Harmful algal blooms on the eastern coast of Russia

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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.

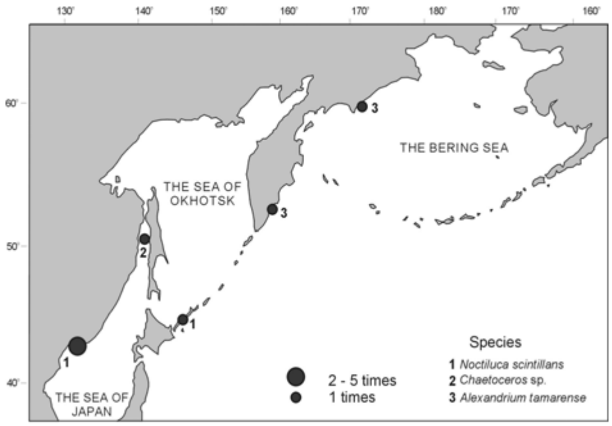

Fig. 16 Harmful algal blooms in the Far Eastern Seas of Russia (1909-1979).

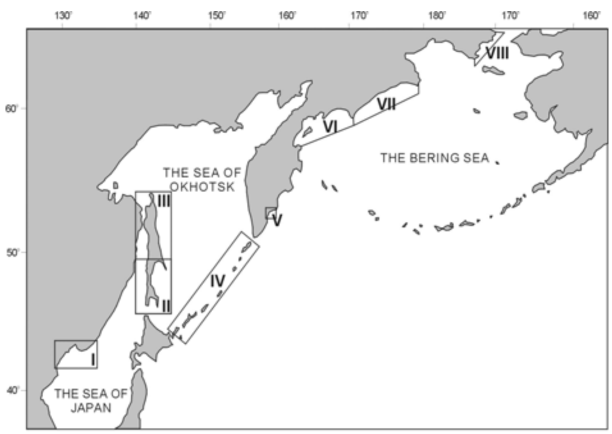

Fig. 17 Russian coastal waters into numbered sectors where harmful algae were studied.

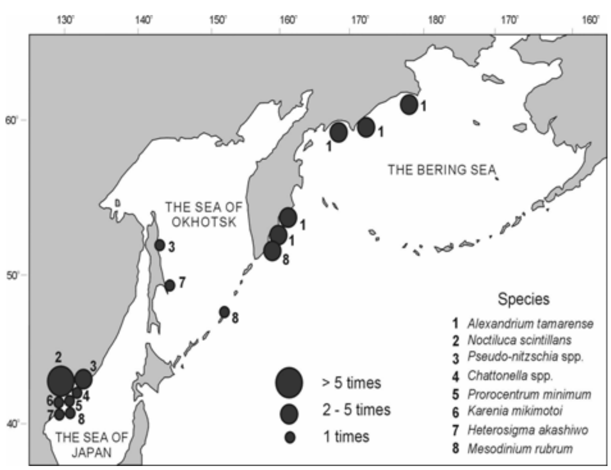

Fig. 18 Harmful algal blooms in the Far Eastern Seas of Russia (1980-2000).

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.

