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NORTH PACIFIC MARINE SCIENCE ORGANIZATION

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2014

Proceedings of the Workshop on Economic Impacts of Harmful Algal Blooms on Fisheries and Aquaculture

Edited by
Vera L. Trainer and Takafumi Yoshida

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In Memoriam

On Friday, October 11, 2013, the international oceanographic community, and PICES in particular, lost one of their outstanding scientists when Professor Mingyuan Zhu passed away from a heart attack while walking to join members of the Section on *Ecology of Harmful Algal Blooms in the North Pacific* for dinner after their meeting at PICES-2013 (Nanaimo, Canada). He had given the China country report that afternoon with his usual enthusiasm.

Prof. Zhu became involved with PICES in 1995, as a member of the Biological Oceanography Committee. He served as a member of the Working Group on *Effective Sampling of Micronekton to Establish Ecosystem Carrying Capacity* (1997–2004) and Working Group on *Ecology of Harmful Algal Blooms (HABs) in the North Pacific* (1999–2003), and the Section on *Ecology of Harmful Algal Blooms in the North Pacific* upon its establishment in 2003. He was also a member of the Advisory Panel on *Anthropogenic Influences on Coastal Ecosystems* of PICES' integrative science program FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty, and **R**esponses of North Pacific Marine **E**cosystems). Prof. Zhu presented his research at many PICES Annual Meetings, and gave an invited talk at the Topic Session on "*The relative contributions of off-shore and in-shore sources to harmful algal bloom development and persistence in the PICES region*" at the PICES 2007 Annual Meeting (October 5–13, 2007, Victoria, Canada). During this period, he actively contributed to PICES' development and to the promotion of international approaches to marine science. His warm personality, sense of humor, and frankness made communication and collaboration with him so rewarding.

Prof. Zhu's contributions are well known to the world's HAB family. Upon his passing, an obituary was circulated to HAB researchers by the International Society for the Study of Harmful Algae (ISSHA) to remember Prof. Zhu's career. He served as Vice-Chairman of the IOC-FAO Intergovernmental Panel on Harmful Algal Blooms (1992–1996) and as Secretary General of the Chinese Committee of SCOR since 2004. He was very active in Chinese ocean science and in regional and international programs and projects such as the China Experts Group for the GEF/UNEP Yellow Sea Large Marine Ecosystem project, GEOHAB, where he was one of the pioneers coordinating research on both "red" and "green" tides in China, GLOBEC, and many others. He was instrumental in producing China's national protocol standards on chlorophyll *a* and primary productivity measurements, greatly adding to the development of knowledge of both HABs and biological oceanography in the regional seas.

Prof. Zhu's career as an oceanographer at the First Institute of Oceanography, State Oceanic Administration (SOA), China, spanned almost 40 years. Starting as a Research Associate, he then became the Director of the Department of Marine Biology and Deputy Director of the SOA Key Lab for Marine Ecological Science and Engineering. He was the principal investigator of many key national projects and strongly promoted domestic and international collaboration in scientific research such as the joint study of the Yellow Sea with Korean colleagues at the China–Korea Joint Ocean Research Center, for which he served as Director, the study of environmental carrying capacity with Japanese researchers, the study of eutrophication and shellfish toxins with U.S. scientists, and the study of sustainable mariculture with European partners. During his career, Prof. Zhu trained many graduate students and young scientists, who are a rich legacy of his honest and enthusiastic attitude for cooperative approaches to marine science research.

Prof. Zhu's leaving is a huge loss for the Chinese as well as worldwide phytoplankton and HAB communities. His passing is a shock to the many regional and international colleagues who had close ties with him, and his research team. We dedicate this PICES Scientific Report to Prof. Mingyuan Zhu with the spirit "to live and learn".

MINGYUAN ZHU

1943–2013

Introduction

The Section on *Ecology of Harmful Algal Blooms in the North Pacific* (S-HAB) was established in October 2003, under the direction of the Marine Environmental Quality Committee, to promote the sharing of information among PICES member countries on HAB occurrences in the North Pacific. Since its formation, the Section has studied the characteristics of HAB occurrences and the differences between them in the eastern and western Pacific, including historical changes, and has provided scientific information to PICES member countries and relevant stakeholders.

