stonik

Pseudo-nitzschia multistriata from Pacific coast of Russia (the Sea of Japan)



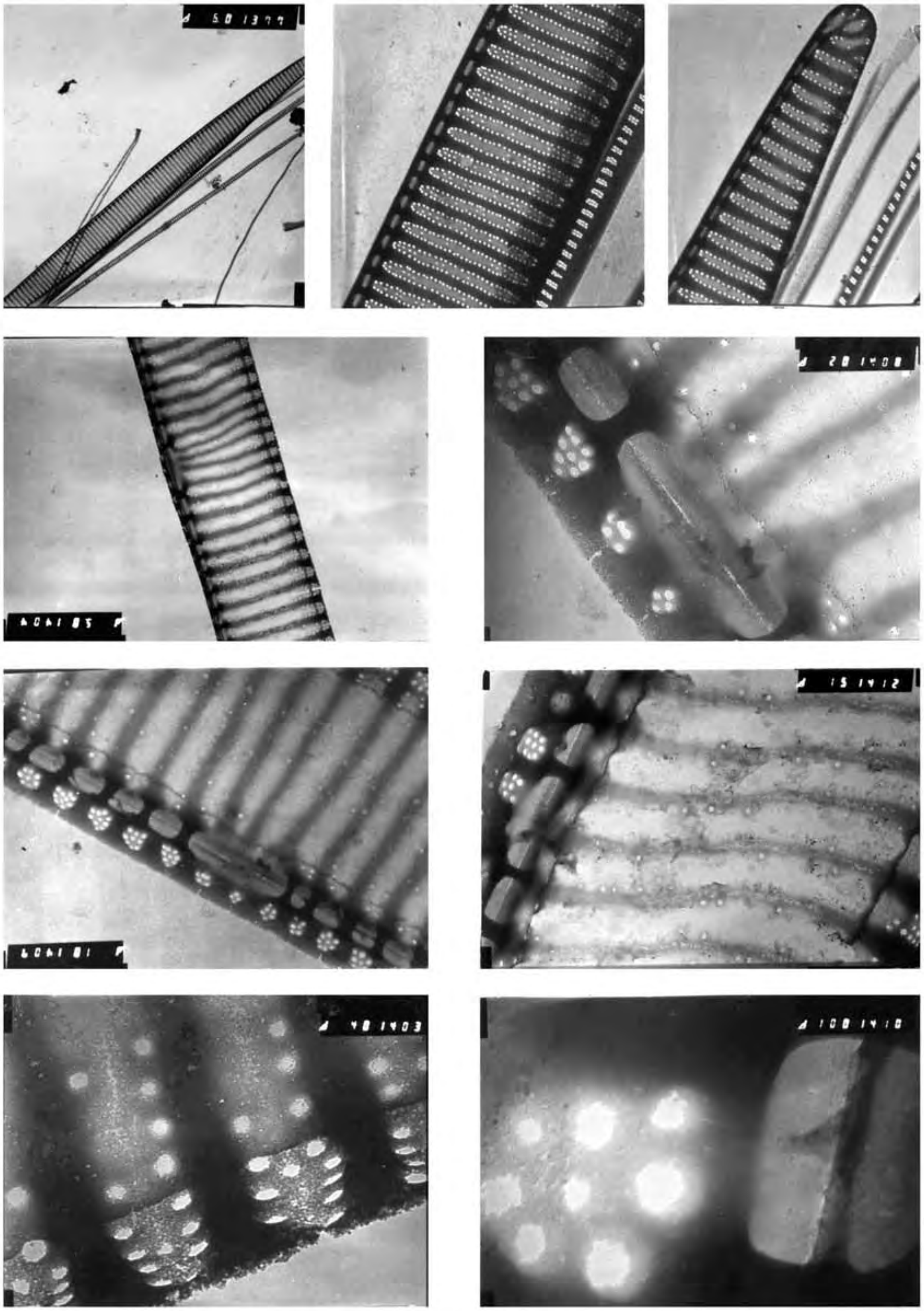
Photos by I.V. Stonik and O.G. Shevchenko

***Pseudo-nitzschia pungens* (1-5), *P. multiseries* (6), *P. pseudodelicatissima* (7-9) from Pacific coast of Russia**



Photos by T.Yu. Orlova and I.V. Stonik

Pseudo-nitzschia sp. from Pacific coast of Russia (Bering Sea)



Photos by I.V. Stonik and O.G. Shevchenko

Table 14b Major HAB events in each sector of the Far Eastern Seas of Russia.

Species	Sector number	Location	Latitude	Longitude	Date	Concentration (cells l^{-1})	Comments
Pseudo-nitzschia pungens/multiseries	I	Amursky Bay	43^{0}15' N	131^{0}50' E	June, 1992	$16*10^{6}$	red tide
Pseudo-nitzschia pungens/multiseries	I	Amursky Bay	43^{0}15' N	131^{0}50' E	June, 1993	$1*10^{6}$	
Pseudo-nitzschia pungens/multiseries	I	Amursky Bay	43^{0}11' N	131^{0}54' E	September, 1997	0,6	
Pseudo-nitzschia pungens	I	Golden Horn Bay	43^{0}06'05" N	131^{0}52'48" E	August, 2000	$1.5*10^{6}$	
Pseudo-nitzschia pungens	I	Rinda Bay	43^{0}01'40" N	131^{0}47'50" E	May, 2000	$1*10^{6}$	
Pseudo-nitzschia pungens	I	Rinda Bay	43^{0}01'40" N	131^{0}47'50" E	August, 2000	$1.4*10^{6}$	
Pseudo-nitzschia pseudodelicatissima	I	Amursky Bay	43^{0}11' N	131^{0}54' E	November, 1997	$2.7*10^{6}$	
Dinophysis acuminata	I	Amursky Bay	43^{0}15' N	131^{0}50' E	July, 1992	$8*10^{4}$	
Dinophysis acuminata	I	Amursky Bay	43^{0}11' N	131^{0}54' E	August, 1997	$15*10^{3}$	
Dinophysis acuminata	I	Amursky Bay	43^{0}11' N	131^{0}54' E	June, 1998	$5*10^{3}$	
Dinophysis acuminata	I	Amursky Bay	43^{0}11' N	131^{0}54' E	July, 1998	$2*10^{3}$	
Dinophysis acuminata	I	Rinda Bay	43^{0}01'40" N	131^{0}47'50" E	August, 2000	$1.1*10^{4}$	
Dinophysis acuta	I	Amursky Bay	43^{0}11' N	131^{0}54' E	June, 1998	$2*10^{2}$	
Dinophysis fortii	I	Vostok Bay	42^{0}50' N	132^{0}46' E	August, 2000	$3*10^{3}$	
Dinophysis rotundata	I	Amursky Bay	43^{0}11' N	131^{0}54' E	July, 1998	$3*10^{1}$	
Alexandrium acatenella	I	Vostok Bay	42^{0}50' N	132^{0}46' E	August, 2001	$2*10^{2}$	
Alexandrium tamarense	I	Vostok Bay	42^{0}50' N	132^{0}46' E	August, 2001	$3*10^{2}$	
Alexandrium tamarense	I	Amursky Bay	43^{0}15' N	131^{0}50' E	September, October, 1990	$1*10^{6}$	

Species	Sector number	Location	Latitude	Longitude	Date	Concentration (cells l^{-1})	Comments
Alexandrium pseudogonyaulax	I	Amursky Bay	$43^0$15' N	$131^0$50' E	July, 1999	$3*10^4$	
Gymnodinium breve	I	Amursky Bay	$43^0$15' N	$131^0$50' E	October, 1993	$3,5*10^3$	
Gymnodinium mikimotoi	I	Amursky Bay	$43^0$15' N	$131^0$50' E	September, October, 1990	$1*10^6$	
Noctiluca scintillans	I	Peter the Great Bay	$132^0$10' N	$43^0$07' E	April, 1980	$1*10^5$	massive red tide
Noctiluca scintillans	I	Peter the Great Bay	$132^0$10' N	$43^0$07' E	May, 1980	$1*10^6$	massive red tide
Noctiluca scintillans	I	Peter the Great Bay	$132^0$10' N	$43^0$07' E	June, 1992	$1*10^5$	massive red tide
Noctiluca scintillans	I	Peter the Great Bay	$132^0$10' N	$43^0$07' E	June, 1993	$3*10^5$	massive red tide
Chattonella globosa	I	Amursky Bay	$43^0$15' N	$131^0$50' E	November, 1993	$9*10^5$	
Chattonella globosa	I	Amursky Bay	$43^0$15' N	$131^0$50' E	August, 2000	$5*10^5$	
Prorocentrum minimum	I	Amursky Bay	$43^0$15' N	$131^0$50' E	July, 1991	$2*10^6$	
Prorocentrum minimum	I	Amursky Bay	$43^0$15' N	$131^0$50' E	July, 1991	$3*10^6$	
Prorocentrum minimum	I	Amursky Bay	$43^0$15' N	$131^0$50' E	August, 1991	$8*10^6$	
Prorocentrum minimum	I	Amursky Bay	$43^0$15' N	$131^0$50' E	July, 1992	$1*10^6$	
Prorocentrum minimum	I	Amursky Bay	$43^0$11' N	$131^0$54' E	August, 1997	$10*10^3$	
Thalassiosira mala	III	coastal waters of Sakhalin Island	52^o 51' N	$143^0$22' E	September, 2000	$5*10^6$	
Pseudo-nitzschia pungens	III	coastal waters of Sakhalin Island	52^o 51' N	$143^0$22' E	August, 2000	$2.1*10^5$	
Dinophysis acuminata	III	coastal waters of Sakhalin Island	52^o 51' N	$143^0$22' E	August, 2000	$5*10^2$	
Dinophysis acuta	III	north-eastern coastal waters of Sakhalin Island	$51^0$25'689" N	143 47 395 E	August, 2000	$2*10^2$	

Species	Sector number	Location	Latitude	Longitude	Date	Concentration (cells l^{-1})	Comments
Dinophysis acuta	II	Aniva Bay	46^{0}12'817" N	143 36 073 E	August, 2000	$2*10^{2}$	
Dinophysis norvegica	II	Terpenie Bay	49^{0}221'678" N	144 25 516 E	August, 2000	$8*10^{2}$	
Alexandrium catenella	II	Terpenie Bay	49^{0}221'678" N	144 25 516 E	July, 2000	$1.5*10^{4}$	
Alexandrium pseudogonyaulax	II	Terpenie Bay	49^{0}221'678" N	144 25 516 E	July, 2000	$2*10^{2}$	
Alexandrium tamarense	II	Aniva Bay	46^{0}12'817" N	143 36 073 E	June, 2001	$3.5*10^{4}$	
Alexandrium acatenella	III	coastal waters of Sakhalin Island	51^{0}25'689" N	143 47 395 E	August, 2000	$2*10^{4}$	
Alexandrium tamarense	III	coastal waters of Sakhalin Island	51^{0}25'689" N	143 47 395 E	August, 2000	$4*10^{2}$	
Alexandrium acatenella	II	Aniva Bay			July, 2001	$5.2*10^{3}$	
Alexandrium tamarense	II	Aniva Bay	46^{0}12'817" N	143 36 073 E	August, 2000	$4*10^{4}$	
Alexandrium tamarense	II	Aniva Bay			July, 2001	$1.6*10^{4}$	
Heterosigma akashiwo	III	north-eastern coastal waters of Sakhalin Island	49^{0}25'239" N	144 47 537 E	August, 2000	$5*10^{6}$	

Table 14c Locations of PSP events in the Far Eastern Seas of Russia.

Toxin	Sector number	Location	Latitude	Longitude	Date obtained	Species/Clone	Culture collection	Comments
PSP	IV	Avachinskaya Bay	$53^0$00' N	$158^0$30' E	August, 1973			12 people were poisoned, 2 died
PSP	V	Kamchatka, Bering Sea	$60^0$13' N	$166^0$48' E	July, 20,1999	*Alexandrium tamarense*/ATR U6/1	Woods Hole Oceanographic Institution	
PSP	V	Tyulenye Ozero, Bering Sea	$60^0$21' N	$170^0$37' E	July, 21,1999	*Alexandrium tamarense*/ATR U5/1	Woods Hole Oceanographic Institution	
PSP	VI	Pavla Bay, Bering Sea	$61^0$07' N	$172^0$15' E	July, 22,1999	*Alexandrium tamarense*/ATR U10/1	Woods Hole Oceanographic Institution	
PSP	VII	Mys Konovak, Bering Sea	$64^0$38' N	$172^0$31' E	July, 26,1999	*Alexandrium tamarense*/ATR U9/1	Woods Hole Oceanographic Institution	

Bibliography of HABs events in the Far Eastern Seas of Russia

Balagurova N.K. 1988. Species Structure of Planktonic Phytocenosis during a Summer Red Tide in Avachinskaya Guba Inlet (Kamchatka). Tezisy docladov III Vsesoyuznoi konferentsii po morskoi biologii (Abstract of Paper, III All-Union Conf. on Marine Biology), Sevastopol, part 1, pp. 104-105 (in Russian).

Gail, G.I. 1936. The distribution of phytoplankton in the upper layer of coastal waters of the northwestern part of the Sea of Japan. Vestnik DVF Akademii nauk SSSR 18: 81 – 107 (in Russian).

Gail, G.I. 1950. Phytoplankton of the Sea of Japan [Opredelitel phitoplanktona Yaponskogo moray]. Izvestiya TINRO 33: 3 – 177 (in Russian).

Gail, M.M. 1963. Spring phytoplankton of Southeastern Tatar Strait. Izvestiya TINRO 49: 137 – 158 (in Russian).

Goncharov, I. 1857. Frigate Pallada. Moscow, Hydojestvennaya Literatura (1978) II: 508 pp. (in Russian).

Ilychev, V.I., Anikiev, V.V., Starodubtsev, E.G., Rodionov, N.M., Kulinich, N.M., and Shornikov, A.V. 1985. Observations on the distribution of the red tide in Peter the Great Bay (Sea of Japan). The Soviet Journal of Marine Biology 5: 6-9 (in Russian).

Konovalova, G.V. 1989. Morphology of Three Species of *Alexandrium* (Dinophyta) from Coastal Waters of East Kamchatka. Russian Journal of Botany [Botanicheskiy Zhurnal] 74(10): 1401-1409 (in Russian).

Konovalova, G.V. 1989. Phytoplankton Blooms and Red Tides in Far East Coastal Waters of the USSR. Red Tides, Proc. 1st Int. Symp., New York: Elsevier, pp. 97-100.

Konovalova, G.V. 1991. Morphology of *Alexandrium ostenfeldii* (Dinophyta) from Coastal Waters of East Kamchatka. Russian Journal of Botany [Botanicheskiy Zhurnal] 76(1): 79-82 (in Russian).

Konovalova, G.V. 1992. Red Tide in the Seas (Some Results of Studying the Problem). Algologiya 2(3): 18-25 (in Russian).

Konovalova, G.V. 1993. Harmful dinoflagellate blooms along the eastern coast of Kamchatka. Harmful Algae News. No. 4, p. 2.

Konovalova, G.V. 1993. Toxic and Potentially Toxic Dinoflagellates from the Far East Coastal Waters of Russia. Toxic Phytoplankton Blooms in the Sea. Amsterdam, Elsevier, pp. 275-279.

Konovalova, G.V. 1995. *Krasnye prilivy u vostochnoi Kamchatki (Atlas-spravochnik)* (Atlas-handbook on red tides along East Kamchatka). Petropavlovsk-Kamchatski: Kamchat, 24 pp (in Russian).

Konovalova, G.V. 1995. The dominant and potentially dangerous species of phytoflagellates in the coastal waters of east Kamchatka. *In* P. Lassus, G. Arzul, E. Erard, P. Gentien and Marcaillon (Eds.) Harmful marine algal blooms. Lavoisier, Paris, pp. 169-174.

Konovalova, G.V. 1998. Dinoflagellatae (Dinophyta) of the Far Eastern Seas of Russia and adjacent waters of the Pacific Ocean. Dalnauka, Vladivostok, pp. 300 (in Russian).

Konovalova, G.V. 1999. Red tides and Blooms of waters in the Far Eastern Seas of Russian and adjacent areas of the Pacific Ocean. Russian Journal of Marine Biology 25(4): 295-304.

Konovalova G.V., Orlova, T.Yu., and Pautova, L.A. 1987. Atlas of phytoplankton of the Sea of Japan. Leningrad, Nauka, 169 pp. (in Russian).

Konovalova, G.V., Orlova T., Selina, M.S., Stonik, I.V., Simakova, N.K. 1995. Events of ''Blooms'' of Dangerous Phytoplankton Species in Coastal Waters of the Far Eastern Seas of Russia. Abstract VII Intern. Conf. On Toxic Phytoplankton. July 12 - 16. Sendai. Japan, p. 31.

Konovalova, G.V. and Selina, M.S. 1986. First report of a red tide caused by the infusorian *Mesodinium rubrum* in the Sea of Japan. The Soviet Journal of Marine Biology, 3: 62-63.

Koon, M.S. 1949. Nutrition of Pacific herring in the northern part of Tatar Strait. Izvestiya TINRO 29: 107 - 138 (in Russian).

Kurenkov, I.I. 1973. Red Tide in Avachinskaya Bay in 1973. Report No. 6294818, Archives of Kamchatka division of the Pacific research institute for fisheries and oceanography. Petropavlovsk-Kamchatski (in Russian).

Kurenkov, I.I. 1974. Red Tide in Avachinskaya Bay. Rybnoe Khozyaistvo 4, pp. 20-21 (in Russian).

Kusmorskaya, A.P. 1947. Observations on the death of Copepoda caused by massive concentrations of diatoms. Dokladi AN SSSR 7 (3), pp. 293 – 294 (in Russian).

Lebedev, S.P. 1968. Caution: Red Tides. Rybnoe Khozyaistvo 5, pp. 19-20 (in Russian).

Meshcheryakova, I.M. 1960. Seasonal changes in plankton in open waters of the Sea of Japan. Izvestiya TINRO 46: 95 - 144 (in Russian).

Morozova, T.V., Orlova T., and Selina, M.S. 2001. Phytoplankton in the Area of Mollusk Farm in the Minonosok Bay of the Sea of Japan. Russian Journal of Marine Biology, (in press).

Orlova, T.Y., Konovalova, G.V., and Oshurkov, V.V. 1985. Red tide Caused by the Bloom of Infusorian *Mesodinium rubrum* in Avacha Bay (Kamchatka). The Soviet Journal of Marine Biology l. 11(6): 342-348.

Orlova, T.Y., and Selina, M.S. 1993. Morphology and Ecology of the Bloom-forming Planktonic Diatom *Chaetoceros salsugineus* Takano in the Sea of Japan. Botanica Marina 36: 123-130.

Orlova, T.Y., Zhukova, G.V., and Stonik, I.V. 1996. Bloom-forming diatom *Pseudo-nitzschia pungens* in Amurskii Bay (the Sea of Japan): Morphology, Ecology and Biochemistry. *In* Yasumoto, T. *et al.* (Eds.) Harmful and Toxic Algal Blooms. Intergovernmental Oceanographic Commission of UNESCO, pp. 147-151.

Orlova, T.Y., Selina, M.S. and Stonik, I.V. 1998. Distribution of potentially toxic and harmful microalgae in Peter the Great Bay, the Sea of Japan, Russia. *In* B. Reguera *et al.* (Eds.) Harmful Algae. IOC of UNESCO Publishers, pp. 86-88.

Orlova, T.Y., Selina, M.S. and Stonik, I.V. 2000. Phytoplankton of the Tumannaya River basin and adjacent waters of the Peter the Great Bay. *In* Kasyanov B.L. (Ed.) Ecological State and Biota of the South Western part of the Peter the Great Bay and Tumannaya River basin. Vladivostok, Dalnauka, pp. 129-146.

Orlova, T.Y., and Stonik, I.V. 2001. The species of the Genus *Pseudo-nitzschia* (Bacillariophyta) found in the Far Eastern Seas of Russia. Russian Journal of Botany [Botanicheskiy Zhurnal] 86 (4): 47-52 (in Russian).

Ostroumov, A. 1924. *Noctiluca miliaris* in Simbiosis Mit Grunen Algen. Zool / Anzeiger, Bd 58.

Propp, L.N., Konovalova G.V., Kuznetsov L.L., Dobryakov, Y.I. 1982. Red Tide in Peter the Great Bay (Sea of Japan): hydrochemical, hydrobiological and physiological studies. The Soviet Journal of Marine Biology 5: 9-14 (in Russian).

Propp M.V., Propp L.N., and Tarasov, V.G. 1989. Hydrochemical conditions and daily dynamics of oxygen, chlorophyll "a" and nutrient in Kraternaya Bight. The Soviet Journal of Marine Biology 3, pp. 36-44 (in Russian).

Selina, M.S. 1993. Distribution of potentially toxic dinoflagellates *Dinophysis* (Dinophyta) in Vostok Bay of the Sea of Japan. Russian Journal of Marine Biology 5-6: 23-29.

Selina, M.S. 1993. *Raphydophyta* of the Peter the Great Bay (the Sea of Japan). Algologiya 3 (2): 60-66 (in Russian).

Selina, M.S., Simakova, N.K., and Yasnetskaya, L.V. 1992. *Gymnodidium nagasakiense* Takayama et Adachi (Dinophyta). Algologiya 2 (1) pp. 51-55 (in Russian).