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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	Amurskii Bay	43°15' N	131°50' E	VII-1992	8×10^4
	I	Minonosok Bay	42°36' N	130°51' E	VI-1997	4×10^2
	I	Amurskii Bay	43°11' N	131°54' E	VIII-1997	1.5×10^4
	I	Amurskii Bay	43°11' N	131°54' E	VI-1998	5×10^3
	I	Amurskii Bay	43°11' N	131°54' E	VII-1998	2×10^3
	III	coastal waters of Sakhalin Island	52°51' N	143°22' E	VIII-2000	5×10^2
	I	Rinda Bay	43°02' N	131°48' E	VIII-2000	1.1×10^4
	III	Sakhalinskii Bay	54°29' N	142°03' E	VIII-2001	5×10^2
D. acuta	I	Amurskii Bay	43°11' N	131°54' E	VI-1998	2×10^2
	II	Aniva Bay	46°13' N	143°36' E	VIII-2000	2×10^2
	III	north-eastern coastal waters of Sakhalin Island	51°26' N	143°47' E	VIII-2000	2×10^2
	III	Sakhalinskii Bay	54°29' N	142°03' E	VIII-2001	2.1×10^3
D. fortii	I	Vostok Bay	42°50' N	132°46' E	VIII-2000	3×10^3
D. norvegica	II	Terpenie Bay	49°13' N	144°15' E	VIII-2000	8×10^2
	III	Sakhalinskii Bay	54°29' N	142°03' E	VIII-2001	1×10^2
D. rotundata	I	Amurskii Bay	43°11' N	131°54' E	VII-1998	3×10^1
	III	Sakhalinskii Bay	54°29' N	142°03' E	VIII-2001	6×10^2
Karenia brevis	I	Amurskii Bay	43°15' N	131°50' E	X-1993	3.5×10^3
K. mikimotoi	I	Amurskii Bay	43°15' N	131°50' E	IX-X-1990	1×10^6
Noctiluca scintillans	I	Peter the Great Bay	43°07' N	132°10' E	IV-1980	1×10^5
	I	Peter the Great Bay	43°07' N	132°10' E	V-1982	1×10^6
	I	Peter the Great Bay	43°07' N	132°10' E	VI-1992	1×10^5
	I	Peter the Great Bay	43°07' N	132°10' E	VI-1993	3×10^5
	I	Peter the Great Bay	43°07' N	132°10' E	IV-VII – -1994-1995	3×10^5
Prorocentrum minimum	I	Amurskii Bay	43°15' N	131°50' E	VII-1991	2.6×10^6
	I	Amurskii Bay	43°15' N	131°50' E	VIII-1991	8×10^6
	I	Amurskii Bay	43°15' N	131°50' E	VII-1992	1.1×10^6
	I	Minonosok Bay	42°36' N	130°51' E	VII-1997	2.4×10^4
	I	Amurskii Bay	43°11' N	131°54' E	VIII-1997	1×10^4
	I	Minonosok Bay	42°36' N	130°51' E	VIII-1999	4.2×10^4
RAPHIDOPHYTES						
Chattonella sp.	I	Amurskii Bay	43°15' N	131°50' E	IX - 1987	10×10^6
Chatonella globosa	I	Amurskii Bay	43°15' N	131°50' E	XI-1993	9×10^5
	I	Amurskii Bay	43°15' N	131°50' E	VIII-2000	5×10^5
Heterosigma akashiwo	I	Amurskii Bay	43°15' N	131°50' E	VI-1995	5×10^6
	III	north-eastern coastal waters of Sakhalin Island	49°25' N	144°48' E	VIII-2000	5×10^6

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.