Over the past decades, serious damage caused by HABs has been reported with increasing frequency in the North Pacific. These blooms have adverse economic and social impacts on the aquaculture industry, human health, coastal economies, and wild fisheries. HABs have prompted routine closures of both commercial and recreational shellfish harvesting and have contributed to the deaths of aquaculture finfish, resulting in financial losses in coastal communities. However, the economic impacts generated by these events extend far beyond the industry itself. Obtaining more realistic estimates of HAB economic impacts, and the costs of preventing and managing them, calls for an integrated assessment approach that comprises the following: the economic impact of HABs on the aquaculture industry, the secondary integrated industries, and consumers, on both local and regional scales; some valuation of the costs and benefits of taking any recognized steps to lessen the HAB problem (*e.g*., reducing coastal pollution and other human-related activities); and weighing the costs and benefits of enhanced monitoring and surveillance that potentially reduces the magnitude of the impacts (*e.g*., by limiting shellfish harvesting closure windows or alteration in the timing of finfish harvesting).

This publication includes presentations made at a workshop on "*Economic impacts of harmful algal blooms on fisheries and aquaculture*" co-convened by Drs. Chang Hoon Kim (Korea) and Vera Trainer (USA) on October 11, 2013 at the PICES 2013 Annual Meeting in Nanaimo, Canada (see Appendices 1 and 2 for a summary of the workshop and list of participants), and three additional papers on the topic submitted by scientists who were planning but were unable to attend the workshop (Appendix 3). The following reports detail what is known about the economic and social impacts of HABs in the eastern and western Pacific by PICES and NOWPAP researchers who describe cutting edge approaches and methodologies for assessment of HABs. The thrust of the workshop, and the findings and insights that were derived, directly address two research themes of the PICES' integrative science program FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty, and **R**esponses of North Pacific Marine **E**cosystems), namely: (1) What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing? and (2) How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?

This scientific report is published jointly with the Northwest Pacific Action Plan of the United Nations Environmental Programme (UNEP NOWPAP). One of the Regional Activity Centres of NOWPAP, CEARAC (Special Monitoring and Coastal Environmental Assessment Regional Activity Centre), focuses on HABs as an environmental issue in the Northwest Pacific and collaborates with PICES' S-HAB as an *ex-officio* member.

PICES' S-HAB and NOWPAP hope this publication will provide useful information for the member countries of both organizations, and for our colleagues around the world.

Economic losses to the British Columbia salmon aquaculture industry due to harmful algal blooms, 2009–2012

Nicola Haigh and Svetlana Esenkulova

Harmful Algae Monitoring Program, Vancouver Island University, Nanaimo, British Columbia, Canada

Introduction

Marine salmon farming in British Columbia (BC), Canada, started in the early 1970s, and grew rapidly through the 1980s; by the early 1990s there were nearly 80 farms in BC producing approximately 20,000 tonnes of salmon annually (BCSFA, 2006; Fisheries and Oceans Canada, 2011). Currently, BC is the world's fourth largest farmed salmon producer after Norway, Chile, and the UK (Fisheries and Oceans Canada, 2011) with an annual salmon production of more than 70,000 tonnes and a market value of approximately 500 million Canadian dollars (Statistics Canada, 2010). Farmed salmon is BC's largest agricultural export and contributes approximately $150 million CAD a year ("gross value added") to the BC economy (Statistics Canada, 2011). There are four major salmon aquaculture companies in BC holding approximately 130 tenure licences, but only 75 to 80 farms are active at any one time (Ministry of Agriculture, 2011). Most of the tenures are located around Vancouver Island and in the south–central coast (Fig. 1).

Harmful algal blooms (HABs) are the largest cause of mortality to BC aquacultured salmon. Problems with harmful algae were seen almost as soon as the salmon farming industry began in the province, and product losses soon reached into the millions of dollars (Black, 1990; Horner 1999). During the late 1980s and 1990s, salmon farms in BC and Washington State lost in excess of US$35 million due to *Heterosigma akashiwo* and *Chaetoceros* spp. blooms (Horner *et al*., 1997; Whyte, 1997). In 1999 alone, the first recorded bloom of *Cochlodinium* sp. caused approximately $2 million CAD in losses in BC (Whyte *et al*., 2001). Fish mortality in BC is generally caused by: physical damage or irritation of gill tissue, reaction to ichthyotoxic agents, or hypoxia from oxygen depletion (Rensel and Whyte, 2003). It should be noted that finfish flesh does not become toxic due to HABs and does not cause human health concerns.