Selina, M.S., Stonik I.V., and Bondartsova, T.V. 1999. Species composition and seasonal dynamics of dinoflagelates in Peter the Great Bay, Sea of Japan. Russian Journal of Marine Biology 25 (2): 189-190.

Selina, M.S., and Konovalova, G.V. 2001. Morphology of *Alexandrium pseudogonyaulax* (Dinophyta) from the Far Eastern seas of Russia. Russian Journal of Botany [Botanicheskiy Zhurnal] 86 (10): 22-25 (in Russian).

Semina, G.I. 1959. Distribution of phytoplankton in Kronotsky Bay. Trudi Inst. Okeanol. Akad. Nauk SSSR 36: 73-91 (in Russian).

Shumilin, E.N., Kassatkina, A.P., Orlova, T.Y. and Goryachev, N.A. 1994. Trace metals in seston during red tide in estuarine zone of Razdolnaya river. Russian Journal of Marine Biology 20 (4): 286-290.

Simakova, N.V., Orlova, T.Y., and Selina, M.S. 1990. Red tide caused by raphidophytes *Chattonella* sp. in Amurskii Bay, the Sea of Japan. Russian Journal of Marine Biology 16 (5): 77-79.

Stonik, I.V. 1994. Potentially Toxic Dinophyte *Prorocentrum minimum* in Amursky Bay, Sea of Japan. Russian Journal of Marine Biology 20 (6): 419-425.

Stonik, I. V., Orlova, T.Y. and Schevchenko, O. G. 2001. Species of the Genus *Pseudo-nitzschia* H. Perag. (Bacillariophyta) from the Peter the Great Bay, the Sea of Japan. Russian Journal of Marine Biology 27 (4) (in press).

Tagatz, V. 1933. Some data on zooplankton in Patrokl Bay (Peter the Great Bay) in summer 1926. Issledovaniya morei SSSR 19: 59 – 71 (in Russian).

Vyshkvartsev, D.I., Taratuchin, A. F. and Kharlamenko, V. I. 1982. The 1982 red tide in Peter the Great Bay (Sea of Japan). The Soviet Journal of Marine Biology 5: 18 – 20 (in Russian).

Zhirmunsky, A.V., and Konovalova G.V. 1982. Red tide in Peter the Great Bay, Sea of Japan. The Soviet Journal of Marine Biology 5: 3-6 (in Russian).

Zhukova N.V., Orlova, T.Y. and Aizdaicher, N.A. 1998. Fatty Acid Composition as an Indicator of Physiological Status of the Diatom *Pseudonitzschia pungens* in Natural Assemblages and in Culture. Russian Journal of Marine Biology 24 (1): 42-47.

Section B

Eastern North Pacific

Harmful algal blooms in western Canadian coastal waters

F.J.R. "Max" Taylor and Paul J. Harrison
University of British Columbia, 6270 University Boulevard, Vancouver, B.C., Canada V6T 1Z4.
E-mail: maxt@unixg.ubc.ca, pharrison@eos.ubc.ca

Introduction

British Columbia (B.C.), the Pacific province of Canada, has one of the longest documented histories of the severest form of harmful algal blooms, paralytic shellfish poisoning (PSP), along its entire 27,000 km coastline. The first documented case was in 1793 when four of Capt. George Vancouver's survey crew became ill after a meal of mussels while charting the central coast (Mussel Inlet, originally named Mussel Canal, a side-arm of Mathieson Channel; see Fig. 23). The location where they had the toxic breakfast of mussels was named Poison Cove by Vancouver. One of them died five and a half hours later and the location of his burial was named Carter's Bay. Their symptoms, described in detail by Vancouver (1798, quoted by Quayle 1969), are unmistakably characteristic of PSP. Earlier illnesses from the consumption of mussels in Europe differ in detail from classic PSP, most notably in the struggle to breath before the cessation of respiration. In PSP breathing stops gradually without struggle (Taylor 1992). In 1799, only a few years after the Capt. Vancouver incident, a major poisoning episode with many fatalities involving Aleut Indians working with Alexander Baranoff in the Russian-American sea-otter fur trade occurred in nearby southern Alaska (detailed by Trainer, this volume).

Ever since monitoring of shellfish for the presence of toxins began in 1942, following a severe outbreak with fatalities in B.C. and adjacent Washington State, PSP has been recorded primarily in filter-feeding shellfish on the coast (Quayle 1969). These include mussels, various species of clams, oysters, geoducks and scallops (Anderson 1960; Quayle 1969). PSP toxins and domoic acid have been found in the guts of Dungeness crabs (Wekell *et al.* 1994).

Since 1965, when one of the authors began to focus on HABs on the B.C. coast (Prakash and Taylor 1965), most other forms of HABs, or the species known to produce them (Taylor *et al.* 1994), have been recorded from B.C., including domoic acid poisoning (also known as amnesic shellfish poisoning or APS) and fish kills. Further summaries have been provided by Taylor (1994) and Taylor and Horner (1994), the latter limited to the Strait of Georgia and its tributary inlets. The present report provides a summary of current knowledge of HABs in western Canada.

Shellfish poisoning

This is the potentially fatal poisoning of humans by the consumption of shellfish that have accumulated toxins from their phytoplankton diet. It exists in several forms, some of which are known from British Columbia.

Paralytic shellfish poisoning (PSP)

This phenomenon, caused by the concentration of saxitoxin and its derivatives by shellfish consumed by humans, is severe and chronic on the B.C. coast. Since monitoring began in the late 1940s, there has not been a year in which toxicity has not occurred and virtually everywhere on the coast has been toxic at one time or another. Some areas are toxic every year. The worst single fatality episode recorded in B.C. was in May 1942, in which three native Indians died in Ucluelet and Bamfield, on either side of Barkley Sound on the west coast of Vancouver Island, and three near Port Angeles close by in Washington State (details are provided in an appendix by Quayle 1969). Since records were first officially kept (1942) and a monitoring program established, there has not been a single year in which shellfish did not become toxic, the years differing only in the extent and duration of the closures (a complete summary of data from 1942-1965 was provided by Quayle and Bernard 1966). Further fatalities occurred in 1965 (Theodosia Inlet; details in Prakash and Taylor 1965 and Quayle 1969) and in 1980 at Health Harbour on Gilford Island (southern Queen

Charlotte Sound). Illnesses and near-fatalities are common (Fig. 23).

Although it did not result in fatalities, there was a particularly severe incident in the Comox area on eastern Vancouver Island in 1957, with 61 human illnesses and seven domestic cat fatalities. Although mussels and clams were involved, the majority became ill after eating oysters. At this time, toxin levels reaching 19,840 Mouse Units (MU, roughly equivalent to 3200 µg per 100g) were measured (for details see Quayle 1969). A severe, potentially fatal incident, summarized by Taylor (1992), occurred in Kingcome Inlet (on the mainland not far from Gilford Island) in 1992, when two individuals were poisoned sufficiently to cause rapid death (one stopped breathing twenty minutes after consuming less than one butter clam). Although there is no antidote to saxitoxin they were both saved by continuous artificial respiration. Recovery was complete after several days on respirators in hospital. This is the first known case in which the importance of artificial respiration in saving severely poisoned individuals was demonstrated.

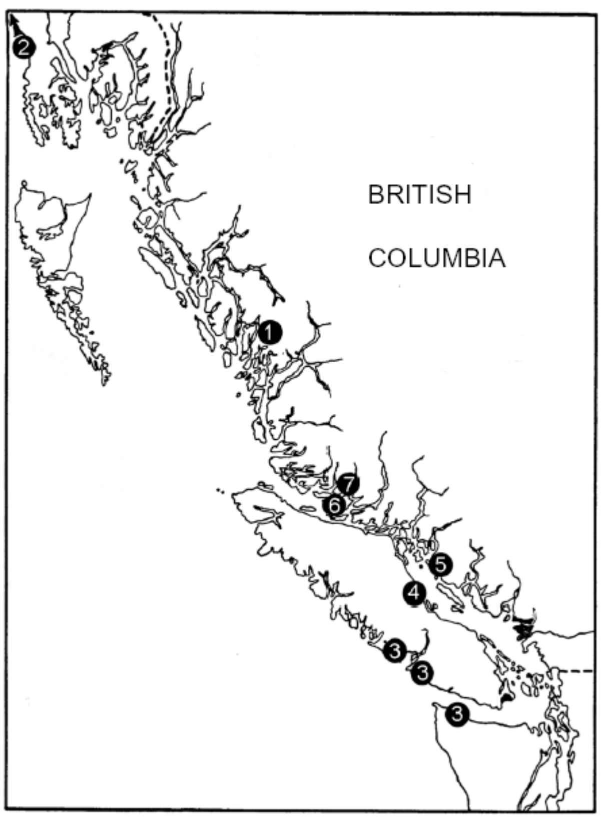


Fig. 23 Fatalities and severe incidents of paralytic shellfish poisoning (PSP) ion the B.C. coast and adjacent waters (see text and U.S. report for details). 1. Vancouver, 1793. 2. Baranoff, 1799 (Peril Strait, near Sitka, Alaska). 3. The 1942 outbreak. 4. Comox, 1957. 5. Theodosia Arm, Malaspina Inlet, 1965. 6. Health Harbour, Gilford Island, 1980. 7. Kingcome Inlet, 1994.

An interesting feature of PSP occurrence on the B.C. coast is that it frequently occurs earliest in this part of the coast (Fisheries statistical areas 12 and 13), as early as April or May, whereas it usually appears in June in the Strait of Georgia and later off the west coast of Vancouver Island. Most recently (1999-2001) the closures in southern B.C. were extensive and persisted in some areas of Vancouver Island until November (Canadian Food Inspection Agency reports). Because butter clams *(Saxidomus giganteus)* retain toxin in their black siphon tips potentially for more than a year (Quayle 1969), and because the current monitoring program relies on mussel toxicity, butter clams are now permanently prohibited from collection along the entire coast. Other shellfish that become potentially fatal to humans include mussels, other clams, scallops, oysters, moonsnails and geoducks. The guts of crustaceans such as barnacles, Dungeness crabs and sand crabs *(Emerita analoga)* have been found to contain PSP, as well as ASP (see below).

Schallié (2001) has discussed the philosophy, nature and limitations of the current B.C. shellfish monitoring program. The locations of monitoring sites for PSP toxins in shellfish (during 1999) are shown in Figure 24. The north coast can be subject to prolonged toxicity but is logistically very difficult to monitor effectively and has been permanently closed since 1964 to the collection of bivalves except at a few monitoring sites (see Purkis 2001; Purkis in Martin 2002). Some data from the north coast suggests that it differs from the south in that high levels of toxin can persist in winter (Gaines end Taylor 1985). Anecdotal information from local inhabitants (Taylor, unpubl.) suggests otherwise, with avoidance of shellfish consumption confined to the summer months.

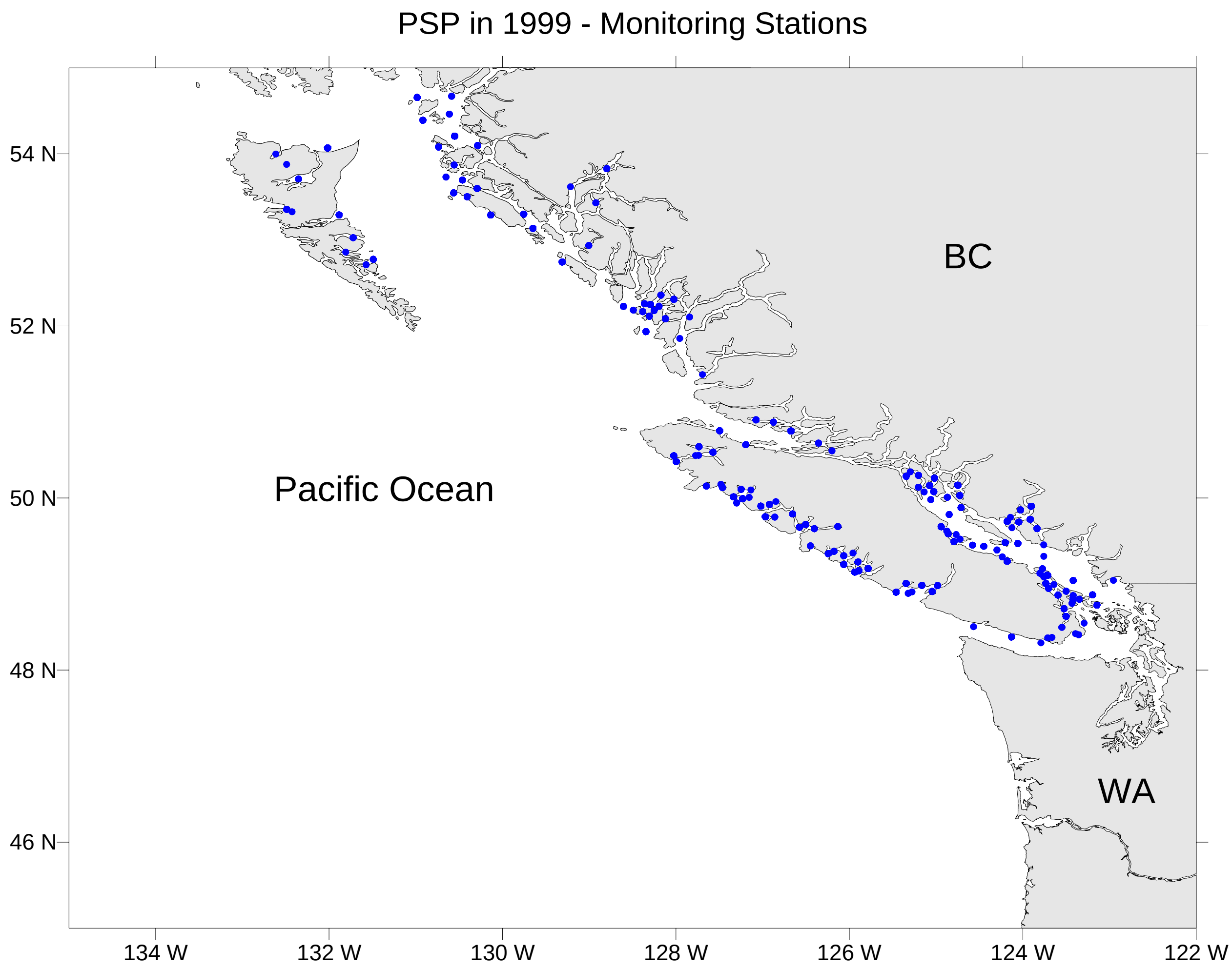


Fig. 24 Shellfish testing sites sampled for PSP toxins in 1999 (Canadian Food Inspection Agency, Shellfish Inspection).

The link to species of the dinoflagellate, genus *Alexandrium* (formerly attributed to the genera *Gonyaulax* and *Protogonyaulax;* see illustrations of some of the species elsewhere in this report*)* in British Columbia, was made unequivocally by Prakash and Taylor (1966): the Theodosia Inlet episode was the first recorded instance anywhere in which human fatality was coincident, not only with toxic shellfish, but also with a bloom of toxic *Alexandrium (A. acatenella).*

Usually when poisoning occurs the bloom has already passed. A. *catenella* also occurs in B.C., where it is the chief source of PSP off the west coast and eastern Vancouver Island. In more estuarine waters, such as the east side of the Strait of Georgia, *A. tamarense* is the dominant taxon (Taylor 1984, see Figure 25). A. *minutum,* also known to be toxic, is present in English Bay near Vancouver although a bloom of it has not been recorded so far (Taylor, unpubl.), as well as several non-toxic species of *Alexandrium,* such as *A. pseudogoniaulax* and *A. hiranoi. A. ostenfeldii* is present in English Bay, Vancouver (Haigh end Taylor, unpubl.), but not in bloom quantities. Canadian east coast populations of the latter have been shown to produce spirolides causing rapid death in mice, but spirolides have not been demonstrated in B.C. shellfish.

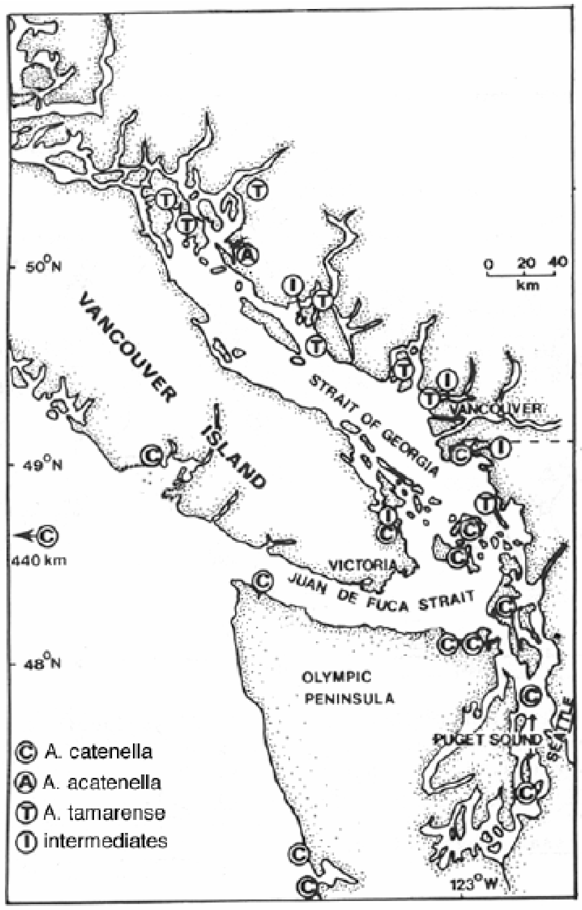


Fig. 25 Distribution of three toxic species of *Alexandrium* and intermediate forms in the Strait of Georgia and adjacent Washington State waters (slightly modified from Taylor 1984).

Ecology of PSP species in B.C.

Alexandrium blooms have been observed repeatedly in several studies in B.C. waters although there has not been a large-scale effort focused specifically on their outbreaks. In English Bay, multi-year sampling at Jericho Pier (Haigh and Taylor 1993) has shown that blooms first appear subsurface (1-3 m) in May or June, coincident with surface *Heterosigma* blooms, and persist throughout the summer months.

The blooms are initiated from benthic cysts, as is well known elsewhere, but studies have shown that there is no simple spatial correlation with cyst density in sediments. In B.C., blooms seem to originate in shallow, nearshore localities and spread into adjacent, larger bodies of water, *e.g.*, in Barkley Sound where cells are first seen in the inner northern corner (Taylor *et al.* 1994). In Barkley Sound, cells appear at depth sooner than indicated by intertidal toxicity values, with the blooms rising nearer to the surface as the season progresses.

Although PSP is present every year, there are clear oscillations in intensity (Fig. 26). There is a problem comparing years with widespread, medium-level toxicity, to years with isolated intense toxicity, and Chiang (1985) created a "PSP activity scale" formula in an attempt to make these comparisons. Using a simpler method, Gaines and Taylor (1985) found a cyclical periodicity that seemed to be roughly five to seven years. Often these years have been El Niño years (Erickson end Nishitani 1985) but the recent high toxicity around Vancouver Island, reaching more than 9000 µg per 100 g of shellfish in Barkley Sound, in October 2000 (K. Schallie, pers. comm.), was during an inter-year. Prolonged calm, sunny weather late in the season may have contributed to prolongation of *Alexandrium* blooms past the summer.

There appears to be no link to pollution (Taylor and Horner 1994), because *Alexandrium* species usually occurring subsurface during the growing season (Taylor and Haigh 1994). They are thus able to take nutrients from below. PSP is worst in many of the least inhabited parts of the coast. There is no positive correlation of PSP with aquaculture activities in B.C. judging by a detailed, multiyear study in Sechelt Inlet (Taylor *et al.* 1994). Blooms are not apparent in surface waters, at least in early stages of bloom development. They often occur in dense layers close to the nutricline. In Barkley Sound, Taylor and Haigh (1994) observed that *A. catenella* was present at depth long before toxicity was recorded in intertidal shellfish.

An interesting anomaly in the PSP data is the unusually early appearance of toxicity in the inlets and around the islands at the southern end of Queen Charlotte Strait, extending through to the northern Strait of Georgia. This is also where several of the fatalities or serious illnesses have occurred, *e.g.*, Gilford Island, Kingcome Inlet, Theodosia Inlet (see Fig. 23).