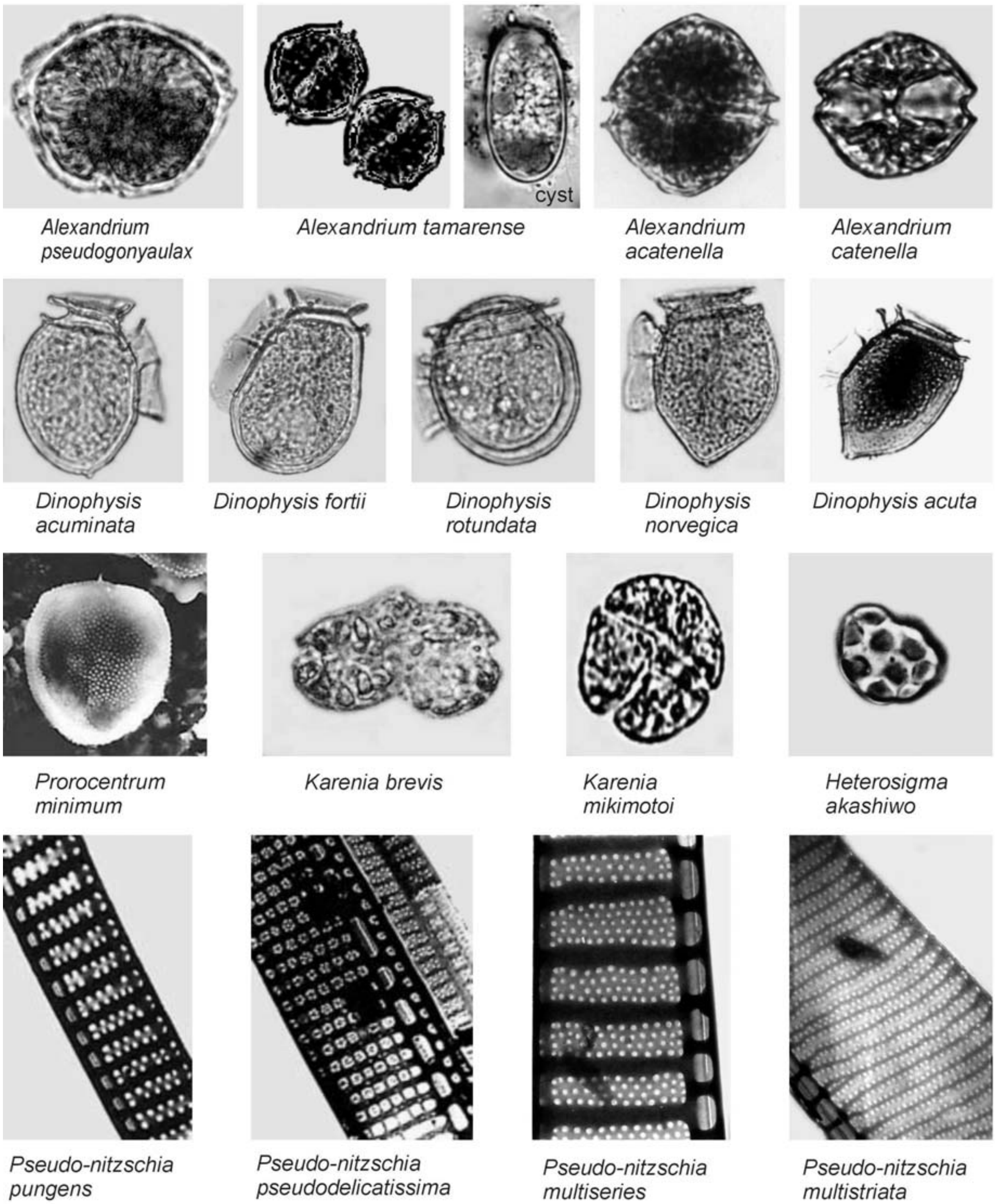

Fig. 19 Species found in the Far Eastern Seas of Russia and known to be harmful elsewhere.

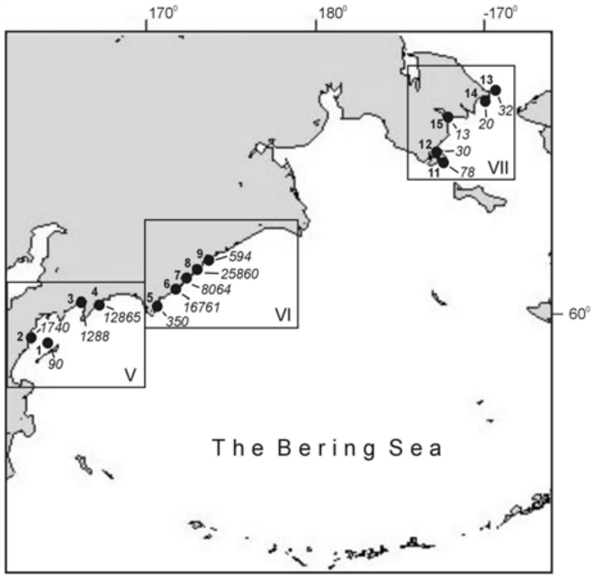

Fig. 20 The abundance of *Alexandrium tamarense* cysts per milliliter of sediment at 15 stations on the west coast of the Bering Sea (sectors V-VIII).

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)?

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Appendix RU

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

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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).

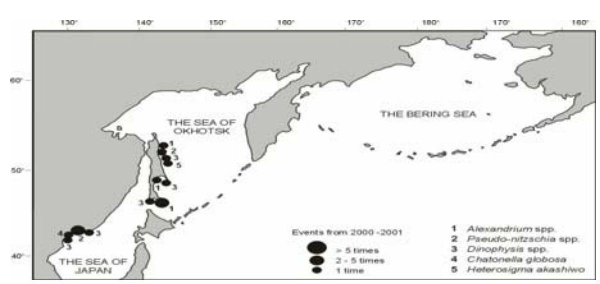


Fig. 21 Harmful algal blooms in the Far Eastern Seas of Russia (2000-2001).

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.

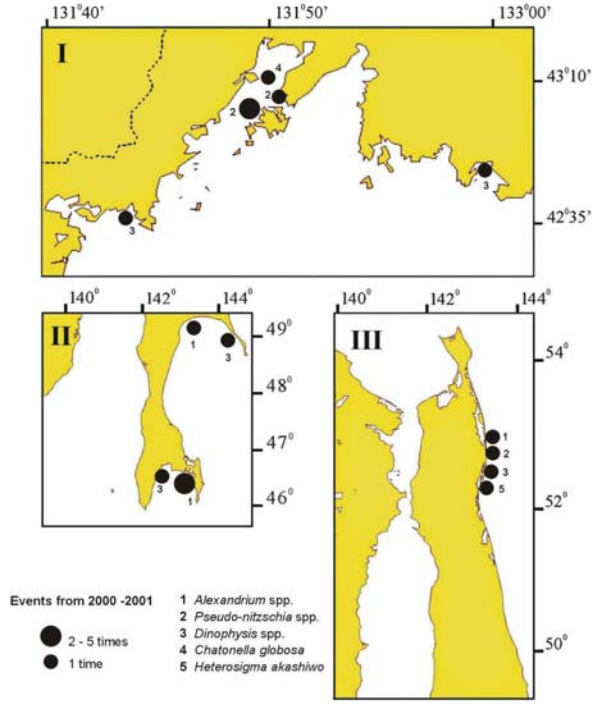
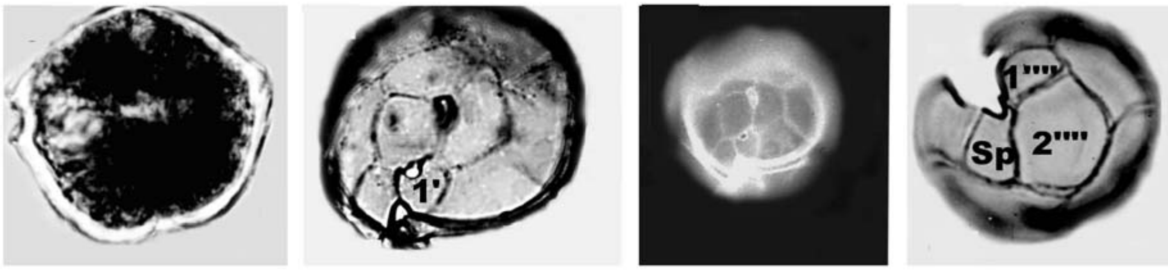