Due to the devastating effect of harmful algae on farmed fish, the BC salmon aquaculture industry has supported the Harmful Algae Monitoring Program (HAMP) since 1999. Initially HAMP was managed by Dr. J.N.C. (Ian) Whyte of Fisheries and Oceans Canada (DFO) and Nicky Haigh. Since Dr. Whyte's retirement in 2004, HAMP has been run by Nicky Haigh as a private business. In the 15 years of the program to date, there have been between three and nine finfish aquaculture companies participating, with 12 to 28 sites sampling annually around Vancouver Island and in the BC Central Coast. The major focus of HAMP has been weekly analysis (with emphasis on harmful species identification and enumeration) of phytoplankton samples sent to the HAMP laboratory by aquaculture operations, consultation with the salmon aquaculture industry when harmful blooms or fish kills occur, and education of farm staff in phytoplankton identification and sampling. Detailed information on HAMP history, mandate, sampling sites, and analysis can be found elsewhere (*e.g.* Haigh *et al*., 2004; Haigh and Esenkulova, 2011).

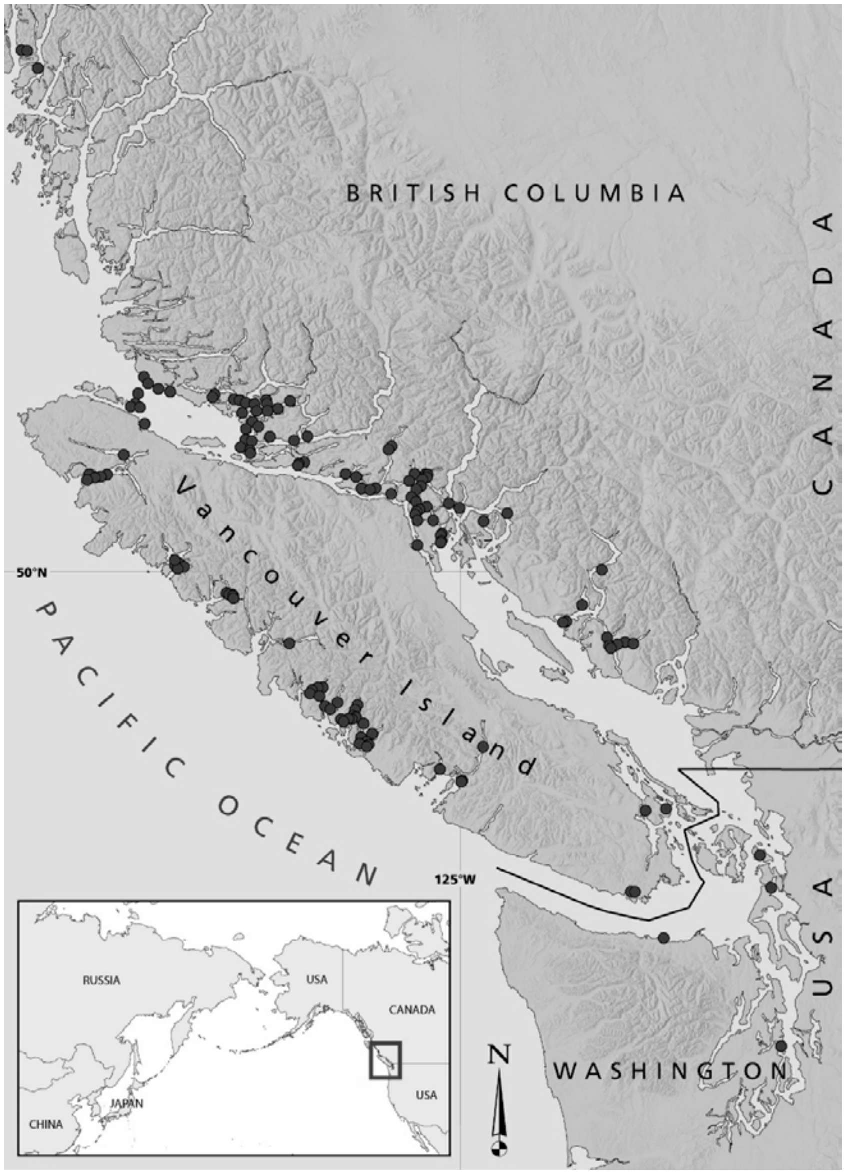

Fig. 1 Map of British Columbia, Canada, and Washington State, USA, salmon farm locations in 2004 (adapted from Steinback and Fuller, 2004).