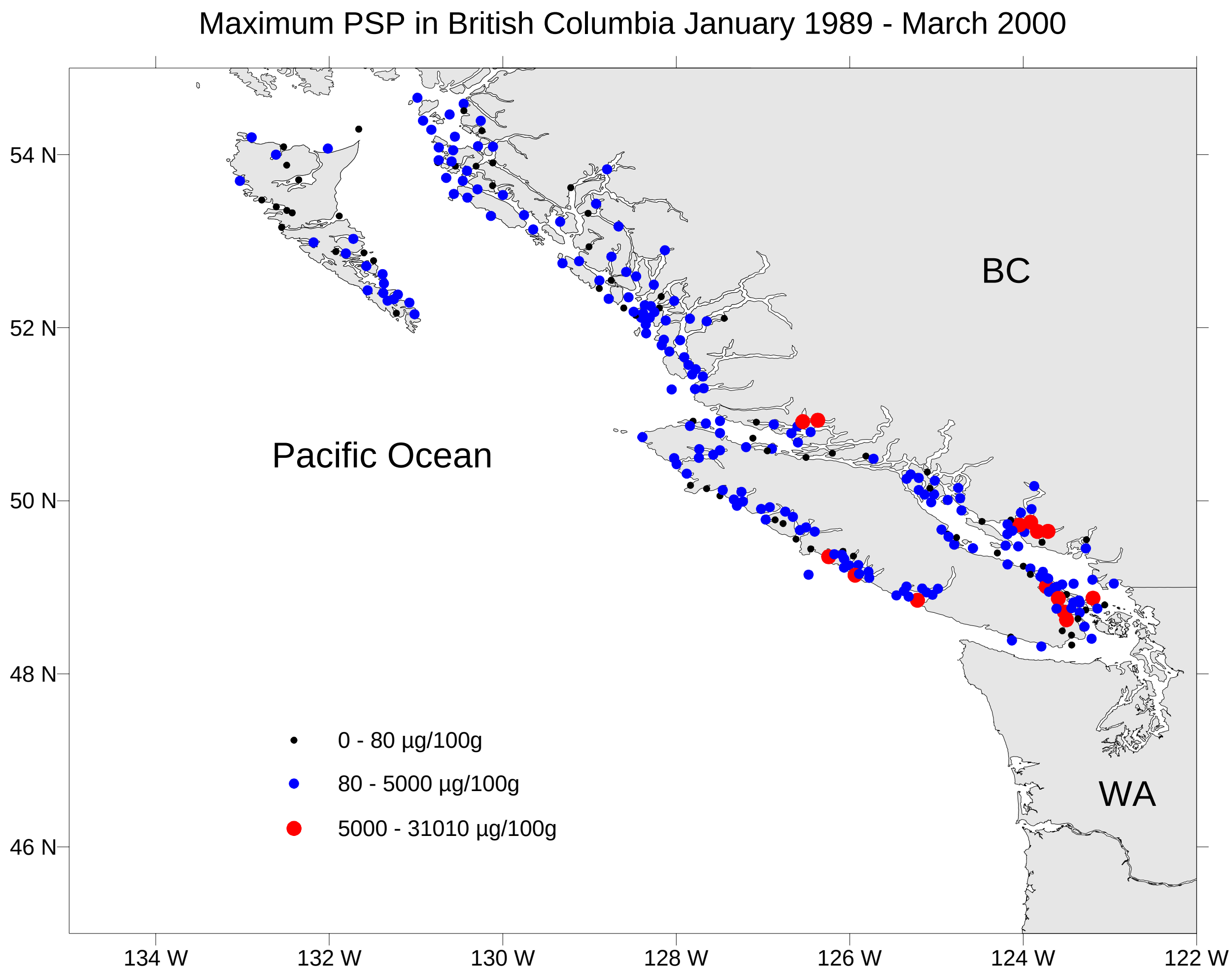


Fig. 26 Historic highs in saxitoxin equivalent concentrations on the B.C. coast. Note that sampling intensity is much higher in the south, which probably skews the picture.

Domoic acid poisoning **(**DAP or Amnesic shellfish poisoning, ASP)

Domoic acid production has been linked to blooms of several species of the diatom genus *Pseudo-nitzschia*, notably *P. multiseries*, *P. australis* and *P. pseudodelicatissima.* The toxin is retained the longest by razor clams but also occurs in mussels, used in the B.C. monitoring program (K. Schallie, pers. comm.) and in Dungeness crab guts. Cooking of the latter whole causes the toxin to spread into the flesh.

Pseudo-nitzschia spp. are present and often abundant in all B.C. marine water bodies throughout the summer and fall, *e.g.*, Sechelt Inlet (Taylor *et al.* 1994) but the biggest blooms seem to occur over the outer continental shelf (Forbes and Denman 1991; see Fig. 25). Taylor and Haigh (1996) observed that blooms enter Barkley Sound from the open coast and appear to sink out. Taylor (2001) has suggested that this may be necessary for the sexual cycle since *Pseudo-nitzschia* like other pennate diatoms, requires direct contact of compatible cells and movement is only possible on a hard surface.

There is a provocative timing series along the west coast of North America in terms of the first appearance of domoic acid toxicity, with that in British Columbia appearing later than further south. So far, southern outbreaks have invariably

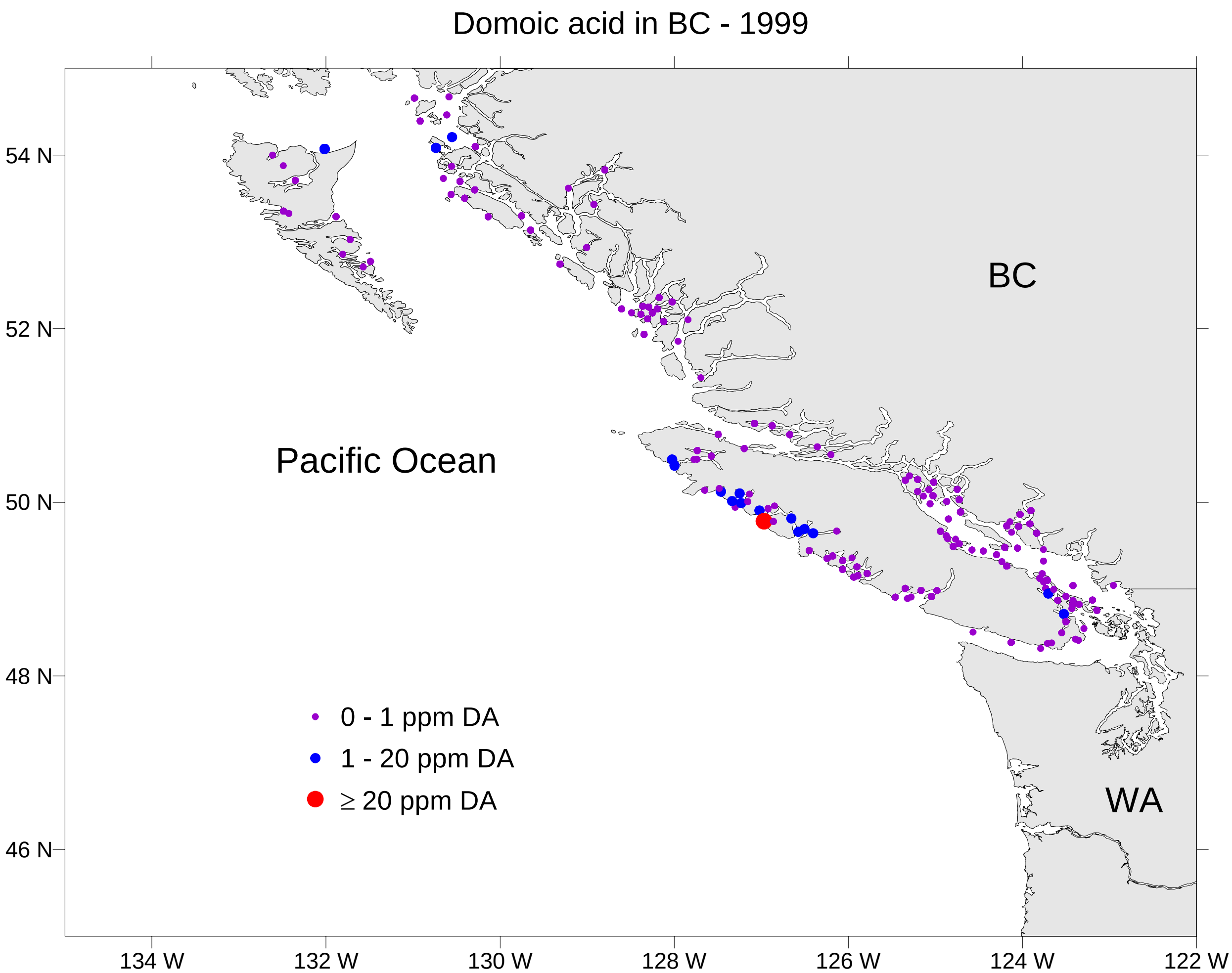


Fig. 27 Domoic acid levels in 1999 (Canadian Food Inspection Agency, Shellfish Inspection).

preceded those further north in B.C. and Alaska. This provides forewarning, allowing increased vigilance and raises interesting questions regarding possible advection (Taylor and Haigh 1996) or a seasonal wave of altered environmental conditions (discussed in Summary and conclusions).

Other potential shellfish toxin producers

Species of the dinoflagellate genus *Dinophysis* have been linked to diarrheic shellfish poisoning (DSP). In particular *D. fortii*, *D, acuta*. *D. acuminata* and *D. norvegica*, all of which have been linked to DSP elsewhere are common, but never abundant.

However, it has been claimed that prolonged presence in concentrations of thousands per litre or less may cause levels sufficient to cause illness. No DSP has been diagnosed in humans in B.C. but, given its resemblance to diarrhea caused by bacterial contamination (*Vibrio haemolyticus* in particular), would DSP be detected without testing specifically for okadaic acid or dinophysistoxin? *Prorocentrum lima*, a known okadaic acid producer, has been recorded as common in benthic environments (sand) in B.C. (Taylor, unpubl.) but local strains have not been tested for toxin production.

Most recently the common temperate dinoflagellate species *Protoceratium reticulatum*, also known as *Gonyaulax grindleyi*, has been shown to reproduce yessotoxins which have contaminated shellfish in New Zealand. This species is very common and occasionally abundant in British Columbia coastal waters (its benthic cyst stage is the commonest dinoflagellates cyst in B.C. coastal sediments (Dobell, Ph.D. thesis, UBC)) but no illnesses have been linked to this species in this region so far. It should be noted that yessotoxins are not part of the standard monitoring program. Like the potential DSP producers, local culture isolates need to be made for toxin testing. This is also true for potential spirolide production by *A. ostenfeldii.*

A disturbing development was the discovery of microcystins in samples of fouling on farmed salmon pens in the Strait of Georgia (Andersen, Kent, Taylor REF.). Microcystins are tumor promoters so far known only to be produced by fresh-water cyanobacteria. Their presence in sea samples in B.C. is a mystery at present.

Fish killers

In general wild fish are not harmed by HABs in B.C. This is probably due to the high tidal exchange preventing the hyper-bloom concentration and subsequent plankton death and decay which causes mass mortalities elsewhere. Also, there is possibly behavioural adaptation, such as avoidance by swimming around or under surface blooms, arising from long-term exposure (thousands of years or more) to the same HABs that occur now. On the other hand, farmed fish are more vulnerable to such blooms because they are kept in pens in the ocean where they cannot avoid the noxious plankton concentrations. The loss to salmon aquaculture in B.C. between 1986 and 1990 was estimated to be CDN$ 15 million (Black 1990).

Chaetoceros concavicomis, Ch. convolutus

Bell (1961) first showed that spines of the common, chain-forming diatom *Ch. convolutus* (probably including the closely similar *Ch. concavicornis*) could lethally damage the gills of ling-cod held in cages near Nanaimo. Relatively low concentrations of cells (5000 l^{-1}) of these two diatom species, particularly *Ch. concavicornis,* can also kill farmed salmon by physically damaging their gills. Small spines on their setae cause them to irreversibly penetrate the gill tissue and cause capillary damage. This also makes the fish more vulnerable to *Vibrio* infections. Quite often the fish produce large quantities of mucus in their gills. The diatoms are most abundant in the summer and fall in the Strait of Georgia (Haigh and Taylor 1990) and coastal inlets (Taylor et al. 1994) in waters above 25‰ for *Ch. convolutus* and 17‰ for *Ch. concavicornis* (Albright *et al.* 1992, Harrison *et al.* 1993).

Heterosigma akashiwo (= H. carterae)

This small species of chloromonad (raphidophyte) flagellate has been the principal killer of farmed salmon in British Columbia since 1986. Blooms can be extremely extensive in B.C. coastal waters (Taylor end Haigh 1993).

In 1989, the entire Strait of Georgia was covered by the reddish brown of a bloom of this organism (E. Black and F. Taylor, unpubl.obs.). The precise mechanism of death is uncertain although the organism is presumed to release harmful substances into the water which cause gill and/or liver damage in salmon. Black *et al.* (1991) could not observe gill damage in fish killed in their experiments. Excessive gill mucus production is sometimes also observed with *Heterosigma* blooms, but not always.

Regular, multi-year monitoring of bloom development in English Bay, Vancouver (Taylor and Haigh 1993), has shown that cells abruptly appear in the water when the temperature reaches 15°C (usually in June), apparently due to excystment from shallow sediments. Blooms are most extensive in the Strait of Georgia during summers with strong, shallow stratification due to high runoff from the Fraser River, in turn resulting from a higher than normal snow-pack the previous winter. A drop in salinity in English Bay to 15‰ coincides with 15°C in severe bloom years in this area. A prerequisite to strong blooms is that the spring diatom bloom must be over (usually by late May) and the surface water depleted of nitrate.

Cochlodinium sp.

In the summer of 1999 a series of salmon kills at farms on the west coast of Vancouver Island was linked to a bloom of the naked dinoflagellate *Cochlodinium* sp. (Whyte *et al.* 2001). The cells resembled *C. polykrikoides,* the major fish killer of Korea and in Japan (see this report) but showed less chain formation, usually occurring in pairs or singly. The initial outbreak was estimated to cause losses of approximately CDN$ 2 million. This phenomenon has recurred less severely in subsequent years with a suggestion of southward spread along the coast of Vancouver Island. The cause of death is unknown although a similar mechanism to that in Korea and Japan (oxygen radical production leading to gill, and perhaps also liver damage) is suspected.

Others

Visible discolourations due to blooms of many other species of phytoplankton are common in B.C. waters during spring and summer (reviewed for the Strait of Georgia by Harrison *et al*. 1983). There is a regular spring bloom of diatoms, primarily consisting of *Thalassiosira nordenskioldii*, *Skeletonema costatum* and several species of *Chaetoceros*, notably *Ch. debilis*. This is often followed by the heterotrophic dinoflagellate *Noctiluca scintillans* which regularly blooms intensely enough to strongly discolour the water an orange-red (see cover photograph). In these waters it is usually not harmful. Esquimalt Lagoon near Victoria on Vancouver Island is frequently intensely discoloured by late summer blooms of *Akashiwo sanguinea* (formerly *Gymnodinium sanguineum*) which is also not harmful unless trapped in a decaying state. Watanabe and Robinson (1979) studied an intense bloom of it in September-October 1978.

Another very common discolouration is caused by intense, maroon, surface blooms of the photosynthetic ciliate *Mesodinium rubrum*, which aggregates particularly at downwelling fronts or in internal waves in the Strait of Georgia (reviewed by Taylor *et al.* 1971). It has been invariably harmless although it can cause a red discolouration in shellfish. AVHRR imagery has detected large reflective blooms off B.C., particularly off the coasts of Vancouver Island and the Queen Charlotte Islands (Gower 1997). These are probably caused by harmless coccolithophorids but this has not been properly “ground-truthed” yet. We do not include such harmless blooms in our HAB data.

In 1990, a particularly extensive and intense bloom of the dinoflagellate *Gonyaulax spinifera* was implicated by Heath and Lindsay (1993) in the mass mortality of shellfish such as oysters, clams and mussels in tributary inlets to Barkley Sound on the west coast of Vancouver Island. This non-specific mortality was attributed to oxygen depletion accompanying collapse of the bloom. Usually blooms are not as concentrated as this in local areas due to strong tidal exchange. Such non-specific kills due to high B.O.D. are known from other parts of the world where other species of *Gonyaulax* and also *Ceratium*, have caused fish and shellfish kills without the involvement of toxin release.

In Japan, the commonest fish killers are species of the chloromonad genera *Chattonella* and *Fibrocapsa.* A few cells of an unidentifiable species of *Chattonella* have been seen in preserved samples from open west coast waters (Taylor, unpubl. obs.) but never a bloom. Sea temperatures on the B.C. coast are generally colder than areas commonly subject to *Chattonella* blooms, such as the Inland Sea of Japan. This is also true of the fish- killing dinoflagellate *Pfiesteria.*

Discussion

Given that reports have been increasing and new species implicated in HABs in B.C. and on many coastlines, it is reasonable to wonder if this is due to human activities, such as eutrophication. Taylor *et al.* (1994) and Taylor and Horner (1994) concluded that there was no evidence for links between HABs and salmon aquaculture in B.C. waters. The sites usually chosen for salmon farming are deep and the large tidal range flushes the surface waters well. Many of the highest PSP sites are along very lightly populated coasts. On the other hand there is evidence of cyclical interannual variation that is presumably due to interannual climatic variation. In the case of

Heterosigma there is a clear link to snow pack accumulation the previous winter and subsequent runoff. Also, Taylor (in press) has argued that the natural adaptation of local fauna, such as the avoidance of toxic shellfish by sea otters or *Heterosigma* blooms by Pacific salmon, is strong evidence for the presence of particular HABs over evolutionary time.

Another question is whether some local HAB species have been introduced by, for example, the discharge of foreign ballast water. Again, Taylor (in press) has drawn attention to the general biogeographic phenomenon of "latitudinal cosmopolitanism" exhibited by groups such as dinoflagellates (Taylor 1987).

Management at present consists of monitoring shellfish, primarily mussels, for the presence of saxitoxins and domoic acid, by the Canadian Food Inspection Agency, Fish Inspection Branch, with closures declared when levels reach or exceed 80 µg saxitoxin equivalents per 100 grams of shellfish meat. This program is aided in collection and sample preparation for toxin testing by the North Coast Water Quality and Biotoxin Program, a private agency based in Prince Rupert (see Purkis in Martin 2002). While the use of mussels as indicators of the presence of toxins is favourable for a variety of reasons (see Schallié 2001) including their rapid uptake abilities relative to other shellfish, their rapid depuration abilities make them unreliable as indicators of the state of shellfish in general. As noted above, butter clams retain saxitoxins for longer and oysters only accumulate PSP slowly, requiring longer exposure to reach dangerous levels. In the case of domoic acid it is known that razor clams retain the toxin the longest. At present plankton monitoring is not part of the Food Inspection Agency activities although it could be a valuable adjunct to shellfish testing, as shown on the east coast, *e.g*., Prince Edward Island and New Brunswick. A consortium of fish farmers, aided by staff of the Department of Fisheries and Oceans at the Pacific Biological Station in the Nanaimo, participate in a Harmful Algae Monitoring Program (HAMP) that does include plankton sampling from farm sites, resulting in warnings of potentially fish-killing blooms. However, because it is restricted to near-shore sites, it is of limited ecological value. Some plankton monitoring is also being done at a few northern sites near Prince Rupert by the North coast plankton identification and monitoring program (Shaw 2001).

It is clear that the siting of aquaculture sites in particular should require a prior investigation of the broad aspects of the phytoplankton community of the area. So far this has not been the case, often to the cost of the farmers. Much remains to be done, both to understand and effectively manage HABs in British Columbia and this will be most effective if it is integrated with the confluent waters of its neighbours, Washington State and Alaska.

Specific questions needing near-future examination

- What is the causal nature of the multi-year (six- to eight-year) cycles on the coast? Is there a direct link between El Niño (ENSO) and higher levels of PSP?
- Are *Alexandrium* blooms in B.C. coastal waters all locally triggered events or is long-shore transport also important?
- What is the source of extensive blooms visible by satellite off the east coast of the Queen Charlotte Islands and in Queen Charlotte Strait?
- Why is the southern Queen Charlotte Strait region (Gilford Island, Kingcome Inlet, Johnstone Strait area) the earliest in southern B.C. to experience high PSP toxicity?
- Is PSP more persistent in the winter months in the north than the south?
- How many toxin-producing species and strains of *Alexandrium* and *Pseudo-nitzschia* are there in B.C. waters?
- Is there a hydrographic link between off-shore blooms of *Pseudo-nitzschia* along the west coast of North America?
- Are *Cochlodinium* and *Heterosigma* blooms relatively recent developments or have aquaculture activities drawn attention to their presence? Are they spreading?
- Blooms of *Heterosigma* in the Strait of Georgia are apparently strongly linked to river runoff and stratification but how are blooms on other parts of the coast regulated?

- What is the source of microcystins in salmon net pen fouling organisms?
- Do viruses play a role in the collapse of *Heterosigma* or other B.C. HABs?
- Are HAB species responsible for "summer die-off" in cultivated mussels or oysters?
- Have there been any introduced HAB species due to ballast water or other sources in B.C. waters?

Acknowledgments

The authors wish to acknowledge the assistance of the Canadian Food Inspection Agency and Klaus Schallié in particular, for discussions and use of their toxicity data. The charts were produced with the assistance of the NOAA Northwest Fisheries Science Center, Seattle, and the manuscript was reviewed and discussed with Vera Trainer.

References

Albright, L.J., Johnson, S., and Yousif, A. 1992. Temporal and spatial distribution of the harmful diatoms *Chaetoceros concavicomis* and *Chaetoceros convolutus* along the British Columbia coast. Can. J. Fish. Aquat. Sci. 49: 19-24.

Anderson, L.S. 1960. Toxic shellfish in British Columbia. Amer. J. Publ. Health, 30(l): 71-83.

Bell, G.R. 1961. Penetration of spines from a marine diatom into gill tissue of ling cod (*Ophiodon elongates*). Nature 192: 279-280.

Black, E.A. 1990. Algal blooms in British Columbia. Harmful Algae Newsletter 3 (2): 11- 12.