Fig. 22 HAB events in the Far Eastern Seas of Russia in 2000-2001.

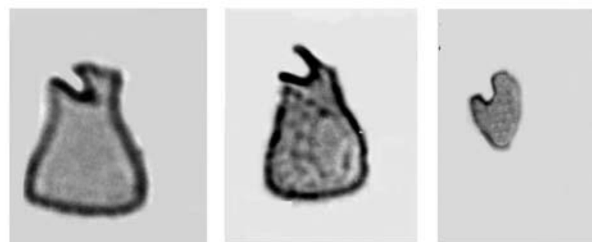
Table 14a Species found on the eastern coast of Russia in 2000-2001, and known to be harmful elsewhere.

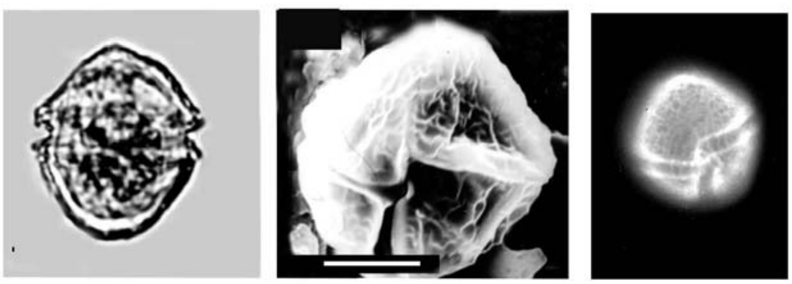
1.	Dinoflagellate species found in Russian waters and known to produce saxitoxins that causes paralytic shellfish poisoning (PSP)	*Alexandrium acatenella* *Alexandrium catenella* *Alexandrium tamarense*
2.	Dinoflagellate species that known to produce okadaic acid that causes diarrhetic shellfish poisoning (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