HABs are natural phenomena affecting farmed and wild fish. Generally, the harmful effect on farmed fish appears more evident as (1) fish in net pens do not have freedom to evade the harmful bloom and (2) any farmed fish loss can be immediately seen and removed, as opposed to wild fish kills that are most likely to be unobserved (Rensel, 2007). In this way, caged fish function like a "canary in a coalmine", and HAB data from fish farms can be a valuable tool for the interpretation of the state of the coastal environment and wild fish health. Although data on fish losses is sensitive information, aquaculture companies have provided it here due to a strong commitment to sharing information that contributes to maintaining a healthy marine ecosystem.

The purpose of this study was to estimate the immediate economic impact of HABs on the BC salmon aquaculture industry in 2009–2012. This was achieved by assessing direct economic losses due to lost fish and indirect economic losses due to employing HAB mitigation measures. These conservative estimates demonstrate the scale of the economic costs to BC salmon aquaculture, which should help researchers and policy makers recognize the sometimes devastating impact of HABs.

Methods

Data on direct fish losses and associated costs due to HABs were gathered by a survey of management of four leading salmon aquaculture companies in BC: Cermaq (previously Mainstream Canada), Creative Salmon Company Ltd., Grieg Seafood BC Ltd., and Marine Harvest Canada Inc. Formal letters requesting data for 1999–2012 were sent in late 2012 and early 2013, followed by obtaining permissions to use the pooled data provided for research purposes.

Both direct and additional costs of HABs were estimated by the companies. Direct fish losses were calculated by multiplying weight of lost fish and approximate commercial cost. Additional costs comprised estimates of reduced fish growth due to withholding feed during HABs (lost production), and mitigation equipment running costs – barrier curtains, upwelling or bubbling equipment, compressors, and fuel. In this study we present the combined losses of all four salmon farm companies in Canadian dollars.

Results

Algal species causing fish kills during 2009–2012

Algal species that caused fish losses to the BC finfish aquaculture industry during 2009–2012 were: *Heterosigma akashiwo*, *Chattonella* cf. *marina*, *Chaetoceros convolutes*, and *Chaetoceros concavicornis* (herein grouped together as harmful *Chaetoceros* spp.), small flagellates (three species that were linked to fish mortalities in BC for the first time by N. Haigh, unpublished observation), and *Dictyocha speculum* (Table 1). Figure 2 shows the total number of blooms during this period. In 2009–2012, blooms of *H. akashiwo* caused five low level (up to 100 fish lost), eight moderate level (up to 1000 fish lost), and nine high level (more than 1000 fish lost) fish killing events around Vancouver Island. This species was responsible for about 65% of the total number of fish killing blooms during these four years and 90% of the total number of high level fish killing events. *Chattonella* cf. *marina* caused four moderate level and one high level fish killing events; harmful *Chaetoceros* spp. caused three low level and four moderate level fish killing events. Blooms of small flagellates (three species) and *Dictyocha speculum* combined caused five low level fish kills that comprised less than 15% of the total number of recorded fish killing events.

Table 1 Number of recorded fish killing blooms, and species that caused them, in British Columbia during 2009–2012. Severity level of the fish killing bloom are defined as low (up to 100 fish killed), moderate (100–1000 fish killed), and high (more than 1000 fish killed).

	2009			2010			2011			2012			Total 2009–2012		
Fish kill level	**low**	**mod**	**high**	**low**	**mod**	**high**	**low**	**mod**	**high**	**low**	**mod**	**high**	**low**	**mod**	**high**
Heterosigma akashiwo	–	1	1	1	4	2	2	1	4	2	2	2	5	8	9
Chattonella cf. *marina*	–	1	–	–	1	–	–	–	–	–	2	1	–	4	1
Harmful *Chaetoceros* spp.	1	3	–	–	1	–	–	–	–	2	–	–	3	4	–
Small flagellates	–	–	–	1	–	–	2	–	–	1	–	–	4	–	–
Dictyocha speculum	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–