Black, E.A., Whyte, J.N.C., Bagshaw, J.W. and Ginther, N.G. 1991. The effects of *Heterosigma akashiwo* on juvenile *Oncorhynchus tschawytscha* and its implications for fish aquaculture. J. Appl. Ichthyol. 7: 168-175.

Chiang, R. 1985. PSP activity scale: a macroscopic measurement of relative paralytic shellfish poison levels in British Columbia, Canada. *In* Anderson, D.M., White, A.W. end Baden, D.G. (Eds.) Toxic Dinoflagellates. Elsevier, New York, pp.451-456.

Environmental Assessment Office, British Columbia Provincial Ministry (web reports on salmon and oyster farming). www.eao.gov.bc.ca/project/aquacult.htm

Canadian Food Inspection Agency, Fish Inspection Branch 2002. Summary of marine toxin records for the Pacific coast of Canada 2001, 138pp.

Erickson, G. and Nishitani, L. 1985. The possible relationship of El Nino/ Southern Oscillation to interannual variation in *Gonyaulax* as shown by records of shellfish toxicity. *In* Wooster, W.S. and Fluharty, D.L. (Eds.) El Niño North: Nino effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, Univ. of Washington, Seattle, pp. 283-290.

Gaines, G. and F.J.R. Taylor. 1985. An exploratory analysis of PSP patterns in British Columbia: 1942-1984. *In* D.M. Anderson, A.W. White, and D.G. Baden (Eds.) Toxic Dinoflagellates. Elsevier, Amsterdam, pp. 439-444.

Gower, J.F.R. 1997. Bright plankton blooms on the west coast of North America observed with AVHRR imagery. *In* Kahru, M. end Brown, C.W. (Eds.) Monitoring algal blooms: new techniques for detecting large-scale environmental change. Landes Bioscience, Texas, pp. 25-41.

Haigh, R. and Taylor, F.J.R. 1990. Distribution of potentially harmful phytoplankton species in the northern Strait of Georgia, British Columbia. Can. J. Fish. Aquat. Sci. 47: 2343-2350.

Harrison, P.J., Fulton, J.D., Taylor, F.J.R., and Parsons, T.R. 1983. Review of the biological oceanography of the Strait of Georgia: pelagic environment. Can. J. Fish. Aquat. Sci. 40: 1064-1094.

Harrison, P.J., Thompson, P.A., Guo, M., and Taylor, F.J.R. 1993. Effects of light, temperature and salinity on the growth rate of harmful marine diatoms *Chaetoceros convolutus* and *Chaetoceros* concavicornis that kill net pen salmon. J. Applied Phycol. 5: 259-265.

Heath, W. and Lindsay, J.G. 1993. Red algal blooms: effects on shellfish farming in British Columbia and steps to prevent shellfish losses,

British Columbia Aquaculture Industry Development Report 93-02, 14pp.
Horner, R.A. and Postel, J.R. 1993. Toxic diatoms in western Washington waters (U.S. west coast). Hydrobiologia 269/270:197-205.
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. Canadian Tech. Rep. Hydrography and Ocean Sciences No. 135, pp. 59-61.
Kvitek, R.G. 1993. Paralytic shellfish toxins as a chemical defense in the butter clam (*Saxidomus giganteus*). *In* T.J. Smayda and Y. Shimizu (Eds.) Toxic Phytoplankton Blooms in the Sea. Elsevier, New York, pp. 407-412.
Martin, J.L. (Ed.) 2002. Developments for a Canadian GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) Program: 2001 workshop report. Can. Tech. Rep. Fish. Aquat. Sci. 2400, 44pp.
Purkis, J. 2001. North coast water quality and biotoxin monitoring program. In Whyte, J.N.C. (Ed.) Proceedings of the Seventh Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 2386: 116-117.
Purkis, J. 2002. North coast water quality and biotoxin program. *In* Martin, J.L. (Ed.) Developments for a Canadian GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) Program: 2001 workshop report. Can. Tech. Rep. Fish. Aquat. Sci. 2400: pp. 11-12.
Quayle, D. B. 1969. Paralytic shellfish poisoning in British Columbia. Bull. 168, Fish. Res. Bd. Canada, 68pp.
Quayle, D.B. and Bernard, F. 1966. Shellfish toxicity records 1942-1965. Fish. Res. Bd. Canada, ms. rept. (Biol.) 860, 222pp.
Rensel, J.E. 1992. Harmful effects of the marine diatom *Chaetoceros concavicornis* on Atlantic salmon *(Salmo salar*). Ph.D. Dissertation, University of Washington, Seattle, 140 pp.
Schallié, K. 2001. Marine toxin monitoring program. *In* RaLonde, R. (Ed.) Harmful algal blooms on the North American west coast. Univ. Alaska Sea Grant Rep. AK-SG-01-05, pp.39-42.
Shaw, B.A. 2001. North coast plankton identification and monitoring program. *In* Whyte, J.N.C. (Ed.) Proceedings of the Seventh Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 2386: p. 19 .
Taylor, F.J.R. 1975. Taxonomic difficulties in red tide and paralytic shellfish poison - the "*tamarensis"* complex of *Gonyaulax.* Environm. Letters 9: 103-119.
Taylor, F.J.R. 1984. Toxic dinoflagellates: taxonomic and biogeographic aspects with emphasis on *Protogonyaulax*. *In* E.P. Ragelis (Ed.) Seafood Toxins. ACS Symp. Ser., 262, Amer. Chem. Soc., Wash., pp.79-97.
Taylor, F.J.R. 1985. The taxonomy and relationships of red tide flagellates. *In* D.M. Anderson, A.W. White, and D.G. Baden (Eds.) Toxic Dinoflagellates. Elsevier, New York, pp. 11- 26.
Taylor, F.J.R. 1987. General and marine ecosystems. *In* F.J.R. Taylor (Ed.) The Biology of Dinoflagellates. Blackwell, Oxford, pp.399-562.
Taylor, F.J.R. 1992. The taxonomy of harmful marine phytoplankton. Giorn. Bot. Ital. 126: 209-219.
Taylor, F.J.R. 1992. Artificial respiration saves two. Harmful Algae News 3, pp. 1,5.
Taylor, F.J.R. 1993. Current problems with harmful phytoplankton blooms in British Columbia waters. *In* T.J. Smayda and Y. Shimizu (Eds.) Toxic Phytoplankton Blooms in the Sea. Elsevier, New York, pp. 699-703.
Taylor, F.J.R., Blackbourn, D.J., and Blackbourn, J. 1971. The red water ciliate *Mesodinium rubrum* and its "incomplete symbionts": a review including new ultrastructural observations. J. Fish. Res. Bd. Canada 28: 391-407.
Taylor, F.J.R. and Haigh, R. 1993. The ecology of fish-killing blooms of the chloromonad flagellate *Heterosigma* in the Strait of Georgia and adjacent waters. *In* T. J. Smayda end Y. Shimizu (Eds.) Toxic Phytoplankton Blooms in the Sea. Elsevier, Amsterdam, pp. 705-710.
Taylor. F.J. R., Haigh, R., and Sutherland, T. F. 1994. Phytoplankton ecology of Sechelt Inlet, British Columbia. 11. Potentially harmful species. Mar. Ecol., Progr. Ser. 103: 151-164.

Taylor, F.J.R. end Horner, R. 1994. Red tides and other problems with harmful algal blooms in Pacific Northwest coastal waters. *In* Wilson, R.C.H., Beamish, R.J., Aitkens, F. and Bell, J. (Eds.) Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Tech. Rep. Fish. Aquat. Sci.1948: 175-186.

Todd, E.C.D. 1989. Amnesic shellfish poisoning - a new seafood toxin syndrome. *In* E. Granéli, B. Sundström, L. Edler, and D.M. Anderson (Eds.) Toxic Marine Phytoplankton. Elsevier, pp. 504-508.

Vancouver, G. 1798. A voyage of discovery to the North Pacific and the world. Vol. 2, 285 pp. (also re-issue Hakluyt Society, London 1984).

Watanabe, L.N. and Robinson, M.G. 1979. Red tide in Esquimalt Lagoon due to *Gymnodinium sanguineum* Hirasaka. Coastal Marine Science Laboratory, Royal Roads Military College, ms. rep. 42pp + 17pls (unpubl.).

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.

Whyte, J.N.C. (Ed.). 2001. Proceedings of the Seventh Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 2386,, 158pp.

Whyte, J.N.C., Haigh, N., Ginter, N.G., and Keddy, L.J. 2001. First record of blooms of *Cochlodinium* sp. (Gymnodiniales, Dinophyceae) causing mortality to aquacultured salmon on the west coast of Canada. Phycologia 40: 298-304.

Harmful algal blooms on the U.S. west coast

Vera L. Trainer
National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, U.S.A. E-mail: Vera.L.Trainer@noaa.gov

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.

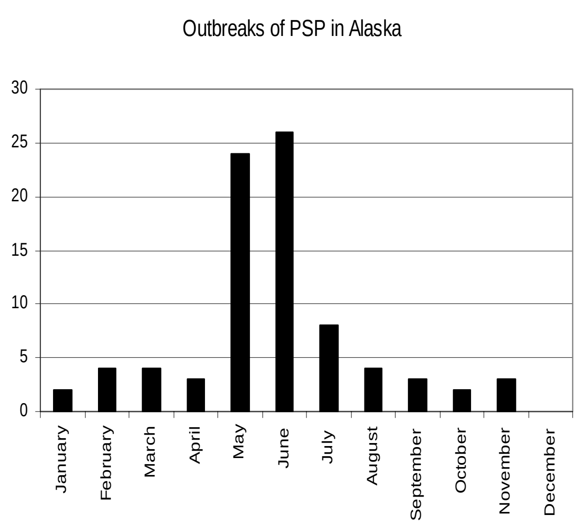


Fig. 28 Reported PSP cases in Alaska from 1973-1994 (from Gnesser and Schloss 1996).

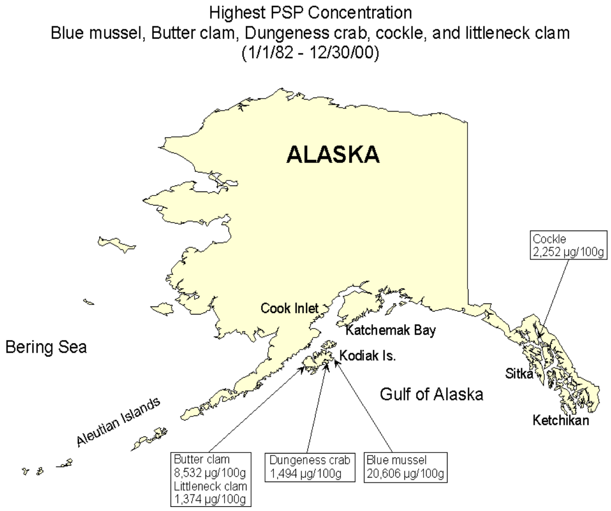


Fig. 29 Locations and levels of highest PSP toxin measured in blue mussel, butter clam, Dungeness crab, cockle, and littleneck clam.

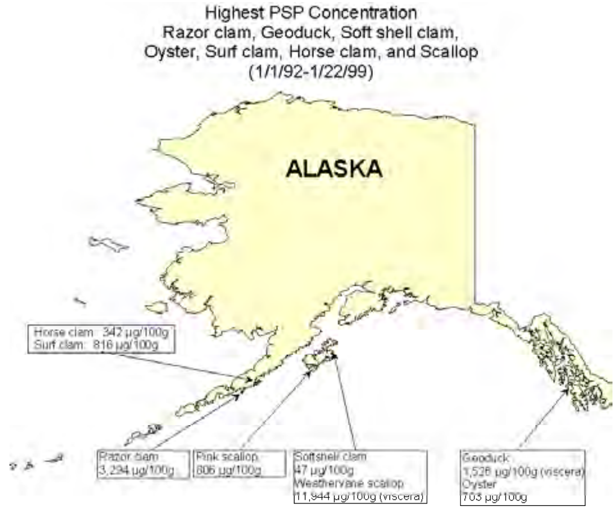


Fig. 30 Locations and levels of highest PSP toxin measured in razor clam, geoduck, softshell clam, oyster, surf clam, horse clam, and scallop.

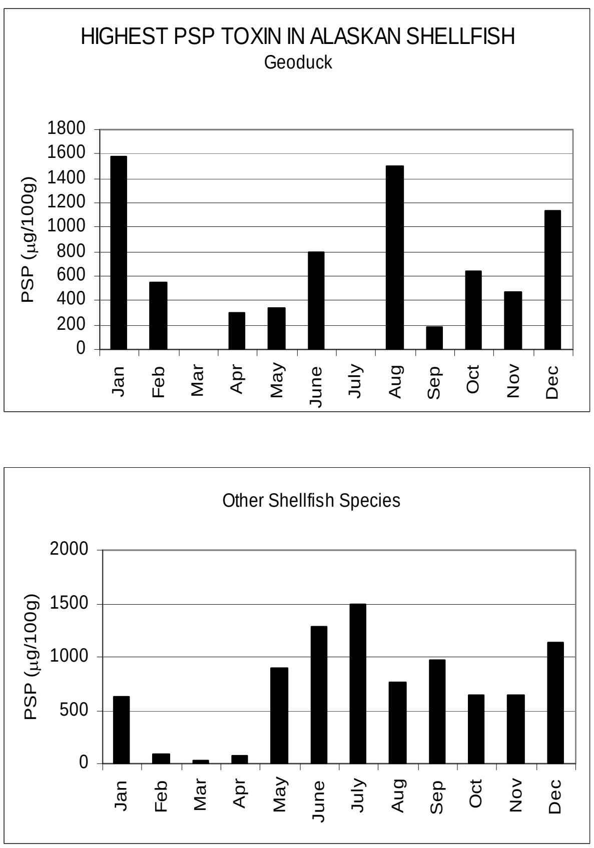


Fig. 31 Highest PSP toxin in Alaska by month for the year 2000.

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).

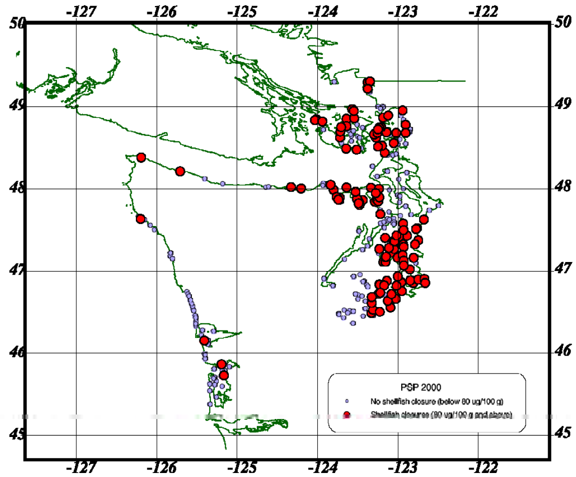


Fig. 32 Locations where closures due to PSP (red circles) occurred in 2000 due to levels of toxin in shellfish at or above 80 µg/100g. Low levels (below 80 µg/100 g) are also shown as smaller blue circles.

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.

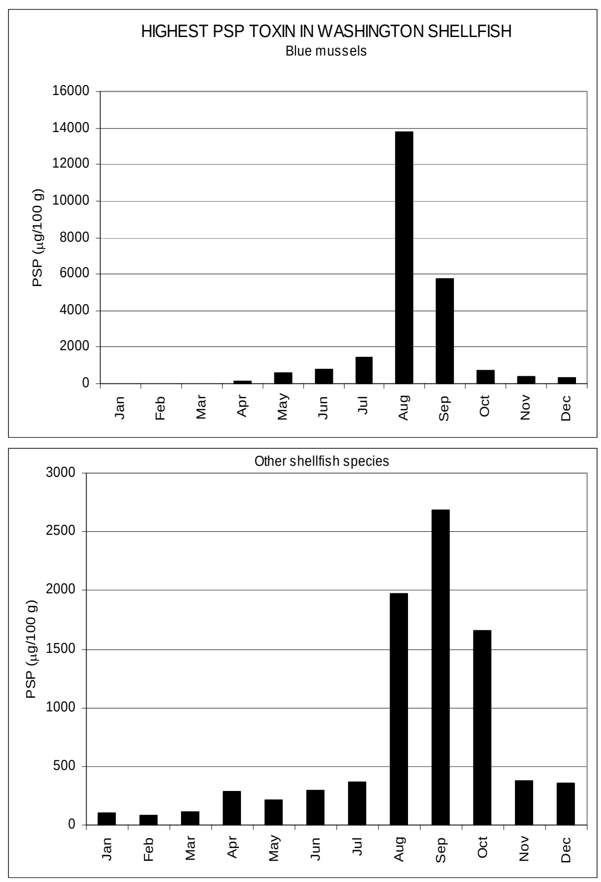


Fig. 33 Highest PSP toxin levels by month in geoduck and other shellfish species (2000).

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).

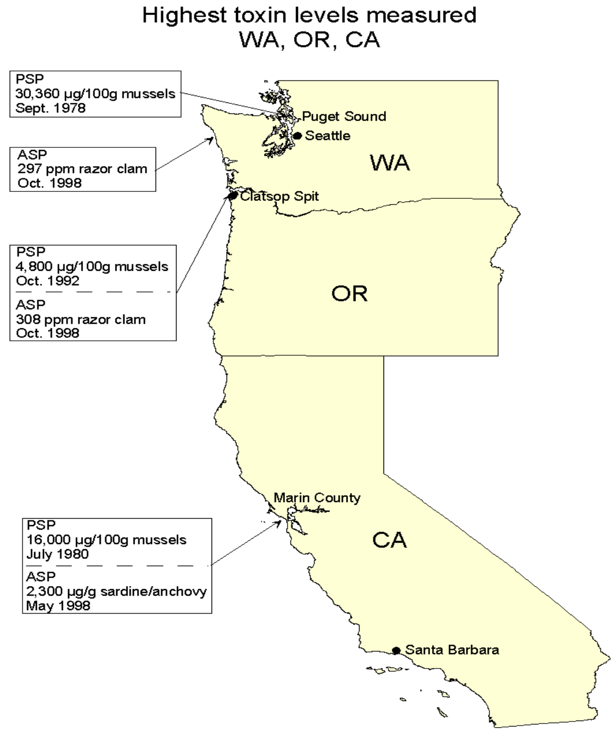


Fig. 34 Highest PSP and ASP toxin levels measured in Washington, Oregon and California.

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

Vera L. Trainer

Northwest Fisheries Science Center, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112, U.S.A. E-mail: Vera.L.Trainer@noaa.gov

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).

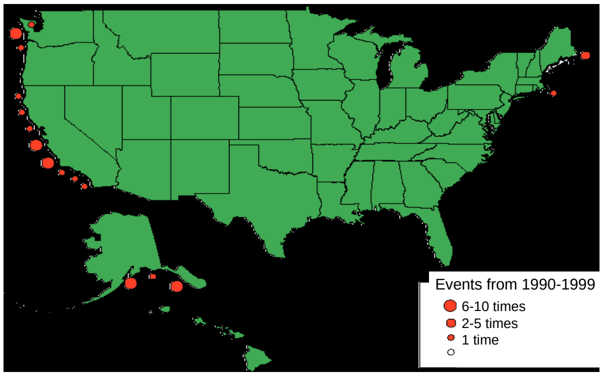


Fig. 35 ASP events in the U.S.A.

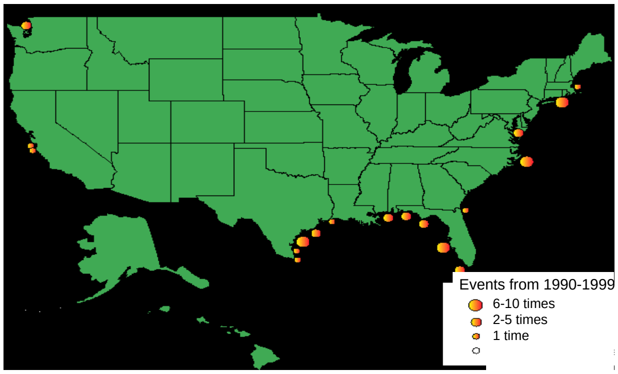


Fig. 36 PSP events in the U.S.A.

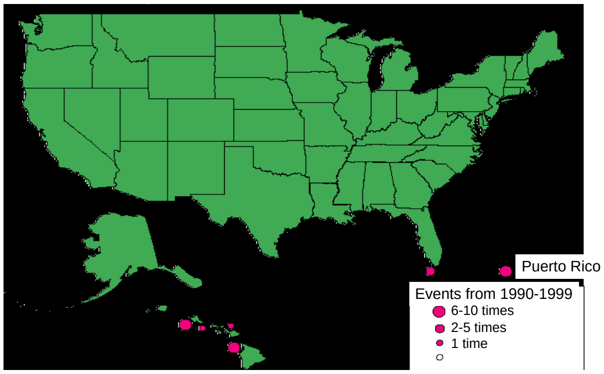


Fig. 37 Ciguatera fish poisoning *Gambierdiscus toxicus* in the U.S.A.