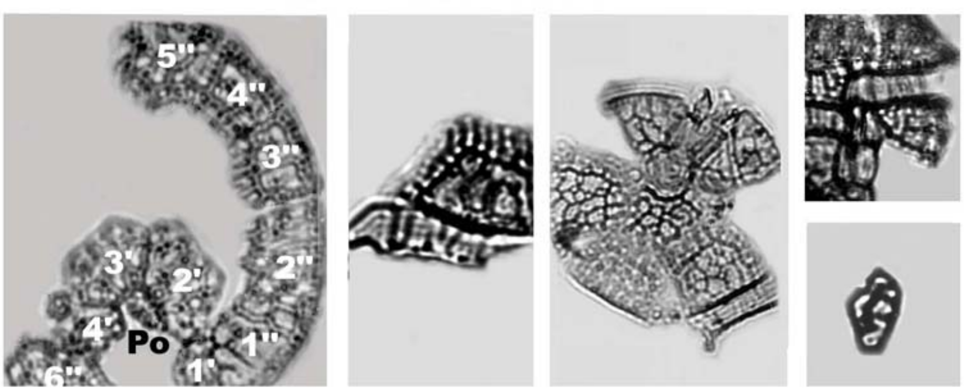


Alexandrium pseudogonyaulax



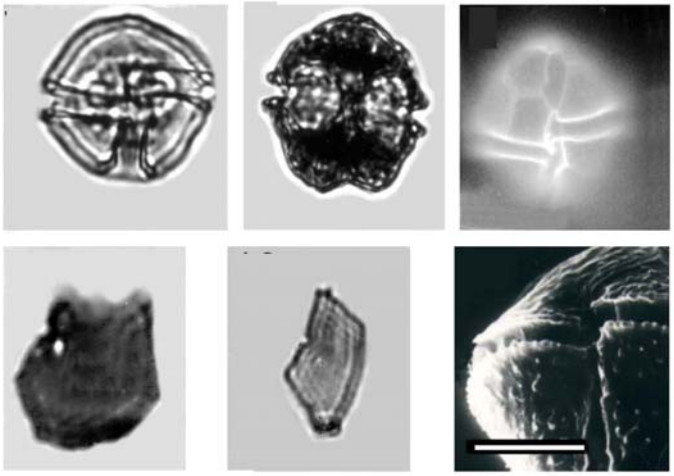


Alexandrium insuetum

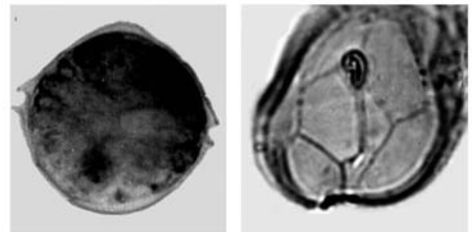


Photos by M.S. Selina

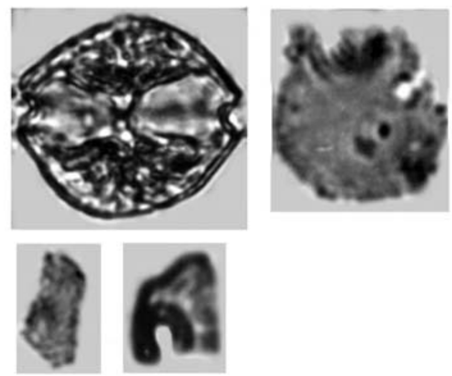
Alexandrium spp. from Pacific coast of Russia