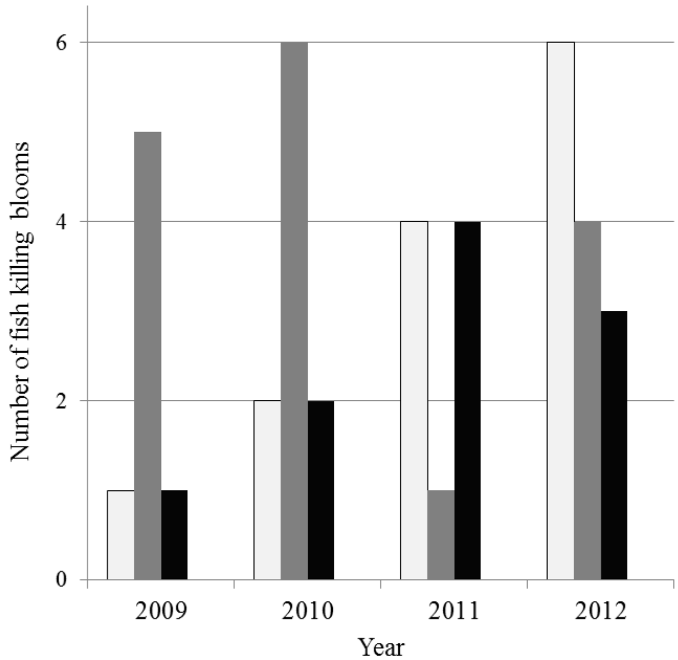

Fig. 2 Total number of fish killing blooms in British Columbia during 2009–2012. Bar color indicates severity level of the fish killing event: light grey for low level (up to 100 fish killed), dark grey for moderate (100–1000 fish killed), and black for high (more than 1000 fish killed).

Direct economic losses due to HABs

Direct losses to the salmon aquaculture industry due to HABs are shown in Figure 3. During the survey period, fish mortalities were the highest in 2012 ($6.445 million CAD losses) and the lowest in 2010 ($1.912 million CAD losses). Total direct losses due to HABs in 2009–2012 comprised $16.135 million CAD.

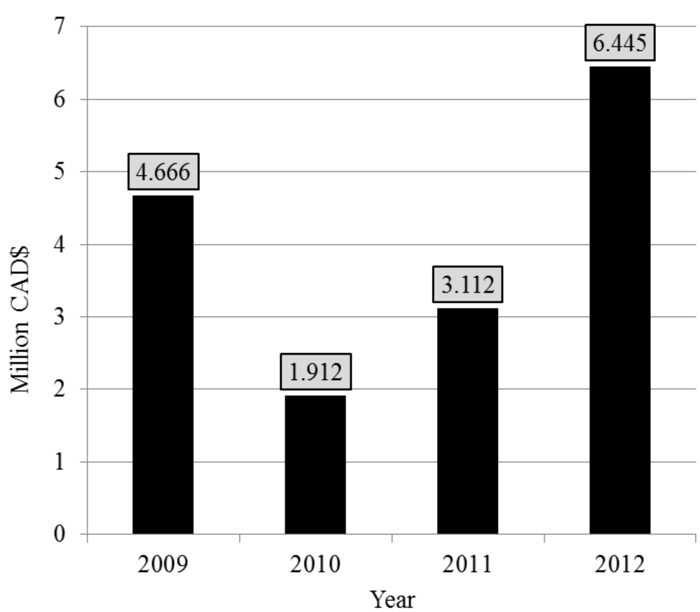

Fig. 3 Direct losses to the salmon aquaculture industry in British Columbia due to harmful algal blooms during 2009–2012.

Associated economic losses due to HABs

Additional economic losses due to HABs include "lost production" and mitigation costs. "Lost production" is defined as reduced fish growth resulting from withholding feed during blooms. This study does not estimate losses due to lost production, although with persistent blooms it may amount to a considerable cost.

Bloom mitigation measures include several techniques (*e.g*., in Rensel and Whyte, 2003) but in BC are mostly limited to barrier curtains, pumping of deep water into cages and water oxygenation/aeration. Cost of maintaining equipment and fuel is estimated to be about $1 to 2 million CAD annually per company.

Summary

During 2009–2012, direct losses to BC salmon aquaculture from HABs exceeded $16 million CAD. Species primarily responsible for fish losses in this period were *Heterosigma akashiwo*, *Chattonella* cf. *marina*, *C. convolutus*, and *Chaetoceros concavicornis.* Other costs to aquaculture from harmful algae are lost production and bloom mitigation equipment, which cost BC salmon aquaculture companies about $4 to 8 million CAD annually.