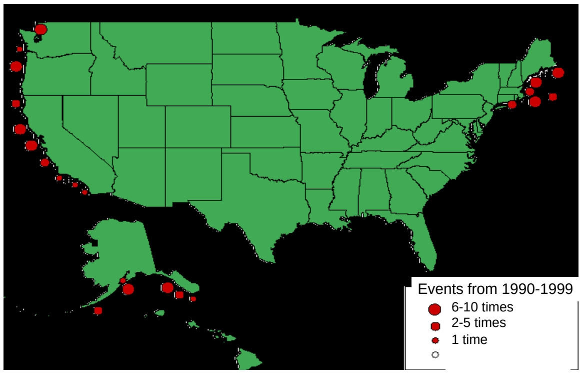


Fig. 38 Animal and plant mortalities in the U.S.A.

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.

Marine biotoxins and harmful algal blooms in Mexico's Pacific littoral

Jose L. Ochoa[1], D.U. Hernández-Becerril[2], S. Lluch-Cota, B.O. Arredondo-Vega, E. Nuñez-Vázquez, A. Heredia-Tapia, J. Pérez-Linares and R. Alonso-Rodríguez

[1] Northwest Center for Biological Research (CIBNOR). Box 128, La Paz, BCS., Mexico 23000. E-mail: jlochoa@cibnor.mx

[2] Institute of Marine Sciences and Limnology, UNAM, Box 70-305, México 04510.

Introduction

Figure 39 summarizes the locations of harmful algal bloom (HABs) events registered in Mexico during the last 25 years (Ochoa 2002). Despite our efforts, this reflects only part of the actual HAB episodes that occurred along the Mexican coastline in this period.

The map was prepared using information collected from over 100 reports of various Mexican researchers describing their observations. These reports are found in different media, sometimes difficult to access (Table 20). Yet, one very important conclusion of the information is that only in a handful of cases has the nature of the toxins, the causative organisms, and/or the implicated ecological and socioeconomic impacts been studied in detail. In these records, very little information is provided about the conditions that triggered the sudden proliferation of noxious microalgal blooms along the Mexican coast. Analyzing the data displayed in Figure 39 and listed in Table 20 together, it can be observed that various reports correspond to the same location. This does not imply that a given "red tide" event was repeatedly reported, rather that such a location was hit several times within the studied period.

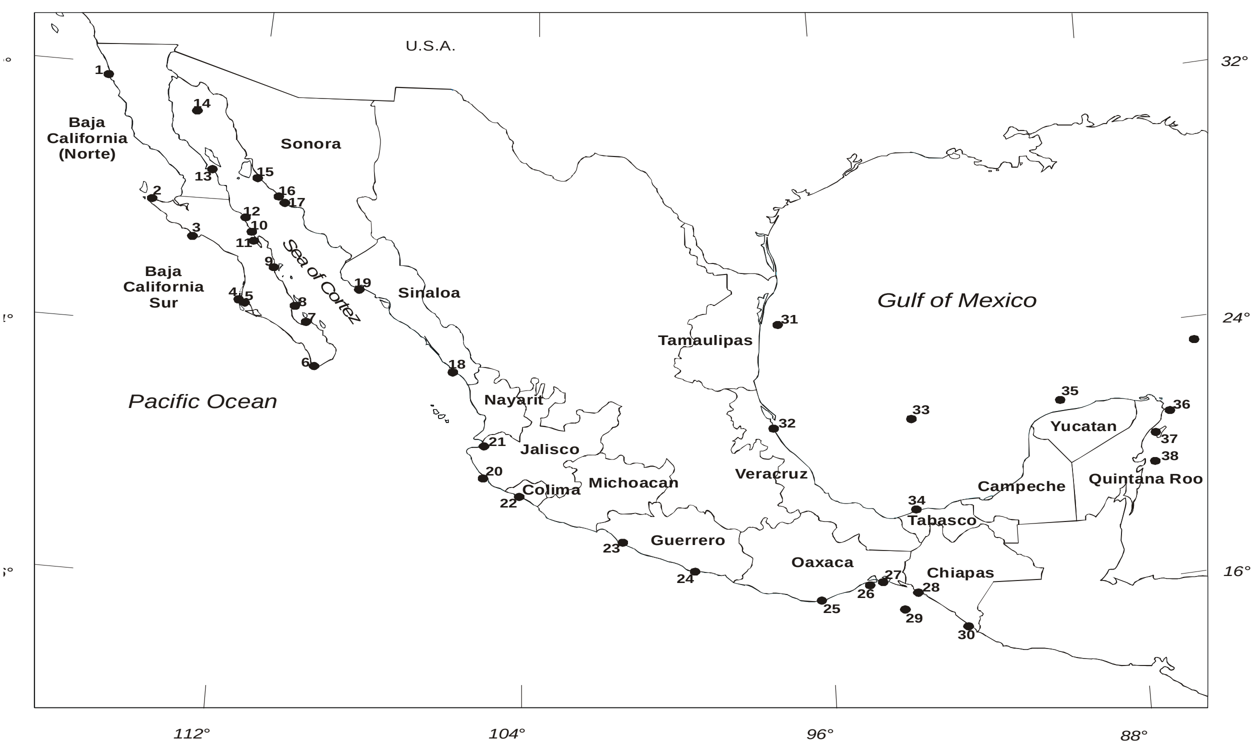


Fig. 39 Locations of the Mexican littoral affected by "red tides" in recent years.

Also, considering the proportion of detected events, it would seem that the Pacific coast had more HAB events than the Gulf of Mexico and the Caribbean together. However, this may be just a result of more research activity in the Pacific region than in the rest of Mexico. In other words, we lack evidence to support the idea that the Mexican Pacific shoreline is more susceptible to HAB episodes than the rest of the Mexican littoral.

It is also interesting to note in Table 20 that at least 39 different dinoflagellate and diatom species have been associated with "red tides" in the Mexican littoral. Of these, some are known to produce toxins (Table 21) and can provoke human seafood poisoning through various vectors (Table 22). Following, some examples are discussed.

Amnesic shellfish poisoning (ASP) in Mexico

HAB events in the Pacific coastline of Mexico have been studied at CIBNOR for the last 12 years. During this period, not only toxins, but also causative organisms in different events have been identified.

The most notorious events involved high mortality of fish, sea birds, and sea mammals, provoked by domoic acid, the toxin responsible for ASP (Ochoa *et al*. 1996, 1997a; Sierra-Beltrán *et al.* 1997). Such events occurred at the tip of the Baja California Peninsula and in the upper Gulf of California in the winter of 1996, and again in 1997. We were able to identify the causative organisms as members of the *Pseudo-nitzschia* genus, and in one case, as *P. australis* (Ochoa *et al.* 1997a). Because previous records indicate its presence in the Gulf of California (Cortés-Altamirano *et al.* 1996), and because of its ability to proliferate under certain oceanographic conditions such as "El Niño" and "La Niña" (Sierra-Beltrán *et al.* 1999), *P. australis* is a suitable candidate for ASP-monitoring in Mexico. In fact, time series analysis have shown that a cooling trend of the water in the upper Gulf of California during the period 1993-1997 (Beier 1997) could have played an important role in ASP outbreaks in this region.

Ciguatera toxin (CTX) and diarrhetic shellfish poisoning (DSP) in Mexico

DSP has not been acknowledged in Mexico by health authorities, although a high incidence of undiagnosed, non-infectious, seafood-related diarrhea events are found in the epidemiological records of the Health Ministry (Ochoa *et al.* 1998a). The presence of toxic species causing DSP (such as *Dinophysis* spp. and *Prorocentrum* spp.) has been well established along much of the Mexican littoral. Therefore, this coastline should be considered a DSP risk area. Incidents where fishermen have been poisoned after eating fish belonging to the Serranidae and Lutjanidae families, at Rocas Alijos (Lechuga and Sierra-Beltrán 1995), and Isla El Pardito (Heredia-Tapia *et al.* 2002), have been linked to "ciguatera," rather than to DSP events. Therefore, further work is necessary to clarify which toxins are affecting the Pacific marine resources. If CTX at Rocas Alijos is confirmed, this will present a new record for a northerly latitude at which the risk of such fish poisoning occurs. On the other hand, if this event and the one reported at El Pardito Island is considered a DSP case, then we can declare that DSP is indeed impacting Mexico's coastal population. As proof, the dinoflagellate *Prorocentrum lima*, associated elsewhere with CTX and DSP cases, was isolated from Isla El Pardito (Heredia-Tapia *et al.* 2002). This isolate has been shown to be smaller, different in toxin composition (at least two components remain to be identified), distinct in toxin profile (dinophysis toxin: okadaic acid ratio is 2:1), and is more toxic than related species. All these properties point to adaptations to local environmental conditions that reinforce the idea of geographic toxic variability within the same species.

Paralytic shellfish poisoning (PSP) in Mexico

PSP is also present along the Pacific littoral of Mexico (Sierra-Beltrán *et al.* 1996; Ochoa *et al*. 1998b). In Mexico, all cases of hospitalization and human casualties recorded after consuming oysters, mussels, or clams, were PSP-related. Either *Gymnodinium catenatum* or *Pyrodinium*

Table 20 "Red tide" forming microalgae in the Mexican littoral.

Species	Location	Reference
Alexandrium catenella	Baja California Sur: Concepción Bay.	Gárate-Lizárraga, 1996; Herrera-Silveira, 1999; Lechuga-Deveze *et al.*, 2000.
Alexandrium monilatum (=Gonyaulax monilata)	Sinaloa: Mazatlán Bay.	Cortés-Altamirano and Núñez-Pastén, 1992.
Ceratium sp	Jalisco: Banderas Bay Oaxaca: Laguna Superior.	Cortés-Altamirano *et al.*, 1996.
Ceratium dens	Baja California.	Blasco, 1977.
Ceratium furca	Baja California: Ensenada Baja California Sur: Concepción Bay Sinaloa: Mazatlán Bay Colima: Manzanillo Tabasco: Del Carmen Lagoon.	Blasco, 1977; Cortés-Altamiranoi *et al.*, 1995, 1996; Herrera-Silveira, 1999; Lechuga-Deveze *et al.*, 2000; Orellana-Cepeda *et al.*, 1993.
Ceratium fusus	Baja California Sur: Concepción Bay	Lechuga-Deveze *et al.*, 2000.
Ceratium tripos var. ponticum	Baja California Sur: Concepción Bay Sinaloa: Mazatlán Bay.	Cortés-Altamirano *et al.*, 1995; Herrera-Silveira, 1999; Lechuga-Deveze *et al.*, 2000;
Chatonella sp.	Baja California Sur: Cabo San Lucas.	Herrera-Silveira, 1999.
Cochlodinium catenatum	Baja California: Ensenada	Orellana-Cepeda *et al.*, 1993.
Dinophysis acuminata	Baja California: Ensenada	Orellana-Cepeda *et al.*, 1993.
Dynophysis caudate	Baja California Sur: Concepción Bay.	Morquecho-Escamilla *et al.*, 1997; Lechuga-Deveze *et al.*, 2000.
Gambierdiscus toxicus	Baja California Sur: Rocas Alijos (?), El Pardito Gulf of California(?) Quintana Roo: Isla Mujeres, Cozumel.	Cortés-Altamirano, *et al.*, 1966; Herrera-Silveira, 1999; Heredia-Tapia *et al.*, 2002.
Gonyaulax sp.	Sonora: Bacochibampo Sinaloa: Mazatlán, Nayarit.	Cortés-Altamirano *et al.*, 1995; Herrera-Silveira, 1999.
Gonyaulax catenella	Oaxaca: Salina-Cruz Huatulco.	Saldate-Castañeda *et al.*, 1991.
Gonaulax digitale	Baja California.	Blasco 1977.
Gonyaulax polyedra	Baja California: San Hipólito Baja California Sur.	Blasco. 1977; Cortés-Altamirano *et al.*, 1996; Gárate-Lizárraga, 1996; Orellana-Cepeda *et al.*, 1993.
Gonyaulax polygramma	Baja California: Los Angeles Bay Gulf of California.	Cortés-Altamirano *et al.*, 1996; Herrera-Silveira, 1999.
Gonyalaux triacantha	Sinaloa: Mazatlán.	Cortés- Altamirano *et al.*, 1995; Herrera-Silveira, 1999.
Gonyaulax verior	Baja California Sur: Concepción Bay.	Morquecho-Escamilla *et al.*, 1997.
Gymnodonium catenatum	Sonora: Bacochibampo, Guaymas Sinaloa: Mazatlán Baja California Sur: Concepción Gulf of California Oaxaca: Salina-Cruz Huatulco	Cortés-Altamirano *et al.*, 1995, 1996; Gárate-Lizárraga, 1996; Herrera-Silveira, 1999; Saldate-Castañeda *et al.*, 1991.
Gymnodinium breve= Ptychodiscus brevis	Veracruz	Cortés-Altamirano *et al.*, 1996.
Gymnodinum peridinium	Guerrero: Acapulco, Puerto Marquéz	Cortés-Altamirano *et al.*, 1996.
Gymnodinium sanguineum	Baja California: San Hipólito Baja California Sur: Tortugas Bay, Magdalena Bay, Concepción Bay	Cortés-Altamirano *et al.*, 1996; Gárate-Lizárraga, 1996; Herrera-Silveira, 1999; Orellana-Cepeda *et al.*,1993.

Species	**Location**	**Reference**
Gymnodinum splendens	Sinaloa: Mazatlán Jalisco: Chametla	Cortés-Altamirano *et al.*, 1996; Herrera-Silveira, 1999.
Gymnodinium tripos var. ponctic.	Sinaloa: Mazatlán	Cortés-Altamirano *et al.*, 1996.
Mesidinium rubrum	Sinaloa: Mazatlán Gulf of California Baja California Sur: La Paz Bay Oaxaca: Barra de San, Francisco, Zicatella Bay, Puerto Escondido, Tonalá	Alonso-Rodríguez *et al.*, 1999; Cortés-Altamirano et al., 1995, 1996; Gárate-Lizárraga, 1996; Herrera-Silveira, 1999.
Nitzchia spp	Guerrero: Zihuatanejo.	Cortés-Altamirano et al., 1996.
Nitszchia pungens	Baja California: Ensenada Bay.	Orellana-Cepeda *et al.*, 1993.
Noctiluca scintillans	Baja California: Ensenada Sonora: Bacochibampo Baja California Sur: Mulegé, Loreto, Concepción Bay Jalisco: Banderas Bay Oaxaca: Salina Cruz	Cortés-Altamirano *et al.*, 1995, 1996; Gárate-Lizárraga, 1996; Herrera-Silveira, 1999; Morquecho-Escamilla *et al*, 1997; Orellana-Cepeda *et al.*, 1993;
Oscillatoria erythraea	Baja California Sur: La Paz, Concepción Bay Sinaloa: Mazatlán	Cortés-Altamirano et al., 1995; Gárate-Lizárraga, 1996; Herrera-Silveira, 1999; Morquecho-Escamilla *et al.*, 1997;.
Proboscia alata	Baja California Sur: Magdalena Bay	Gárate-Lizárraga and Siqueiros-Beltrones, 1998.
Prorocentrum spp.	Sonora: Bachohibampo, Baja California Sur Jalisco: Chametla Oaxaca: Laguna Superior	Cortés-Altamirano *et al.*, 1995, 1996; Gárate-Lizárraga, 1996.
Prorocentrum dentatum	Sonora: Bacochibampo	Cortés-Altamirano et al., 1995.
Prorocentrum micans	Baja California: San Hipólito Baja California Sur: Concepción Bay	Blasco, 1977; Herrera-Silveira, 1999; Lechuga-Devéze *et al*, 2000; Orellana-Cepeda *et al.*, 1993.
Prorocentrum minimum	Sinaloa: Mazatlán Bay	Cortés-Altamirano *et al.*, 1996; Lechuga-Devéze *et al.*, 2000.
Prorocentrum compressum	Baja California Sur: Concepción Bay	Lechuga-Devéze *et al.*, 2000.
Prorocentrum lima	Baja California Sur: Isla El Pardito	Heredia-Tapia *et al.*, 2002.
Prorocentrum mexzicanum	Baja California Sur: Concepción Bay	Lechuga-Devéze *et al.*, 2000; Morquecho-Escamilla *et al.*, 1997;
Pseudonitzchia sp.	Baja California Sur: Cabo San Lucas, Loreto	Herrera-Silveira, 1999; Sierra-Beltrán *et al.*, 1997.
Ptychodiscus brevis	Tamaulipas-Veracruz, Gulf of México, Yucatán	Cortés - Altamirano et al., 1996; Herrera-Silveira,1999.
Pyrodinium bahamense var. bahamense	Veracruz: Tamiahua Lagoon Gulf of México Mexican Caribbean	Cortés -Altamirano et al.,1996; Gómez-Aguirre and Licea, 1998; Herrera - Silveira, 1999.
Pyrodinium bahamense var. compressum	Guerrero: Acapulco Oaxaca: Salina Cruz, Huatulco Chiapas: Puerto Madero	Cortés -Altamirano et al..1996; Herrera-Silveira, 1999; Ramírez- Camarena et al., 1996; Sotomayor -Navarro and Domínguez-Cuellar, 1993.
Scripsiella trochoidea	Baja California: Ensenada Sinaloa: Mazatlán Bay	Alonso-Rodríguez *et al.*, 1999; Cortés - Altamirano et al., 1995; Orellana - Cepeda et al,.1993.
Skeletonema costatum	Sinaloa: Mazatlán Bay	Herrera-Silveira, 1999.
Stephanopyxis palmeriana	Sonora: Kino Bay Gulf of California	Molina *et al.*, 1996.

Table 21 Potentially harmful microalgae present in the Pacific littoral of Mexico.

Group	**Species**	**Reference**
Dinoflagellate		
	Amphidinium carterae Hulburt	Licea *et al.*, 1995
	Ceratium fusus (Ehrenberg) Dujardin var. fusus	Hernández-Becerril, 1989
	Cochlodinium polykrikoides Margalef ?	Morales-Blake, Cavazos Guerra y Hernández-Becerril, 2001
	Dinophysis fortii Pavillard	Hernández-Becerril, 1988
	Dinophysis mitra (Schütt) Abé	Hernández-Becerril, 1988
	Dinophysis rotundata Claparede et Lachmann	Hernández-Becerril, 1988
	Dinophysis tripos Gourret	Hernández-Becerril, 1988
	Lingulodinium polyedrum (Stein) Dodge (*Gonyaulax polyedra* Stein)	Hernández-Becerril, 1988
Haptophytes		
	Phaeocystis pouchetii (Hariot) Lagerheim	Hernández-Beccerril *et al.*, (unpublished)
Bacillariophytes (Diatoms)		
	Cerataulina pelagica (Cleve) Hendey	Hernández-Becerril, 1987
	Chaetoceros concavicornis Mangin	Hernández-Becerril, 1996
	Chaetoceros convolutus Castracane	Hernández-Becerril, 1996
	Coscinodiscus centralis Ehrenberg	Hernández-Becerril, 2000
	Coscinodiscus concinnus Smith	Hernández-Becerril, 2000
	Coscinodiscus wailesii Gran et Angst	Hernández-Becerril, 2000
	Pseudo-nitzschia delicatissima (Cleve) Heiden in Heiden et Kolbe	Cortés Altamirano & Hernández-Becerril, 1998
	Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle	Cortés Altamirano & Hernández-Becerril, 1998
	Thalassiosira diporocyclus Hasle	Cortés Altamirano & Hernández-Becerril, 1998
	Thalassiosira mala Takano	Hernández-Becerril & Tapia Peña, 1995
	Thalassiosira minuscula Krasske	Hernández-Becerril & Tapia Peña, 1995
	Thalassiosira subtilis (Ostenfeld) Gran	Hernández-Becerril & Tapia Peña, 1995
Raphidophytes		
	Heterosigma akashiwo (Hada) Hada ex Hara et Chihara	Hernández-Becerril & Bravo Sierra
Cyanophytes		
	Trichodesmium erythraeum Ehrenberg	Cortés-Altamirano y Hernández-Becerril, 1998
	Trichodesmium hildebrandtii Gomont	Cortés-Altamirano y Hernández-Becerril, 1998
	Trichodesmium thiebautii Gomont ex Gomont	Cortés-Altamirano y Hernández-Becerril, 1998

Table 22 Seafood poisoning caused by marine biotoxins in Mexico.