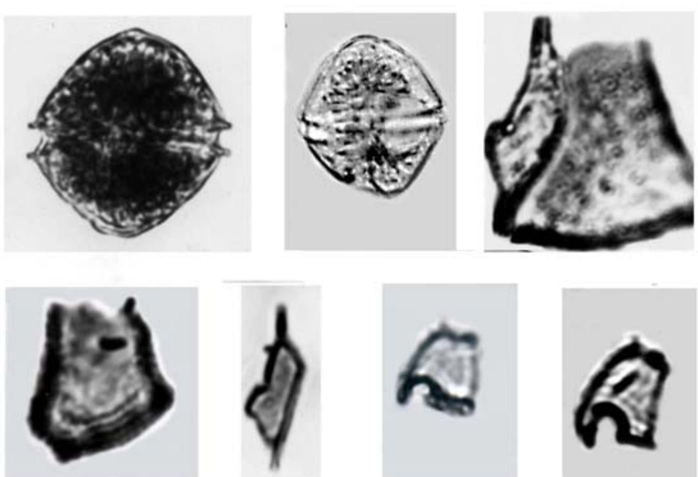
Alexandrium tamarense



Alexandrium ostenfeldi



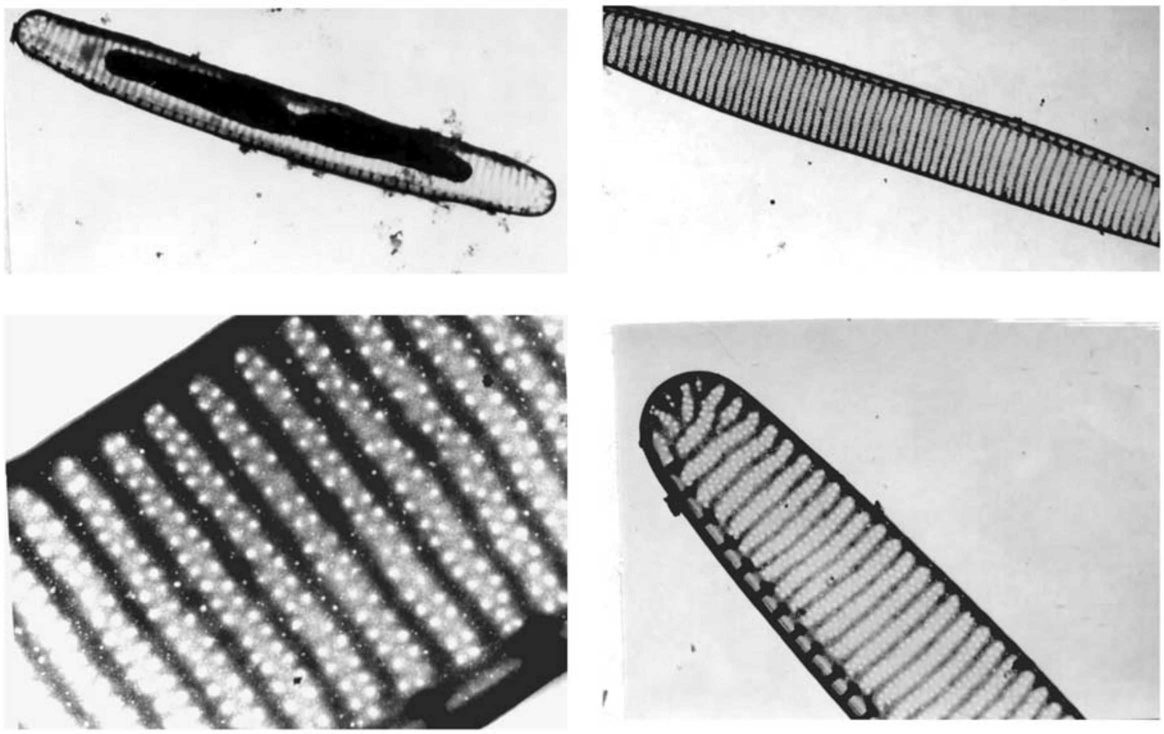
Alexandrium catenella



Alexandrium acatenella

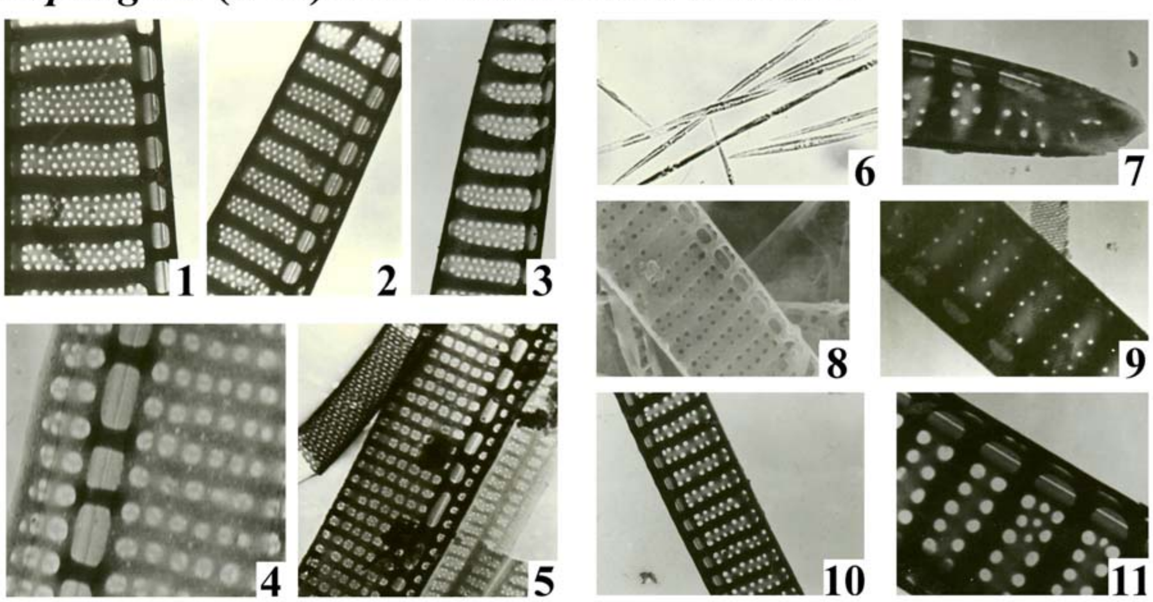
Photos by M.S. Selina