References

BCSFA (BC Salmon Farmers Association). 2006. History of salmon farming. Retrieved from http://www.salmonfarmers.org/sites/default/files/pdf/history_of_salmon_farming.pdf on November 10, 2013.

Black, E.A. 1990. Algal blooms in British Columbia. *Red Tide News Letter* **3**: 11–12.

Fisheries and Oceans Canada. 2011. Aquaculture Canada: facts and figures, 2011. Retrieved from http://www.dfo-mpo.gc.ca/aquaculture/ref/stats/PUB_AQUA_factsfigures_eng.pdf on November 10, 2013.

Haigh, N. and Esenkulova, S. 2011. The Harmful Algae Monitoring Program: The first dozen years and outlook for the future. Proceedings of the Salish Sea Ecosystem Conference, October 25–27, 2011, Vancouver, Canada. Retrieved from http://www.verney.ca/assets/SSEC_Presentations/Session%2010/10A_NickyHaigh_Abstract.pdf on November 10, 2013.

Haigh, N., Whyte, J.N.C. and Sherry, K.L. 2004. Biological and oceanographic data from the harmful algae monitoring program associated with salmon farm sites on the west coast of Canada in 2003. Canadian Data Report of Fisheries and Aquatic Sciences No. 1158.

Horner, R. 1999. Harmful algal blooms in the USA: an update, p. 10 *in* Proceedings of the Sixth Canadian Workshop on Harmful Marine Algae *edited by* J.L. Martin and K. Haya, Canadian Technical Report of Fisheries and Aquatic Sciences No. 2261.

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.

Ministry of Agriculture. 2011. British Columbia seafood industry. Year in review 2011. Retrieved from http://www.env.gov.bc.ca/omfd/reports/Seafood-YIR-2011.pdf on November 23, 2013.

Rensel, J.E. 2007. Fish kills from the harmful alga *Heterosigma akashiwo* in Puget Sound: recent blooms and review. Prepared by Rensel Associates Aquatic Sciences for the National Oceanic and Atmospheric Administration Center for Sponsored Coastal Ocean Research (CSCOR). Washington, D.C., 58 pp.

Rensel, J.E. and Whyte, J.N.C. 2003. Finfish mariculture and harmful algal blooms, pp. 693–722 *in* Manual on Harmful Marine Microalgae. Monographs on Oceanographic Methodology, vol. 11 *edited by* G.M. Hallegraeff, D.M. Anderson and A.D. Cembella, UNESCO Publishing, Paris.

Statistics Canada. 2010. Canadian Aquaculture Production Statistics. Retrieved from http://www.dfo-mpo.gc.ca/stats/aqua/aqua10-eng.htm on November 10, 2013.

Statistics Canada. 2011. Value added account – aquaculture industry. Retrieved from http://www.dfo-mpo.gc.ca/stats/aqua/va11pub-eng.htm on November 10, 2013.

Steinback, C. and Fuller, A. 2004. Map of Canadian salmon aquaculture. Retrieved from http://www.inforain.org/maparchive/maps_big/63007_fishfarms_300dpi.jpg on November 21, 2013.

Whyte, J.N.C. 1997. Impacts of harmful algae on the west-coast aquaculture industry and a National Research Plan by the Phycotoxins working Group of Fisheries and Oceans Canada to address such issues. *Bull. Fish. Res. Bd. Can.* **97**: 19–25.

Whyte, J.N.C., Haigh, N., Ginther, 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.

Prediction of toxic algal bloom occurrences and adaptation to toxic blooms to minimize economic loss to the scallop aquaculture industry in Hokkaido, Japan