Location	Edible organism (Common name)	Edible organism (Scientific name)	Toxin	Reference
Baja California Sur: Concepción Bay	White clam	*Diosinia ponderosa*	PSP	Sierra-Beltrán *et al.*, 1996.
Baja California Sur: Concepción Bay San Carlos Magdalena Bay	Catarina Clam	*Argopecten ventricosus*	PSP	Sierra-Beltrán *et al.*, 1996.
Baja California Sur: La Paz	Almeja Chocolata	*Megapitaria aurantiaca*	PSP	Sierra-Beltrán *et al.*, 1998.
Baja California Sur: Concepción Bay Santa Rosalía	Callo de hacha	*Pinna rugosa*	PSP	Sierra-Beltrán *et al.*, 1996.
Baja California Sur: Concepción Bay	Almeja voladora	*Pecten vogdesi*	PSP	Sierra-Beltrán *et al.*, 1996.
Gulf of Tehuantepec	Goose barnacle	*Pollicipes polinerus*	PSP	Sotomayor-Navarro and Domínguez- Cuellar, 1993.
Baja California Sur: Concepción Bay	Choros	*Modiolus capax*	PSP	Sierra-Beltrán *et al.*, 1996.
Chiapas Oaxaca Guerrero Gulf of Tehuantepec	Mejillón	*Choromytilus palliopuncyayus* and *Mytilus sp*	PSP	Saldate-Castañeda *al.*, 1991; Sotomayor-Navarro and Domínguez-Cuellar, 1993.
Baja California Sur: Concepción Bay	Ostión	*Crasostrea palmula*	PSP	Sierra-Beltrán *et al.*, 1996.
Campeche, Chiapas Guerrero, Oaxaca Quintana Roo, Tabasco Tamaulipas, Veracruz Yucatán	Ostión	*Crasostrea virginica*	PSP?	Saldate-Castañeda, *al.*, 1991; Gómez-Aguírre and Licea , 1998.
Guerrero: Acapulco Gulf of Tehuantepec Michoacán	Ostión	*Ostrea iridiscens*	PSP	Ramírez-Camarena *et al.*, 1996; Sotomayor-Navarro and Domínguez-Cuellar, 1993.
Quintana Roo	Barracuda fish	*Sphyraena* sp.	CTX	Cortés-Altamirano *et al.*, 1996; Sierra-Beltrán *et al.*, 1998.
Baja California Sur	Pargo, snapper and grouper fish	*Lutjaneus* sp. *Seranidae* sp. *labridae* sp. *Mycteroperca prionura*, *Lutjanus colorado*.	CTX? Okadaic acid and DTX-1	Parrilla- Cerrillo *et al.*, 1993; Heredia-Tapia *et al.*, 2002.
Baja California Sur	Mackerel	*Scomber japonicus*	ASP	Sierra-Beltrán *et al.*, 1997.
Gulf of California	Sardine	*Sardinops sagax*	ASP	Ochoa *et al.*, 1998; SEMARNAPPROFEPA, 1997.
Gulf of California	Puffer fish, Bullseye puffer, lobeskin puffer, Guineafowl puffer, sponed sharpnose puffer	*Sphoeroides annulatus*, *S. lobatus*, *Arothron melagris*, *Canthigaster punctatissima*, *Sphaeroides* sp.	TTX	Ochoa *et al.*, 1997; Nuñez-Vázquez *et al.*, 2000.

bahamense var. *compressum* have been clearly identified as the causative organisms in all cases. It is interesting that *G. catenatum* has a maximum distribution from the upper Gulf of California to Acapulco, a range of about 13° of latitude (2200 km of coastline), while *P. bahamense* var. *compressum* has a maximum distribution from Costa Rica to Manzanillo, a range of about 8° of latitude (2200 km of coastline). Both species share a transition zone, between Manzanillo and Zihuatanejo, but do not appear to occur at the same time. The southern expansion of *G. catenatum* and the northern expansion of *P. bahamense* are responses to the influence and mixing of different coastal currents along the western Mexican coastline. It is noteworthy that the majority of *G. catenatum* outbreaks occur in Mazatlán Bay. This area may be considered as a "PSP-spreading center" from which cells are carried southward by the California Current. *P. bahamense* var. *compressum*, on the other hand, seems to originate from a center near Costa Rica and is carried northward by the Panama Current. The impact of ENSO events has a direct influence on the distribution of the two species, which is dictated by the mixing zone or front where the Panama Current encounters the California Current. A deeper study on the links between environmental changes and algal physiology may shed more light on the causes, distribution, and frequency of such noxious blooms.

Marine cyanotoxins in Mexico

The risk of harmful marine cyanobacteria blooms in aquaculture has been recognized during several incidents affecting the shrimp farms of northwestern Mexico in which blooms of *Schizothrix calcicola* were observed. To determine the noxious role of this organism, we ran several experiments and found that *S. calcicola* caused lesions in the gut of exposed post-larval white shrimp (*Litopenneaus vannamei*) interfering with food absorption. The exposed shrimp grew slower and were more prone to be attacked by infectious agents that could induce death (Pérez-Linares *et al.* 2002).

Other fish toxins in Mexico

In addition to suspected DSP and ciguatera cases, some fish poisoning events in Mexico are caused by tetrodotoxin (TTX) in various tissues of edible puffer fish (Tetrodontidae) species. TTX is not produced by harmful algal species but is included here for completeness. Fortunately, poisoning cases involving this toxin are less frequent in Mexico than in Japan. At least 5 edible species of puffer fish are found along the Pacific littoral of Mexico. About 700 tons are harvested every year, and yet only 18 casualties have been registered in the state of Baja California Sur in the past 30 years. Interestingly, the analysis of the various species (*Arothron meleagris*, *Spheroides annulatus*, *S. lispus*, *S. lobatus* and *Canthigaster punctatissima*) revealed that different tissues (mucus, muscle, liver, gonad, and intestine) possess distinct degrees of toxicity (Nuñez-Vázquez *et al.* 2000). In the case of *A. meleagris* and *S. lispus*, for example, the toxicity of the muscle is so high that its consumption should be avoided. The safest species in this family seems to be *Spheroides lobatus*, yet its mucus tested positive for toxin in the mouse bioassay. A conclusion of that work was a suggestion to the Fishery Department and Health Ministry to advise the population of the risk of eating pufferfish, which many consider a delicacy.

Relationship between "El Niño" and the pattern of incidence of HABs in Mexico

In the Gulf of California, there seems to be a positive relationship between occurrences of El Niño events and outbreaks of HAB (Ochoa and Lluch-Cota 2001). In other areas of Mexico, the opposite relationship is true. This is an important problem to approach, and additional attention should be paid to understand and isolate anthropogenic and natural mechanisms underlying HABs (Ochoa *et al.* 1998; Sierra-Beltrán *et al.* 1998).

Acknowledgements

We thank Dr. I. Fogel for help in manuscript revision, and also thank A. Landa and M. Trasviña for assistance with the figures.

References

Alonso-Rodríguez, R., Páez-Ozuna, F., Cortés-Altamirano, R. 1999. Trophic conditions and stechiometric nutrient balance in subtropical waters influenced by municipal sewage effluents in Mazatlán Bay (SE Gulf of California). Mar. Pollution Bull. 40: 331-339.

Beier, E. 1997. A numerical investigation of the annual variability in the Gulf of California. J. Physical Oceanography 27: 615-632.

Blasco, D. 1977. Red tide in the upwelling region of Baja California. Limnol. Oceanogr. 22: 255-263.

Cortés-Altamirano, R., Núñez-Pastén, A. 1992. Doce años (1979-1990) de registros de mareas rojas en la Bahía de Mazatlán, Sin. México. Anal. Inst. Ciencias del Mar y Limnol. (México), 19, pp. 113-121.

Cortés-Altamirano, R., Hernández-Becerril, D.U., Luna-Soria, R. 1995. Mareas Rojas en México: Una Revisión. Rev. Latinoam. Microbiol., 37, pp. 343-352.

Cortés-Altamirano, R., Hernández-Becerril, D.U., Luna-Soria, R. 1996. Red Tides in México: A Review. *In* Yasumoto, T., Oshima, Y., Fukuyo, T. (Eds.) Harmful and Toxic Algal Blooms. IOC-UNESCO, pp. 101-104.

Cortés-Altamirano, R., Manrique. F.A., Luna Soria, R. 1997. Harmful phytoplankton blooms in shrimp farms from Sinaloa, Mexico. In: 8th International Conf. On HABs, Vigo Spain. June 25-29. Abstr. Book.

Cortés Altamirano, R., Hernández-Becerril, D.U. 1998. Especies responsables y probables de mareas rojas. *In* Cortés Altamirano, R. (Ed.) Las Mareas Rojas en México. AGT editores,México, pp. 43-79.

Cortés-Altamirano, R., Licea-Durán, S. 1999. Florecimientos de microalgas nocivas en estanques de cultivo semi-intensivo de camarón en México. Rev. Latinam. Microbiol. 41: 157-166.

Gárate-Lizárraga, I. 1996. Mareas Rojas ocurridas en las costas de la Península de Baja California Sur, México, 1984-1994. *In* 1^{a}. Reunión Int. Planctonl. VIII Reunión Nac. de la SOMPAC. Pátzcuaro Mich. México. 23-26 Abril. Programa y Resúmenes, pp. 17.

Gárate-Lizárraga, I., Siqueiros-Beltrones, D.A. 1998. Time variation in phytoplankton assemblages in a sub-tropical lagoon system after the 1982-1983 El Niño event (1984 to 1986). Pacific Sci. 52: 79-97.

Gómez-Aguirre, S., Licea, S. 1998. Blooms of *Pyrodinium bahamense* (Dinophyceae) in coastal lagoons of the Southern Gulf of Mexico and the Mexican Caribbean. *In* Reguera B., Blanco J., Fernández M.L., Wyatt T. (Eds.) Harmful Algae. IOC-UNESCO, pp. 61-62. [See also: Anal. Inst. Biol. UNAM Ser. Zool. 1998, 69: 121-123].

Heredia-Tapia, A., Arredondo-Vega, B.O., Núñez-Vázquez, E., Yasumoto, T., Yasuda, M., Ochoa, J.L. 2002. Isolation of *Prorocentrum lima* and DSP risk assessment in the Gulf of California, Mexico. Toxicon. (In Press).

Hernández-Becerril, D.U. 1987. Especies de fitoplancton tropical del Pacífico Mexicano. I. Diatomeas y silicoflagelados. Rev. Latinam. Microbiol. 29: 415-426.

Hernández-Becerril, D.U. 1988. Planktonic dinoflagellates (except *Ceratium* and *Protoperidinium*) from the Gulf of California and off the coasts of Baja California. Botánica Marina 31: 423-435.

Hernández-Becerril, D.U. 1989. Species of the dinoflagellate genus *Ceratium (Dinophyceae)* from the Gulf of California and coasts off Baja California, Mexico. Nova Hedwigia 48: 33-54.

Hernández-Becerril, D.U., Tapia Peña, M.I. 1995. Planktonic diatoms from the Gulf of California and coasts off Baja California: species of the genus *Thalassiosira*. Botánica Marina 38: 543-555.

Hernández-Becerril, D.U. 1996. A morphological study of *Chaetoceros* species (Bacillariophyta) from the plankton of the Pacific Ocean of Mexico. Bull. Nat. Hist. Mus. London (Bot.) 26: 1-73.

Hernández-Becerril, D.U. 1998. Species of the planktonic diatom *Pseudo-nitzschia* of the Pacific coasts of Mexico. Hydrobiologia 379: 77-84.

Hernández-Becerril, D.U., Cortés Altamirano, R., Alonso, R. 2000. The dinoflagellate genus *Prorocentrum* along the coasts of the Mexican Pacific. Hydrobiologia 418: 111-121.

Hernández-Becerril, D.U. 2000. Morfología y taxonomía de algunas de las especies de diatomeas del género *Coscinodiscus* de las costas del Pacífico mexicano. Revista de Biología Tropical 48: 7-18.

Herrera-Silveira, J. 1999. Las Mareas Rojas. Biodiversitas, CONABIO, Mexico. 5, pp. 7-11.

Lechuga-Devéze, C., Sierra-Beltrán, A.P. 1995. Documented case of ciguatera on the Mexican Pacific coast. Natural Toxins 3: 415-418.

Lechuga-Devéze, C.H., Morquecho-Escamilla, M. L., Reyes-Salinas, A., Hernández-Alfonso, J.R. 2000. Environmental natural disturbances at Bahía Concepción, Gulf of California. *In* Munawar M., Lawrence, S.G., Munawar I.F., Malley D.F. (Eds.) Aquatic Ecosystems of México: Status and ScopeEcovision World Monopgraph Series. Backhuys Publs. Leiden, the Netherlands, pp. 245-255.

Licea, S., Moreno, J.L., Santoyo, H., Figueroa, G. 1995. Dinoflageladas del Golfo de California. UABCS, SEP-FOMES y PROMARCO.

Molina, R.E., Manrique, F.A., García, J. 1996. (TiTULO). *In* 1ª. Reunión Int. Planctología y VIII Reunión Nac. de la SOMPAC. Pátzcuaro Mich. México. 23-26 Abril. Programa y Resúmenes, pp. 39.

Morales-Blake, A., Cavazos-Guerra, C., Hernández-Becerril, D.U. 2001. Unusual HABs in Manzanillo Bay, Colima, Mexico. Harmful Algae News 22: 6.

Morquecho-Escamilla, M.L., Lechuga-Devéze, C., Hernández-Alfonso, J.R. 1997. Proliferaciones algales masivas en Bahía Concepción, BCS, México (1993-1996). Simp. Sist.. Acuáticos de México, Ciudad de México, 8-9 Marzo, Abs. 062.

Ochoa, J.L., Sierra-Beltrán, A., Cruz-Villacorta, A., Núñez-Vázquez, E. 1996. Domoic Acid in Mexico. *In* 5th Canadian Workshop on Harmful Algal Blooms, Sep. 10-13, St. John's, Newfoundland. Can. Tech. Rep. Fish. Aqua. Sci. 2138: 82-90.

Ochoa, J.L., Lluch-Cota, S., Sierra-Beltrán, A.P. 1997a. Mortandad de mamíferos marinos en el alto Golfo de California en Febrero de 1997. Reporte Técnico final. Secretaría de Ecología Medio Ambiente y Recursos Naturales (SEMARNAP)-Procuraduría Federal de Protección al Medio Ambiente (PROFEPA). México.

Ochoa, J.L., Sánchez-Paz, A., Cruz-Villacorta, A., Núñez-Vázquez, E., and Sierra-Beltrán, A. 1997b. Toxic Events in the Pacific coastline of the California peninsula in Mexico during 1992-1995: Origin and Impact. Hydrobiología 352: 195-200.

Ochoa, J.L., Sierra-Beltrán, A.P., Olaiz-Fernández, G., Del Villar Ponce, L.M. 1998a. Should mollusk toxicity in Mexico be considered a public health issue? J. Shellfish Res. 17: 1772-1673.

Ochoa, J.L., Sierra-Beltrán, A., Alonso-Colmenares, G., Barrada-Sánchez, H., Cruz-Villacorta, A., Núñez-Vázquez, E., Sánchez-Paz, A. 1998b. Biotoxins in the Pacific coast of Mexico. *In* Mycotoxins and Phycotoxins-Developments in Chemistry, Toxicology and Food Safety. Miraglia M., Van Egmond H., Brera C., Gilbert J. (Eds.). Academic Press, USA, pp. 441-448.

Ochoa, J.L., Lluch-Cota, S. 2001. El impacto del fenómeno El Niño/Oscilación Sur (ENOS) y su relación con las mareas rojas en México. *In* Escobar Briones E., Bonilla M., Badán A., Caballero M., and Winckell A., (Eds.) Los efectos del fenómeno El Niño en México 1997-1998. CONACYT, México.

Ochoa, J.L. 2002. The "ENSO" Phenomenon and the Toxic "Red Tides" in Mexico. Geophysics Int. (In press).

Orellana-Cepeda, E., Morales-Zamorano, L.A., Castro-Castro, N. 1993. A Conceptual model of coastal Red Tides off Baja California. *In* VIth Conf. Int. Toxic Mar. Phytoplankton. Nantes, France. Oct. 18-22, pp. 152.

Núñez-Vázquez, E., Yotsu-Yamashita, M., Sierra-Beltrán, AP, Yasumoto, T., Ochoa, J.L. 2000. Toxicities and distribution of tetrodotoxin in the tissues of puffer fish found in the coast of Baja California Peninsula, Mexico. Toxicon 38: 729-734.

Parrilla-Cerrillo, M.C., Vázquez Castellanos, J., Saldate-Castañeda, E.O., Nava-Fernández, L.M. 1993. Brotes de Toxicoinfecciones Alimentarias de Origen Microbiano y Parasitario. Salud Pública México. 35: 456-463.

Pérez-Linares, J., Cadena, M., Rangel, C., Unzueta-Bustamante, M.L., Ochoa, J..L. 2002. Effect of *Schizothrix calcicola* on white shrimp *Litopenaeus vannamei* (*Penaeus vannamei*) postlarvae. Aquaculture, (Submitted).

Ramírez-Camarena, C., Muñoz-Cabrera, L., Cabrera-Mancilla, E., Castro-Ramos, A.R., López-Ramírez, P., Orellana-Cepeda, E. 1996. *In* 1ª Reunión Int. Planctonlogía VIII Reunión Nac. de la SOMPAC. Pátzcuaro Mich. México. 23-26 Abril. Programa y Resúmenes, pp. 47.

Saldate-Castañeda, O., Vázquez-Castellanos, J.L., Galván, J., Sánchez-Anguiano, A., Nazar, A. 1991. Intoxicaciones por Toxina Paralizante de Molusco en Oaxaca. Rev. Salud Pública de México, 33: 240-247.

SEMARNAP-PROFEPA. 1997. Mortandad de mamíferos marinos cuyos cadáveres arribaron a las costas de Sinaloa. Informe Técnico. México.

Sierra-Beltrán, A.P., Morquecho-Escamilla, M.L., Lechuga-Deveze, C., Ochoa, J.L. 1996. PSP Monitoring Program at Baja California Sur, México. *In* Yasumoto, T., Oshima, Y., Fukuyo, Y. (Eds.) Harmful and Toxic Algal Blooms. IOC-UNESCO, Paris, pp. 105-108.

Sierra-Beltrán, A., Palafox-Uribe, M., Grajales-Montiel, L., Cruz-Villacorta, A., Ochoa, J.L. 1997. Sea bird mortality at Cabo San Lucas, Mexico: Evidence that toxic diatom blooms are spreading. Toxicon 35: 447-453.

Sierra-Beltrán, A.P., Cruz-Villacorta, A., Núñez-Vázquez, E., Del Villar, L.M., Crerecero, J., Ochoa, J.L. 1998. An overview of the marine food poisoning in Mexico. Toxicon 35: 447-453.

Sierra-Beltrán, A.P., Ochoa, J.L., Lluch-Cota, S., Cruz-Villacorta, A., Rosiles, R., López-Valenzuela, M., Del Villar-Ponce, L.M., Cerecero-Gutiérrez, J. 1999. *Pseudonitzschia australis* (Frenguelli) Responsable de la Mortandad de Aves y mamíferos Marinos en el Alto Golfo de California, México, en 1997. *In* Proceedings of the VIIIth COLACMAR. Tresierra-Aguilar A.E., Culquichicón-Malpica Z.G. (Eds.) Trujillo, Perú, October 17-21, pp. 886-887.

Sotomayor-Navarro, O., Domínguez-Cuellar, E. 1993.

Toxic red tide of *Pyrodinium bahamense* Var. *Compressum*, in the Tehuantepec Gulf of Mexico, and the Central American Pacific System. *In* VIth. Int. Conf. Toxic Marine Phytoplankton, Nantes France. Oct 18-22, pp. 185.

Summary and conclusions

F.J.R. "Max" Taylor[1] and Vera L. Trainer[2]

[1] University of British Columbia, 6270 University Boulevard, Vancouver, B.C., Canada V6T 1Z4. E-mail: maxt@unixg.ubc.ca

[2] Northwest Fisheries Science Center, National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112, U.S.A. E-mail: Vera.L.Trainer@noaa.gov

The national reports included here give, for the first time, an overview of HAB problems experienced by PICES member countries of the northern North Pacific and the state of knowledge in each. Although PICES has focused on the northern North Pacific (as reflected in the choice of the logo for the Organization), HAB phenomena do not respect such boundaries. For example, tropical ciguatera fish poisoning occurs within the warmer waters of countries such as China and the United States and there are tropical shellfish poisonings and fish killers that also extend beyond the southern limits of the current PICES member countries. To include warmer North Pacific waters we have invited scientists in Mexico to provide a national report to supplement those of member countries. In the future, we hope that other countries within or adjacent to the region will be linked by this or similar organizations. Ultimately it is hoped that all these will contribute to a synoptic, global review under the auspices of the IOC-UNESCO program, GEOHAB and the International Society for the Study of Harmful Algae (ISSHA).

From the country reports a number of general conclusions are evident. Serious HAB problems occur in all member and adjacent countries. These include human health hazards from various forms of shellfish poisoning that are not only of similar type but are often caused by the same organisms, even to the species level. Before noting some of these, attention should be drawn to name changes that may confuse the picture. We allowed the use of original species and genus names in the country reports. However the reader should be aware that all the toxic *Nitzschia* species in older literature are now in the genus *Pseudo-nitzschia* (always hyphenated), *Protogonyaulax* species are now all in *Alexandrium.* Several HAB species of *Gymnodinium* are now in other dinoflagellate genera such as *Karenia* (*brevis*, *mikimotoi*), *Karlodinium* and, most unfortunately because of the potential for genus/species confusion *Akashiwo* (*sanguineum*). The IOC has recently provided a list of all HAB species and their synonyms on its website.