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



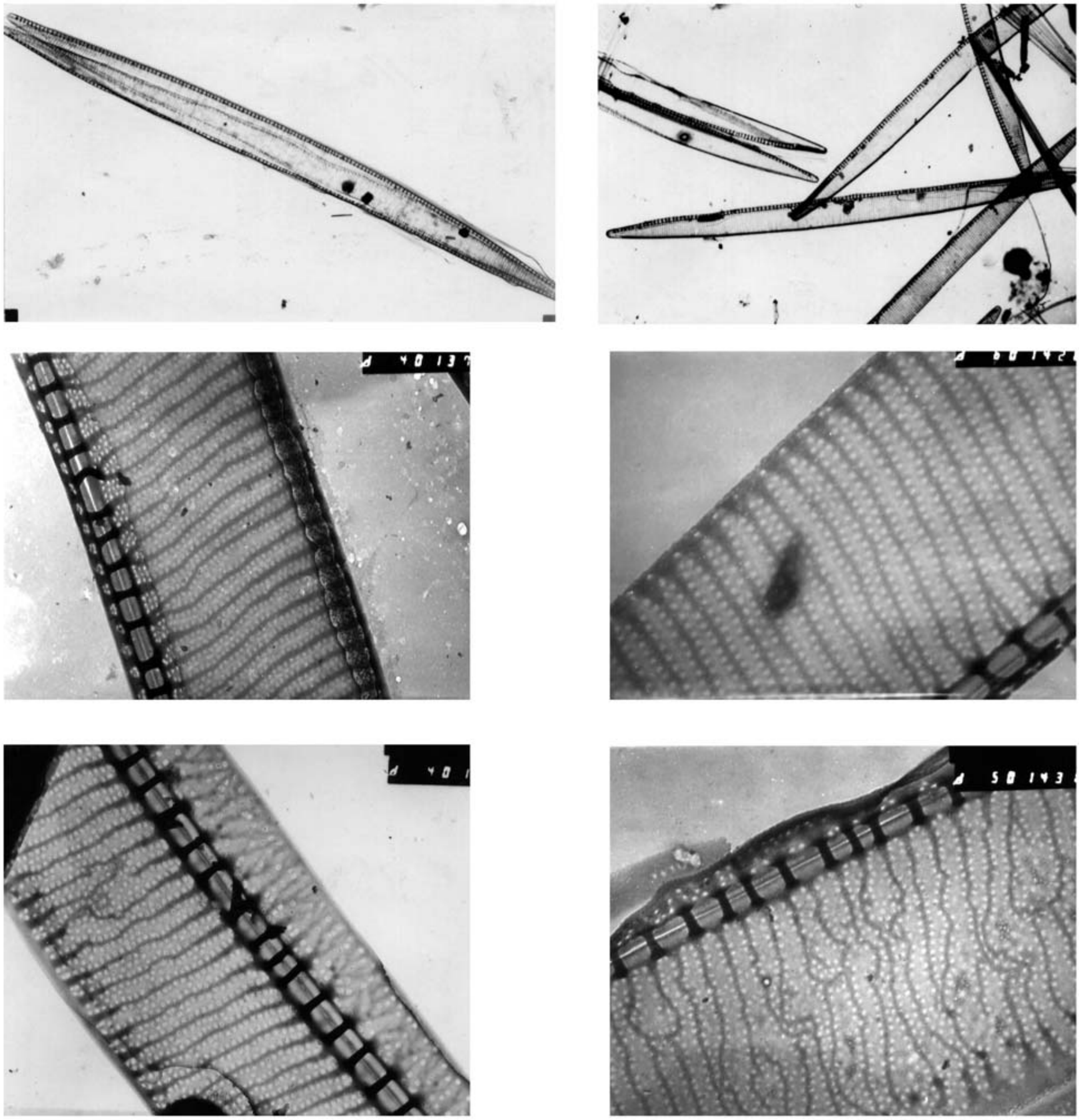
Photos by O.G. Shevchenko

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



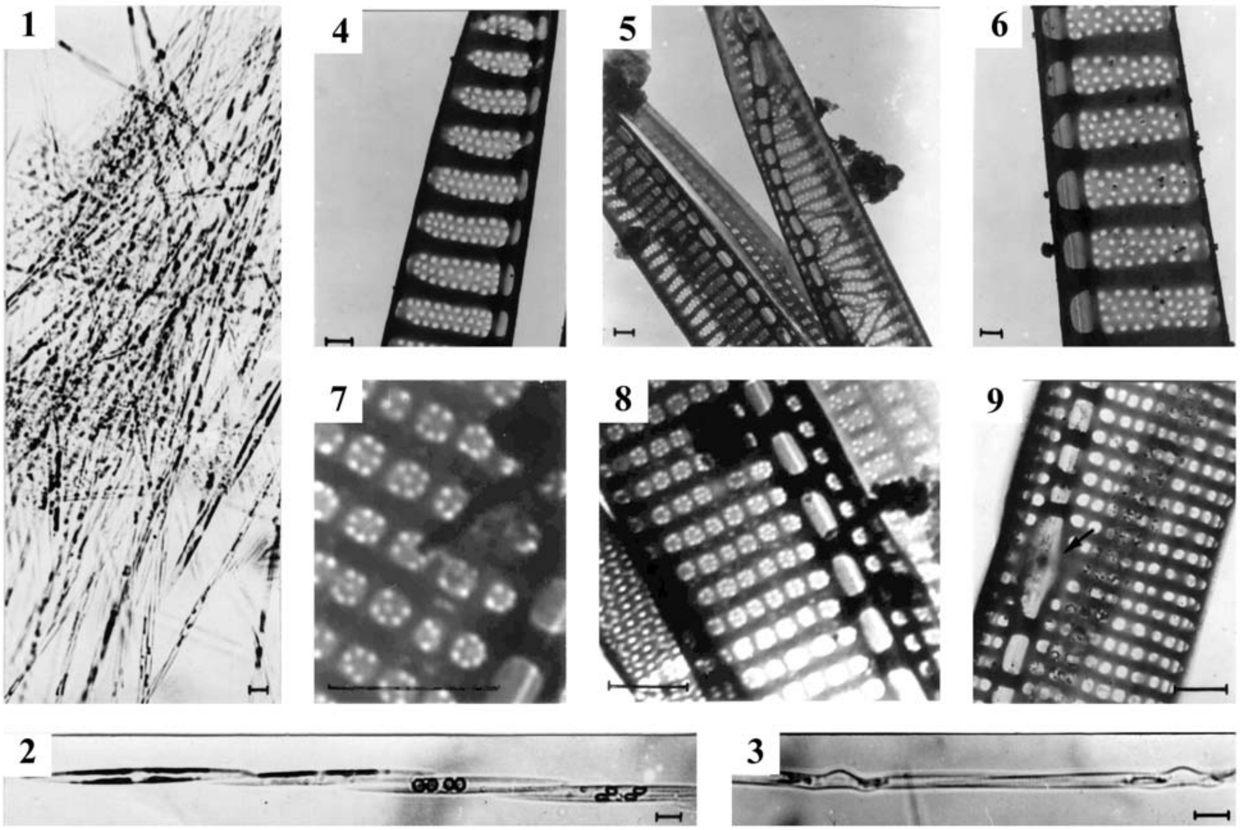
Photos by T.Yu. Orlova and I.V. Stonik