Although taxonomic citation may vary, we know that similar species of *Alexandrium* cause paralytic shellfish poisoning (PSP) in all the PICES countries. In warmer waters of both the eastern and western North Pacific, tropical members of the same genus cause PSP, as well as *Pyrodinium bahamense* var. *compressum* and *Gymnodinium catenatum*. Similar species of the diatom genus *Pseudo-nitzschia* produce, or have the potential to produce, domoic acid (amnesic shellfish poisoning and its counterpart in benthic crustaceans and planktivorous fish) in all the member countries. The diarrheic shellfish poison producers of the dinoflagellate genus *Dinophysis* are also common. Fish and shellfish killers are almost as ubiquitous. Raphidophyte (chloromonad) flagellates of the genera *Heterosigma*, *Chattonella* and *Fibrocapsa* kill farmed fish in areas where there is major aquaculture activity, with the latter two genera more prevalent in the warmer waters. The dinoflagellate, *Noctiluca scintillans,* is ubiquitous in the coastal waters of the region but only seems to be a serious problem when it blooms within the confines of shrimp farms, such as those of southern China, where its effects can be catastrophic. Some fish killers, such as *Cochlodinium polykrikoides* and closely related species, seem to be predominantly problems in Korea (where it is the main source of severe losses), Japan and British Columbia. *Heterocapsa circularisquama* is so far only a destroyer of shellfish in Japan.

As noted earlier, human illness from ciguatera fish poisoning, caused by benthic dinoflagellates, primarily *Gambierdiscus toxicus*, is limited in the PICES region to the warmer waters of the U.S. and China, such as Hawaii and in the South China Sea. However, it is widespread in other tropical countries including Mexico and the Philippines. Additionally, the import of fish from tropical sources, *e.g*., Hong Kong, as well as tourist exposure while visiting the tropics, causes this illness to be more far-reaching to most temperate countries. These facts lend credence to earlier assertions that there is no coastal country in the world that does not have one form of HAB or another, or most likely several. Cyanobacteria, which are the predominant group causing HABs in freshwater, are less of a problem in the marine environment although microcystins, known only to be produced by cyanobacteria so far, have turned up in B.C. salmon farms. *Trichodesmium*, a common and abundant tropical cyanobacterium, is not usually harmful but can be if it enters the confined waters of shrimp ponds (China and S.E. Asian countries) and the Mexican report identifies others as being a serious problem in shrimp farms.

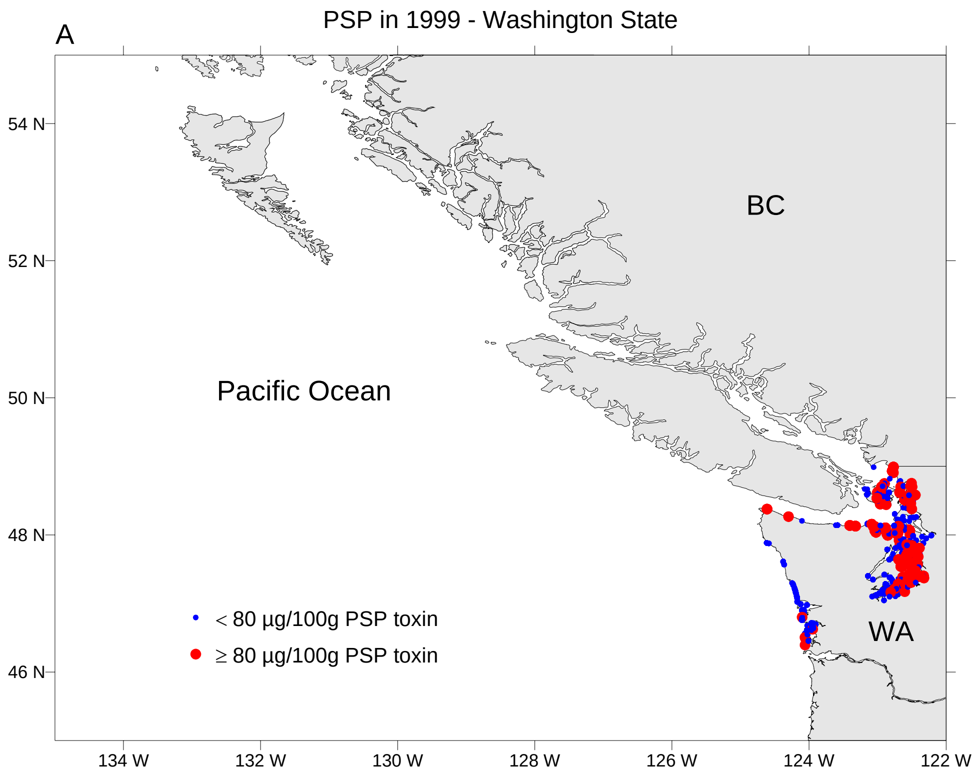
Combining the information from adjacent countries can provide a much more complete view of the scope of HAB problems and may even provide insights into important ecological questions that would not be apparent form viewing one country alone. In Figure 40 we show the PSP data for Washington State alone, and in combination with British Columbia for the same year. Not only is the scope of high PSP evidently much wider in the combined picture, but it also reveals an interesting difference between the outer coasts of the two. PSP is effectively absent in 1999 from the open Washington coast but commonly present on the west coast of Vancouver Island.

In order to draw realistic comparisons between countries, the standardization of terminology and methodologies is of urgent importance, not only in the PICES region, but also throughout the world. A major discrepancy involves interpretation of the term “red tide”. In some countries this refers only to fish or shellfish killers, but in others it may even include bloom-forming phytoplankton that are non-harmful but are a local economic problem. These non-harmful blooms commonly occur in other countries but would not be included in each country’s HAB reports. Some countries restrict reports of harmful algal blooms to those algae known to produce a toxin. Others distinguish “toxic red tides” from non-toxic ones where harm can be caused by non-toxic factors such as oxygen depletion. The word “toxin” may have different meanings, being synonymous to ingested poison by humans in some countries, but in others including, for example, the brevetoxins which kill fish in Florida.

It is evident that care should be taken in comparing lists of “red tide” species from different countries and particularly total numbers. Similarly, the number of incidents reported may be “sightings” rather than ecologically separate events and are thus dependant on the frequency and comprehensiveness of the observer network employed. Interannual reports can only be compared if the observation protocol is the same each year. Such considerations are obviously critical to the formation of large, multinational databases.

Fortunately the monitoring of PSP toxin levels in shellfish employs fairly standard methodology. Most countries follow the AOAC mouse bioassay method, with a closure level of 80 µg per 100g of shellfish meat in nearly all North Pacific countries. An exception is in the Philippines where, due to the greater concern about very young victims, a lower closure level of 40 µg is used. However, there are significant differences in the species of shellfish tested. This is unfortunate for the purposes of comparison, since different shellfish concentrate different levels of toxin for varying lengths of time. Mussels pick up toxins rapidly upon exposure and lose it the most rapidly, whereas butter clams, for example, retain PSP toxins for long periods of time. Razor clams retain domoic acid for months, whereas mussels depurate this toxin quickly.

In some countries, long-term data sets are of limited value because the species of shellfish routinely monitored has changed with time. Increasingly, for reasons of economy and convenience, many monitoring programs use mussels as “sentinel species” to test for shellfish



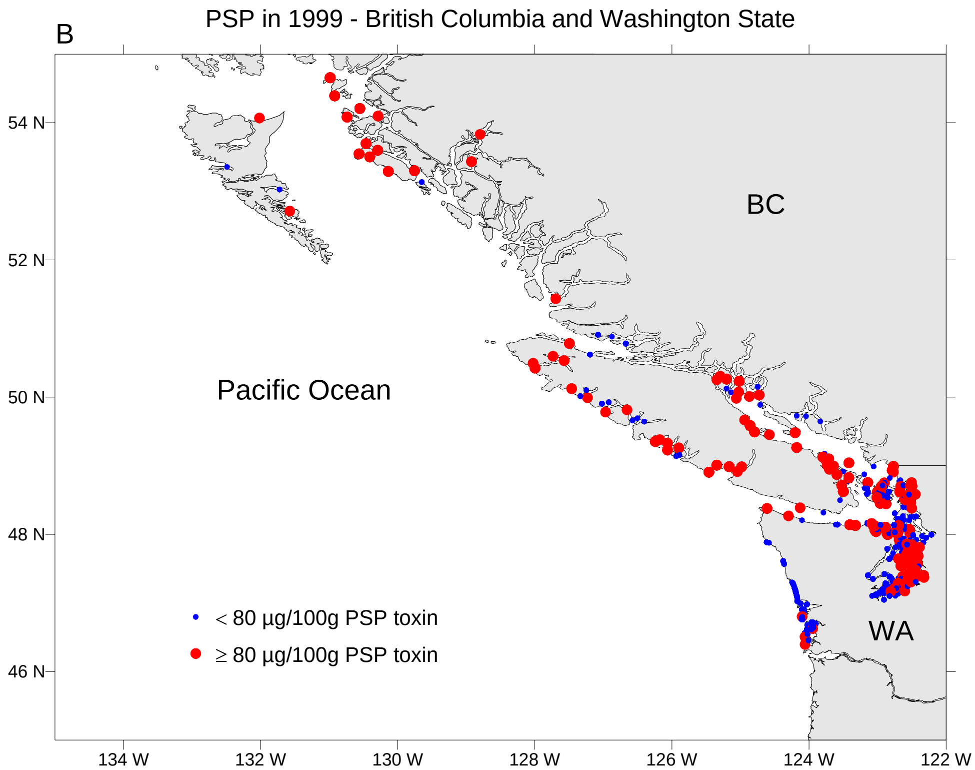


Fig. 40 PSP on the coasts of Washington State and British Columbia in 1999. A: Washington State alone. B: PSP data in the two regions combined.

toxins since these are the standard indicators of pollutants in "world mussel watch" programs. In most member countries, at least some plankton monitoring is carried out. While plankton monitoring programs alone are unlikely to serve as reliable methods of protection on a large scale, within limited areas, such as those of high aquaculture or shellfish harvest, they can provide early and supplemental warning and are essential for the understanding of the ecology of HABs.

Logistical and financial problems cannot be ignored in the management of HABs, given that some coastlines such as British Columbia, Alaska and northeast Russia are impossible to monitor comprehensively because of their length, complexity and difficulty of access. Typically blanket closures are issued for these remote coastal areas. Unfortunately, this can have an unwanted suppressive effect on the development of regional harvesting and aquaculture in economically deprived areas. Local people within these blanket closure areas tend to disregard management dictates and rely instead on traditional folk wisdom. The authorities, while acting responsibly, in fact lose control and respect.

Most reports focus on monitoring and prediction efforts in management, but a few have also provided information on mitigation efforts, such as the use of flocculents to sink blooms or algicidal bacteria and viruses as means of HAB control. These practical approaches are still in early development but clearly need to be encouraged where conditions make them feasible.

Interesting and important ecological questions arise from reviewing the national reports. For example, PSP appears to be less prevalent north of the Aleutians in Alaskan waters and more prolonged in northern British Columbia. The open coast of Washington, Oregon and California seem to be subject to PSP primarily in embayments whereas the B.C. outer coast has plentiful toxicity (Fig. 40 above). Are these observations actually artefacts of low sampling intensity or are they real? If so, why? There is a provocative sequence in timing of *Pseudo-nitzschia* blooms from south to north up the west coast of North America (Fig. 41). Is this due to a physical linkage, such as subsurface northward advection of toxic cells or is it a progressive triggering of local blooms following a seasonal progression whose timing is later in the north?

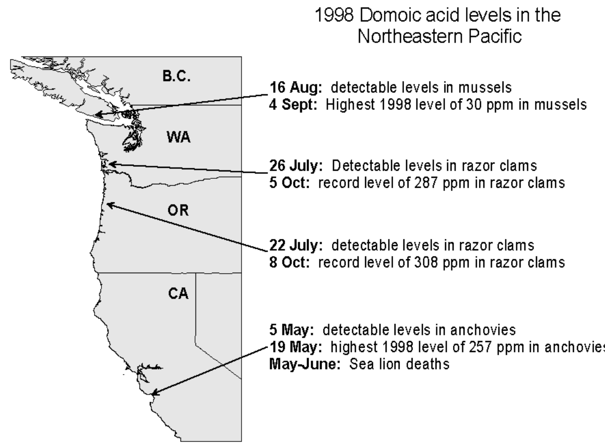


Fig. 41 The sequence of timing of first occurrence and maxima of domoic acid on the west coast of North America in 1998.

Although the primary direction of surface flow is southward throughout the summer months when these HABs are a problem, the northward reversal due to a shallow manifestation of the California Undercurrent, known as the Davidson Current, could provide northward advection of phytoplankton cells. Related to this is the question as to why certain local areas experience blooms much earlier than others?

Questions that occupy a central position in recent HAB literature are whether HABs are increasing in intensity (frequency, abundance and area) and spreading to new, previously unaffected areas. Some authors unjustifiably seem to assume that both are an established fact on a global scale. Others argue that factors such as increased awareness and local increases in aquaculture activity are contributing to false impression of environmental change for the worse.

No one disputes that the number of reports has been increasing exponentially in the past few decades. Several reports here shed light on these important questions. Some areas have undoubtedly had increases in HABs, of which a good example is *Cochlodinium* blooms on the southern coast of Korea.

The Seto Inland Sea of Japan apparently experienced a dramatic rise in phytoplankton blooms in the 1970s, followed by a decline, but harmful blooms remained at a fairly constant level throughout. PSP seems to be cyclic in many countries, with particularly bad years often being strong El Niño years, although a causal link has not been established. These and other important and exciting questions will no doubt continue to occupy a central position in HAB studies in the future. Multinational reports such as this one will provide a larger perspective from which to view HABs and increase awareness of the need for international co-operation.

Appendices

APPENDIX A

Members of Working Group 15

Canada

Paul J. Harrison
AMCE Program
Hong Kong University of Science
Clear Water Bay,
Kowloon,
Hong Kong.
Phone: (852) 2358-7348
Fax: (852) 2358-8363
E-mail: harrison@ust.hk

Maurice Levasseur
Maurice Lamontagne Institute
850 de la Mer Road,
P.O. Box 1000,
Mont-Joli, Quebec
Canada. G5H 3Z4
Phone: (1-418) 775-0608
Fax: (1-418) 775-0546
E-mail: levasseurm@dfo-mpo.gc.ca

F.J.R (Max) Taylor (Co-Chairman)
Department of Earth & Ocean Sciences
University of British Columbia
6270 University Blvd.,
Vancouver, B.C.,
Canada. V6T 1Z4
Phone: (1-604) 822-4587
Fax: (1-604) 822-6091
E-mail: maxt@unixg.ubc.ca

Ian Whyte
Pacific Biological Station
3190 Hammond Bay Road,
Nanaimo, B.C.,
Canada. V9R 5K6
Phone: (1-250) 756-7007
Fax: (1-250) 756-7053
E-mail: WhyteI@pac.dfo-mpo.gc.ca

People’s Republic of China

Tian Yan
Institute of Oceanology
Chinese Academy of Sciences
7 Nanhai Road,
Qingdao, Shandong,
People’s Republic of China. 266071
Phone: (86-532) 289-8589
Fax: (86-532) 289-3088
E-mail: tianyan@ms.qdio.ac.cn

You-Xian Yuan
Yellow Sea Fisheries Research Institute
Chinese Academy of Fisheries Sciences
106 Nanjing Road,
Qingdao, Shandong,
People’s Republic of China. 266071
Phone: (86-532) 583-6341
Fax: (86-532) 587-1514
E-mail: ysfri@public.qd.sd.cn

Ming-Yuan Zhu
Division of Mrine Biology
First Institute of Oceanography
State Oceanic Administration
Xianxianling Road,
Qingdao, Shandong,
People’s Republic of China. 266003
Phone: (86-532) 889-7447
Fax: (86-532) 889-0505
E-mail: myzhu@public.qd.sd.cn

Japan

Yasuwo Fukuyo
University of Tokyo
1-1-1 Yayoi, Bunkyo-ku,
Tokyo.
Japan. 113-8657
Phone: (81-3) 5841-2782
Fax: (81-3) 5841-8040
E-mail: ufukuyo@hongo.ecc.u-tokyo.ac.jp

Ichiro Imai
Graduate School of Agriculture
Kyoto University
Kitashirakawa, Sakyo-ku,
Kyoto,
Japan. 606-8502
Phone: (81-757) 536-356
Fax: (81-757) 536-375
E-mail: imailro@kais.kyoto-u.ac.jp

Masaaki Kodama
School of Fisheries Sciences
Kitasato University
Sanriku, Iwate,
Japan. 022-01
Phone: (81-192) 442-121
Fax: (81-192) 442-125
E-mail: kodama@kitasato-u.ac.jp

Kyoichi Tamai
Director, Harmful Algal Bloom Division
National Research Institute of Fisheries &
Environment of Inland Sea
Maruishi 2-17-5, Oono-cho,
Hiroshima,
Japan. 739-0452
Phone: (81-829) 55-0666
Fax: (81-829) 54-1216
E-mail: tamaik@nnf.affrc.go.jp

Republic of Korea

Man Chang
Marine Biology Division
Korea Ocean Research & Development
Institute
Ansan P.O. Box 29, Seoul,
Republic of Korea. 425-600
Phone: (82-345) 400-6213
Fax: (82-345) 408-5829
E-mail: mchang@kordi.re.kr

Chang-Hoon Kim
Department of Aquaculture
Pukyong National University
599-1 Daeyeon 3 Dong, Nam-Gu,
Pusan,
Republic of Korea. 608-737
Phone: (82-51) 620-6892
Fax: (82-51) 628-7430
E-mail: chkpknu@hanmail.net

Hak Gyoon Kim
Director, Environment Research Division
National Fisheries Research & Development
Institute (NFRDI)
408-1 Shirang-ri, Kijang-up, Kijang,
Pusan,
Republic of Korea. 619-900
Phone: (82-51) 465-0091
Fax: (82-523) 361-8076
E-mail: hgkim@haema.nfrda.re.kr

Russia

Dmitry L. Aminin
Pacific Institute of Bioorganic Chemistry
159 Prospect 100 let Vladivostoku,
Vladivostok,
Russia. 690022
Phone: (7-4232) 311-430
Fax: (7-4232) 314-050
E-mail: aminin@piboc.marine.su

Tatiana Yu. Orlova (Co-Chairman)
Institute of Marine Biology
17 Palchevskogog Street,
Vladivostok,
Russia. 690041
Phone: (7-4232) 317-107
Fax: (7-4232) 310-900
E-mail: orlovat@chat.ru

Vladimir M. Shulkin
Pacific Geographical Institute
7 Radio Street,
Vladivostok,
Russia. 690041
Phone: (7-4232) 320-652
Fax: (7-4232) 257-783
E-mail: shulkin@tig.dvo.ru

Inna Stonik
Institute of Marine Biology
17 Palchevskogog Street,
Vladivostok,
Russia. 690041
Phone: (7-4232) 310-905
Fax: (7-4232) 310-900
E-mail: innast@mail.primorye.ru

U.S.A.

Donald M. Anderson
Biology Department
Woods Hole Oceanographic Institute
Woods Hole, MA 02543
U.S.A.
Phone: (1-508) 289-2351
Fax: (1-508) 457-2134
E-mail: danderson@whoi.edu

William Cochlan
Tiburon Center for Environmental Studies
San Francisco State University
P.O. Box 855,
Tiburon, CA 94920-0855
U.S.A.
Phone: (1-415) 338-3541
Fax: (1-415) 435-7120
E-mail: cochlan@sfsu.edu

David Garrison
Division of Ocean Sciences
National Science Foundation
4201 Wilson Boulevard, Room 725
Arlington, VA 22230
U.S.A.
Phone: (1-703) 306-1587
Fax: (1-703) 306-0390
E-mail: dgarriso@nsf.gov

Vera L. Trainer
Northwest Fisheries Science Center
NMFS, NOAA
2725 Montlake Blvd. East,
Seattle, WA 98112
U.S.A.
Phone: (1-206) 860-6788
Fax: (1-206) 860-3335
E-mail: Vera.L.Trainer@noaa.gov

Mark L. Wells
School of Marine Sciences
University of Maine
5741 Libby Hall,
Orono, ME 04469-5741
U.S.A.
Phone: (1-207) 581-4322
Fax: (1-207) 581-4388
E-mail: mlwells@maine.edu

APPENDIX B

Original terms of reference (Vladivostok, 1999)

1. Identify the various species involved, and the timing, frequency, and duration of harmful algal bloom events;
2. Develop a regional database of relevant observational parameters associated with bloom events, including maps, bibliography, data sets and techniques, existing programs and expanded list of researchers in the area;
3. Investigate links between bloom events and environmental factors, trophic interactions and possible anthropogenic stress (e.g., eutrophication);
4. Assess the economic, health-related, and environmental impacts arising from harmful algal bloom events in order to improve the ability to predict the occurrence of these events and thus minimize their overall impacts;
5. Suggest areas where critical data are missing and where future research is necessary;
6. Facilitate regional collaborative research efforts at various levels to address these problems.

APPENDIX C

Annual reports of WG 15 on Ecology of Harmful Algal Blooms (HABs) in the North Pacific

2000 Annual report

The Working Group 15 held its first formal meeting from 0900 to 1230 hours and from 1330 to 1600 on October 22, 2000. The meeting was attended by 15 members from Canada, China, Japan, Korea, Russia and U.S.A. (*Endnote 1*). The proposed agenda for the meeting (*Endnote 2*) was adopted.

Assessment of HAB problems in the coastal waters of PICES countries (Agenda Item 1)

The Working Group 15 was created to facilitate studies in harmful algal blooms (HABs) in the member countries of PICES. This need was recognized at the previous PICES Annual Meeting in Vladivostok, Russia in 1999. The WG 15's first task has been to evaluate current knowledge of the extent and severity of HABs in these countries and to that end representatives of each of the countries presented reports summarizing the nature and state of knowledge (species, location, intensity and consequences) of HABs in their regions. To put these reports in perspective, a few prefatory remarks have been made by Prof. F.J.R. (Max) Taylor.