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



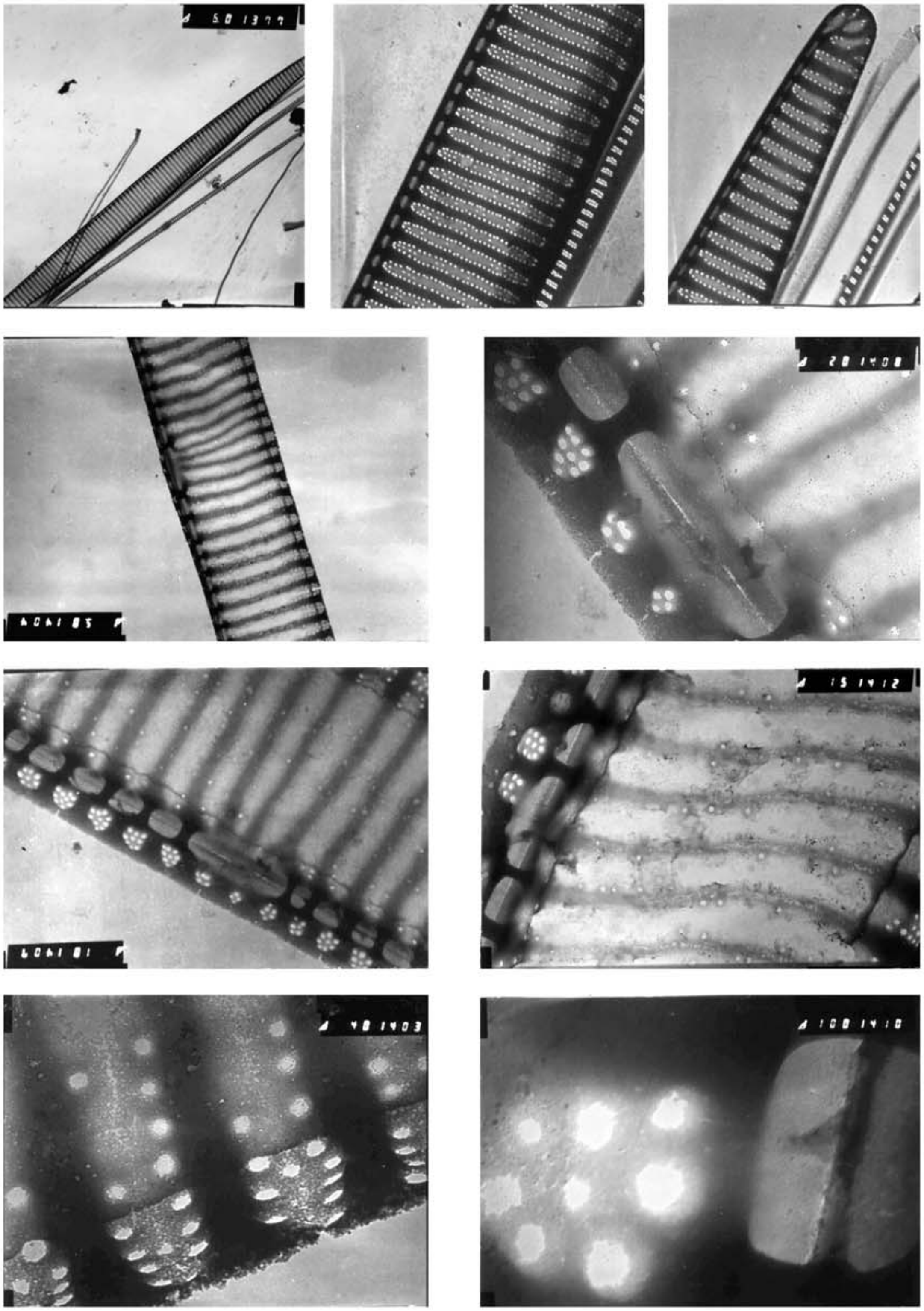
Photos by I.V. Stonik and O.G. Shevchenko

***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	

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