In the past few decades the study of HABs has become a multidisciplinary field of its own, combining taxonomy, phytoplankton ecology (nearly all are caused by photosynthetic microplankton, with *Noctiluca* being a notable exception), limnology, toxicology, public health, epidemiology, economics and aquaculture. At the IX International Conference in Hobart, Tasmania, this year, there were 500 participants from 45 countries. The scope of phenomena and causative organisms has undergone a dramatic expansion, leading to a flood of reports that have caused considerable concern in most coastal countries. HABs can be broadly subdivided into two types: those that harm marine fauna and those that cause potentially fatal human health problems. HABs can be fundamentally subdivided into those harming marine organisms and those that are hazardous to humans.

Marine fauna mortalities

Harmful algae can kill fish, seabirds and marine mammals, either through oxygen depletion, the release of toxins or through food chain transfer and accumulation. This is particularly an economic concern in aquaculture operations. For example, the pioneering, successful cultivation of yellowtail and red bream in the Seto Inland Sea of Japan was plagued by recurring blooms of raphidophyte algae, notably species of *Chattonella*. This also brought the role of eutrophication into focus since this has been known to produce an increase in HABs. In the PICES region this has been demonstrated not only in Japan but also in China and Korea. Fish killing dinoflagellates are also known from the PICES region. Major deaths of seabirds and sea lions have occurred in Monterey, California, in recent years, and elsewhere whales have died from toxins in their food, analogous to human health hazard.

Human health hazards

Humans can be affected by HABs primarily through eating contaminated seafood (shellfish or fish). Toxins produced by HAB species are accumulated by marine organisms feeding on them. The toxins are primarily neurotoxins although gastro-intestinal symptoms often precede them. The toxins act primarily on membrane permeability of sodium or calcium. For example, while saxitoxin blocks sodium channels and blocks nerve transmission ciguatoxin causes them to remain open, resulting in depolarization. The primary forms of HAB-related human intoxications in the North Pacific are:

a. paralytic shellfish poisoning (PSP) caused by saxitoxins;
b. diarrheic shellfish poisoning (DSP) caused by okadaic acid, dinophysisyoxin and pectenotoxins;
c. amnesic shellfish poisoning (ASP) caused by domoic acid; and
d. ciguatera fish poisoning (CFP) caused by ciguatoxin, ostreopsistoxin and possibly maitotoxin.

These are caused chiefly by dinoflagellates but ASP is linked to several species of the diatom genus *Pseudo-nitzschia*.

Summary of the National Reports (Agenda Item 2)

The National Reports on currents knowledge of HABs problem have been presented by all PICES member countries. These reports serve as the baseline on which WG 15 is going to build other activities. The first conclusion to be drawn is that all countries have significant HAB problems and may be worsening in some. Japan experienced costly fish kills in fish farms in the Seto Inland Sea due to chloromonad flagellate blooms, which have also been problematic to salmon farmers in British Columbia. The losses have run into the millions of dollars. Korea is plagued by dinoflagellate-related fish kills as is Hong Kong. China has experienced severe losses from HABs in its extensive shrimp farming activities. Eutrophication has been implicated in the Inland Sea, Hong Kong and Korean localities and shrimp farms are inherently eutrophic.

PSP is present in all PICES countries and particularly severe in western Canada, Alaska (extending as far south as California) and probably Russia. In Japan, PSP appears to have spread since the 1970s from the north down both the east and west coasts. In Korea toxicity has been known from the south coast since the 1970s. DSP has been recorded in Japan but there are few records elsewhere. Since the symptoms of the latter are difficult to distinguish from bacterial contamination it is only the presence of okadaic acid in shellfish that confirms DSP. In most PICES countries this is not tested for. ASP is well established on the west coast of the United States where it has mainly affected seabirds and marine mammals. Ciguatera fish poisoning, found in tropical and subtropical reef systems is a significant problem in Hawaii, is recorded from imported fish in Hong Kong and can be expected in offshore South China Sea locations.

Some coastlines, such as the eastern Bering Sea, are evidently understudied and field monitoring and research in HABs is usually not co-coordinated between adjacent countries even though the phenomena do not respect national boundaries.

Recommendations for 2001 activities (Agenda Items 3 and 5)

During the next year, WG 15 is planning to produce a series of maps showing the location of HABs in the PICES region. The initial maps will indicate historic knowledge of all HAB events in each PICES country. Since ICES is also producing such maps for its region (including the west coast of North America) it seems logical to follow the same format so that they can be additive, eventually contributing to a global picture.

In mid-2000, a questionnaire, based on the ICES equivalent, was sent to each country to serve as the start of a PICES HABs database. The suggested historical maps should be part of the database, which can then be updated by annual event reports.

These should be part of the database, which can then be added to by annual event reports, as is the case in the ICES region. In addition a questionnaire was sent to each country to serve as the start of a PICES database.

The Working Group proposed holding (jointly with POC and BIO) a session at PICES X on "Physical, chemical and biological interactions during harmful algal blooms". Drs. F.J.R. (Max) Taylor (Canada), and Vera L. Trainer (U.S.A.) were suggested as potential convenors, and one more convenor from Asia could be determined later, if the session approved by MEQ.

The Working Group also recommended (subject to approval by MEQ and Science Board) convening a 2-day Practical Workshop on "Taxonomy and identification of harmful algal bloom species" for experienced analysts from each country to ensure that all identifications of harmful species will be based on the same criteria. Many of the species are common to most of the participating countries. It is planned that the workshop will be held at the University of British Columbia in Vancouver, just prior to PICES X.

WG 15 reviewed the list of organizations and programs for collaboration and identified SCOR GEOHAB, IOS/WESTPAC HAB, and ECOHAB as the highest priority programs for interaction.

Steps toward the co-ordination of research, particularly fieldwork, in adjacent waters should be encouraged and facilitated.

Appendix C Endnote 1

Participation List

Canada
Paul J. Harrison
Maurice Levasseur
F.J.R. (Max) Taylor (Co-Chairman)

Japan
Yasuwo Fukuyo
Ichiro Imai

People's Republic of China
Tian Yan

Republic of Korea
Chang-Hoon Kim

Russian Federation
Dmitry L. Aminin
Tatiana Yu. Orlova (Co-Chairman)

U.S.A.
Donald M. Anderson
William Cochlan
David Garrison
Vera L. Trainer
Mark L. Wells

Observer
Young-Shil Kang

Appendix C Endnote 2

Agenda

1. An introduction. (F.J.R. (Max) Taylor)
2. National reports on HAB events in PICES countries:
   Canada (Paul J. Harrison and F.J.R. (Max) Taylor)
   China (Tian Yan)
   Japan (Yasuwo Fukuyo)
   Korea (Young-Shil Kang)
   Russia (Tatiana. Yu. Orlova)
   U.S.A. (Vera L. Trainer)
3. Discussion to plan joint activities.
4. Forum on new results:
   Tian Yan, Mingjiang Zhou, Meng Fu, Yunfeng Wang, Rencheng Yu, and Jun Li "Inhibition of egg hatching success and Larvae survival of the scallop, *Chlamys ferreri*, associated with exposure to cells and cell fragments of the dinoflagellate, *Alexandrium tamarense*"
   Chang-Hoon Kim "Bloom dynamics, physiology and PSP toxin production of *Alexandrium* species and *Gymnodinium catenatum* in the Korean coastal waters"

Vera L. Trainer "US West Coast Monitoring project"

Maria T. Maldonado, Eden L. Rue, and Mark L. Wells "The Role of trace elements in domoic acid production by *Pseudo-nitzschia* spp."

Donald M. Anderson "Biogeography of the Toxic Dinoflagellate Genus *Alexandrium*"

5. General discussion and recommendations to PICES.
6. Closing remarks.

2001 Annual report

Accomplishments in 2000 – 2001

1. Accomplishments include more complete and uniform country reports from China, Japan, Korea, Russia, western U.S.A. and western Canada. Mexico would also like to contribute their report to this publication. The WG 15 requests that national reports be published in the PICES Scientific Report Series. The report will include an introduction/background (Dr. Max Taylor), country reports (these will detail types of HAB events, seasonality, earliest dates recorded, highest toxin levels, general environmental information, comprehensive literature, causative organisms, bloom reports including maps, unanswered questions, and hopes for future work), summary (Dr. Max Taylor), and appendices (to include images, scanning electron micrographs, and maps).

2. A workshop on *Taxonomy and identification of HAB species and data management* was held at the University of British Columbia, October 4-5, 2001, hosted by Dr. Max Taylor. Guest speakers included Dr. Laurie Connell from University of Maine (molecular probes) and Ms. Michelle Tomlinson from the National Ocean Data Center (HAB database). Dr. Connell presented a session on gene probes that are currently being used and/or development for automated HAB species detection. She gave a demonstration of this technique and described the pros and cons of its use. Ms. Tomlinson gave a web-based demonstration of the HAB database that is currently being developed for the entry of biological HAB data. To date, shellfish toxin data from Washington State has been entered. Alaska and British Columbia shellfish monitoring data will be entered by December 2001. These data can be accessed on the web and maps of HAB events can be created. (This work was also presented at the TCODE Electronic Poster Session). The intent of the WG 15 is to add HAB information into this database from as many

PICES member countries as possible (also including Mexico).

3. General recommendations to MEQ
   a. More interaction and collaboration between adjacent/contiguous countries is desired. For example, *Pseudo-nitzschia* and *Heterosigma* projects between the United States and Canada could be encouraged by PICES.
   b. Monitoring of both shellfish and plankton is desired of all countries. There are serious limitations and problems in comparison among countries when only a single sentinel shellfish species is used for monitoring.
   c. Information needs are identified, especially from Russia, the northern B.C. coast, and northern Alaska. Monitoring projects are required in these areas that are generally lacking in HAB data.
   d. Mexico should be included in the database project and has expressed a desire to do so.
   e. There is the need for a basic taxonomy class, especially for young U.S. and Canadian scientists (there are taxonomy

classes that are offered, but these are focused towards scientists from 3rd world countries). This basic taxonomy class could be sponsored by ICES and/or PICES (perhaps jointly).

f. Convene a 2-day workshop on *Development of common standards for HAB data* prior to PICES XI. A possibility to conduct this workshop jointly with TCODE should be pursued.

APPENDIX D

Workshop report on *Taxonomy and identification of HAB species and data management*

Introduction

The workshop was held over one and a half days prior to PICES X, at a venue provided by the Botany Department at UBC. After welcoming the 23 participants, the convenor, Dr. Max Taylor, stated the goals of the workshop, reminding them that it was not a training workshop but rather an opportunity for analysts to discuss problems related to the accurate identification of harmful species, uniformity of taxonomy and data reporting, management and usage. The agenda included presentations by Drs. F.J.R. "Max" Taylor, Yasuwo Fukuyo, Rita Horner, Laurie Connell and Ms. Michelle (Shelly) Tomlinson (in order of appearance), but provided as much time in the laboratory as possible to observe practical demonstrations and to microscopically examine material brought by the participants.

Presentations

Dr. Taylor used a brief summary of problems with fish- and shellfish-killing flagellate species to introduce taxonomic difficulties with HABs. These include misidentification (*Heterosigma* as *Olisthodiscus* in much earlier literature), taxonomic priority and usage (*H.carterae* vs. *H.akashiwo*), recent name changes (*Karenia, Karlodinium, Akashiwo*), species recognition (within *Chattonella*) and the need for infraspecific levels of discrimination. Problems arising from the complex putative life-cycle stages and modes of nutrition in *Pfiesteria*, plus difficulty in distinguishing it from "*Pfiesteria-like organisms*" which may not be closely related (e.g. *Karlodinium galatheanum*), as well as toxin type and source were briefly mentioned. It is suspected that some common (psammophilic) sand dinoflagellates having a similar mode of feeding, currently attributed to *Katodinium*, may be closely related (Taylor, unpubl.).

It was noted that almost any bloom-forming phytoplankter can kill marine fauna if locally over-concentrated, leading to plankton death and oxygen depletion. Members of *Gonyaulax* have been commonly involved in this type of HAB phenomenon. The special case of *Noctiluca*, a microzooplankter often included in HABs because of numerous kills of fish and shrimp, especially in China, was illustrated and discussed. Only one species, *N. scintillans* (syn. *N.miliaris*) has been morphologically discriminated but more may exist and there is a need for genetic studies. The mechanism(s) of death due to *Noctiluca* blooms is unclear although high ammonia levels may be involved. It usually occurs in confined bodies of water, such as shrimp ponds. In passing it can be noted that this common, cosmopolitan species is often treated in ecological studies as if it was a phytoplankter, with possible links to inorganic nutrients being sought, but such links can only be indirect since its blooms have to follow those of a prey species.

The HAB biogeographic picture shows extraordinary latitudinal cosmopolitanism, including bihemispherism and a general lack of true endemicism (except in polar regions) is the norm. This is generally not appreciated by non-phytoplanktological taxonomists and has an important bearing on the significance of supposed ballast water introductions. It is to be expected from general dinoflagellate biogeography that, for example, it is highly likely that species of *Pfiesteria* will be found in shallow estuaries in other countries with similar coastal temperature ranges such as Brazil or southern Africa or Australia. Given the present climate of interpretation, artifical introduction would almost certainly be invoked as an explanation.

Dr. Fukuyo began by illustrating the seven orders of dinoflagellates involved in HABS, with most HAB species being found in the Prorocentrales (*e.g.*, okadaic acid-producing *Prorocentrum* spp,), Dinophysiales (DSP-associated *Dinophysis* spp.), Gonyaulacales (several genera including *Alexandrium, Pyrodinium, Gambierdiscus, Ostreopsis*) and Gymnodiniales (*Karenia, Karlodinium* etc.). He provided plentiful excellent identificatory aid material to the participants, including publications and a CD produced in Japan. In the Peridiniales, the recently described *Heterocapsa circularisquama* requires electron microscopy of its scales in order to identify it, but it has a characteristic movement when seen alive. It has killed oysters and other bivalves in Japan but fish in Hong Kong. The toxin of this economically important, recently described species is unknown.

Dr. Fukuyo then focussed on the PSP-producing genus *Alexandrium* with more than 20 species implicated in this widespread phenomenon as well as fish killers. He used it to illustrate the criteria employed in identification (tabulational features revealed by calcofluor or iodine staining) and visual aids to the identification of the species, including a manuscript by M. Yoshida prepared for a recent IOC-DANIDA training workshop. It was noted here, as seen earlier by Dr. Taylor, that the shape of cells and number of plates change in culture. In particular, chain formation is often reduced in culture, resulting in cells more rounded in shape.

This was followed, after laboratory material examination of dinoflagellates, by Dr. Horner who gave a talk on HAB diatoms, focussing on domoic acid-producing species of *Amphora*, *Nitzschia* (a recently-described benthic species from Vietnam) and *Pseudo-nitzschia* (six species so far). After a brief history of HAB diatom studies on the west coast of North America, noting that it is almost certain that records of *Pseudo-nitzschia seriata* (= *Nitzschia seriata*) before the late 1990's are actually of *P. australis*, focus turned to the problems of visually discriminating between various toxic and non-toxic species of *Pseudo-nitzschia.* Electron microscopy, SEM or TEM, is needed to observe the fine details of valve structure needed to discriminate the species. Examples of local representatives of well-known toxic species were illustrated, including *P. australis, P. multiseries* and *P. pseudodelicatissima. P. granii* has been isolated recently from the open North Pacific Ocean by researchers from UBC. Problems of overlap in descriptions and arising from different views (valve, girdle) were discussed. As toxicity varies with strains or physiological state within known toxic species their mere presence cannot be taken as evidence of the presence of toxins in shellfish. This is also found in culture. Even the type of chain formation can vary, including the formation of *Fragilariopsis*-like chains. A fungal parasite is commonly seen in wild coastal N.E. Pacific populations.

Another problem associated with diatoms in the PICES region is the death of farmed fish due to physical gill damage by *Chaetoceros concavicornis* and, possibly, *Ch. convolutes.* Earlier records referred only to the latter species but Taylor and co-workers have concluded that the former is the greater threat, having more developed spinulae on the setae. It is interesting that this species does not seem to be a problem, or is unrecognized, in other temperate fish farming areas.

In the laboratory, Dr. Connell gave a talk and demonstration of a commercially available LSU RNA sequence quantitative technique for HAB species identification (Saigene). It is almost fully automated and can handle large numbers of samples. It is in current use for identifying species of *Chattonella, Heterosigma, Alexandrium* and *Pseudo-nitzschia* (there are outstanding difficulties with *P. pseudodelicatissima*). In the future, based on complete sequences of rRNA, it is likely that microchip probes will be developed. A very recent presentation at the 7th International Phycological Congress by Linda Medlin and European colleagues showed excellent promise for discriminating species of *Alexandrium.*

Other fluorescent probes are used for toxins, using labelled antibodies. ELISA and other antibody methods for toxin detection in cells or shellfish were not discussed here since this workshop dealt with species recognition, but the need for a workshop on recent developments in these techniques was recognized as a need.

Ms. Tomlinson gave a talk and a web-based demonstration of an online HAB Data Management System (HAB-DMS), which is now available through the National Oceanographic Data Center (NODC, U.S.A.) at www.nodc.noaa.gov/cgi-bin/hab/hab.pl. A Pacific region website has been created and can be found at www.nodc.noaa. gov/col/projects/habs/ pacindex.html. The FGDC record for the Washington State Department of Health PSP and Domoic Acid 1998-2000 (NODC #0000559) has been completed. The online linkage can be found at www.doh.wa.gov/ehp/sf/.

The Northwest Fisheries Science Center (NWFSC, NMFS, USA) has supplied harmful algal bloom datasets to the NODC. These include data from Washington State Department of Health, the Alaska Department of Fisheries. These data have been archived and documented using the FGDC format and are available in the originator's format through the NODC Direct system (www.nodc.noaa.gov/col/project/access/ nodcdir. html). The FGDC metadata descriptions will be provided to the Howard Diamond by NODC, as a part of a routine transfer of metadata. These HAB data sets have been re-formatted, and are in the process of being loaded into the HAB Data Management System (HAB-DMS). Currently, the HAB-DMS and web-based interface are being migrated to an operational mode. Therefore, sample data, which was loaded into the database for testing, are being removed and replaced by the current Washington State data sets archived at NODC.

In collaboration with Michelle Tomlinson, the NWFSC has developed a web-based form to facilitate the acquisition of information regarding Harmful Algal Bloom reports in Pacific Rim countries. These will be linked to the HAB database as another source of HAB data and information. A statement of work is being written to describe additional enhancements to the system, as well as requirements for linking these HAB reports, as well as other sources of coastal data sets which reside within NODC, to the system.

Conclusion and recommendations

There is a need for at least one training workshop in which inexperienced PICES phytoplankton analysts become familiar with a wide range of HAB species potentially harmful in their waters (both Dr. Fukuyo and Dr. Taylor have taught several of these before, mostly in S.E. Asia). A special workshop to be convened in Japan, next October, immediately prior to PICES XI, was recommended, and would focus on antibody-based toxin detection techniques.

Participation by more PICES countries at future workshops, especially countries not present at this workshop (e.g., China, Korea, Russia) has to be encouraged

The initial entry of HAB shellfish data from the western US into the NODC database has been successful. The goals for the upcoming year include entry of data from western Canada and Asian Pacific countries. It was recommended that Asian Pacific country representatives make available their historical shellfish toxin data for entry into the database. There is concern that these data may be of a sensitive nature, and not desirable for general release to the public. This concern can be circumvented by focusing on historical data that is at least two years old. Additional funding should be sought to continue collaboration of PICES with NODC.

There is a need to continue the development of possibly the most useful PICES HAB database. Much further discussion of HAB databases is required to deal with design and standardization issues. A further workshop on the latter seems to be essential.

Appendix D Endnote 1

Workshop agenda

October 5, 2001 (Friday):

0900 Gather at main entrance to Biosciences Bldg.
0915 Opening remarks, introductions, objectives, schedule
0930 *F.J.R. Taylor*. Fish-killing flagellates
0950 *Y. Fukuyo.* Dinoflagellate identification
1010 Coffee break
1030 Sample examination (lab.)
1200 Lunch break
1300 *R. Horner*. Diatom identification

1330 Sample examination/discussion (lab.)
1500 Coffee break
1520 *L. Connell.* Molecular identification aids demo
1700 Close Day 1

October 6, 2001 (Saturday):
0900 *M. Tomlinson.* Web access and HAB data handling
0930 Discussion
1030 Coffee break
1050 Sample examination/discussion (lab)
1200 Workshop conclusion

Appendix D Endnote 2

Participation list

Canada
Alexander Culley, Helen Drost, Nicky Haigh, Lawrence, Adrian Marchetti, F.J.R. (Max) Taylor (Convenor), and J.N.C. (Ian) Whyte

Colombia
Juan Saldarriaga

France
Pascale Loret

Indonesia
Gabriel Wagey

Japan
Yasuwo Fukuyo, Yuichi Kotami

U.S.A.
Brian D. Bill, William Cochlan, Laurie Connell, David Garrison, Julian Herndon, Rita Horner, Racheal Howard, James Postel, Michelle Tomlinson, Vera L. Trainer