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Abstract

Scallop aquaculture is a big industry in Japan, especially in the northern areas of Hokkaido and Tohoku. Production is about 500 thousand tons per year with a value reaching about 84 billion JPY (about 840 million USD). More than 60% of the total production is in Hokkaido, mainly in the Okhotsk Sea and Funka Bay regions. Both areas have long histories of economic impacts due to paralytic shellfish poisoning toxins (PSTs) and diarrhetic shellfish poisoning toxins (DSTs). However, in Funka Bay, in the southwestern part of Hokkaido, the scallop culturing industry has adapted to the frequent occurrences of toxic dinoflagellate blooms that produce DSTs and PSTs, which usually occur in May and during the summer season. The timing of the scallop harvest every year from December to April avoids this toxic bloom season. Scallops are harvested for fresh consumption or for storage by boiling and freezing. Modified harvesting approaches were necessitated, in part, by severe fisheries damage in the 1980s due to high PST contamination that stopped all bivalve shipments. In the Okhotsk Sea, recent occurrences of toxin contamination of scallops by PSTs have been precisely predicted on the basis of the movement of the Soya Warm Current. The strength of this current prevents the transport of the toxic dinoflagellate *Alexandrium tamarense* which typically resides in the offshore water masses of the Okhotsk Sea to locations such as Monbetsu and Abashiri on the northern coast of Hokkaido. Adaptive harvesting in response to these predictive factors is an effective way to avoid the impacts of toxic blooms to the bivalve aquaculture industry in coastal seas.

Introduction

Records of bivalves as an important food for ancient people have been found as early as 5,000 years ago when the shells of the scallop (*Mizuhopecten yessoensis*) were found with high frequency in shell mounds in Hokkaido, Japan (Sakai, 1976). Today, bivalve aquaculture plays an important role in providing food for humans, and scallop aquaculture prevails mainly in the cold temperate coastal sea. The global production of scallops is about 2 million tons per year, and about half that amount is produced in China. About 0.5 million tons per year are produced in Japan, the world's second highest producer, and about 0.4 million tons per year are harvested in the coastal waters of Hokkaido.

Hokkaido is located at the most northern part of Japan (Fig. 1), and is a suitable habitat for scallops. The annual scallop production in Funka Bay is about 100 thousand tons and in the Okhotsk Sea is 200–250 thousand tons (Shimada *et al*., 2000, 2012). The annual production and income values (Japanese yen, JPY) due to scallop aquaculture from 1980 and 2008 in the Okhotsk Sea are presented in Figure 2. Production (annual catch) gradually increased up to a maximum value of about 300 thousand tons, coinciding with an increase in income from about 10 billion JPY to 30–40 billion JPY (300–400 million USD). Thus, scallop aquaculture is an important industry in the coastal areas of Hokkaido.

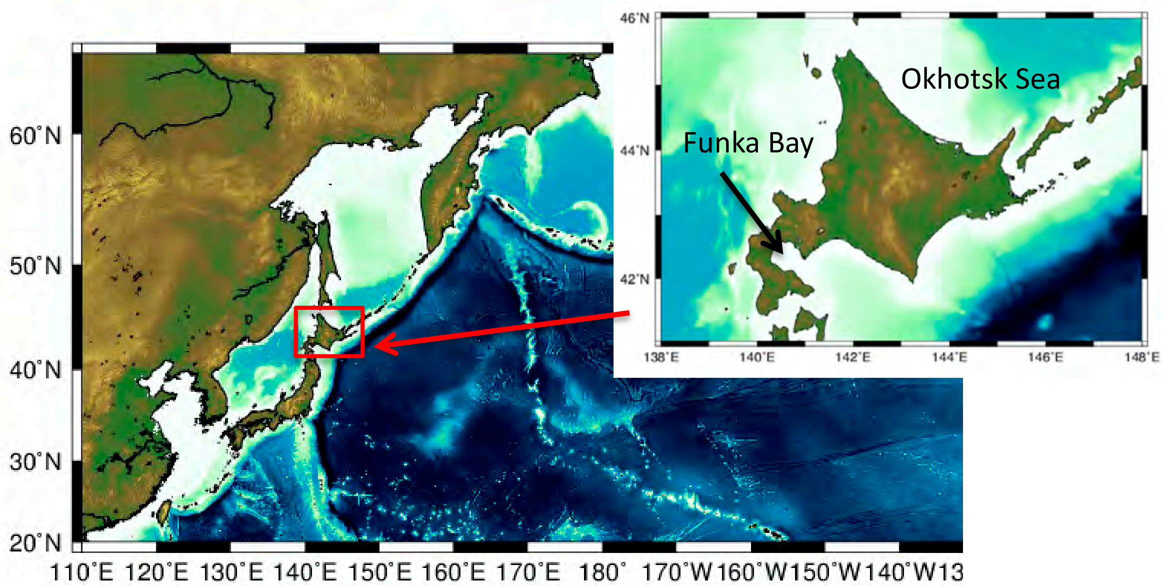

Fig. 1 Funka Bay and Okhotsk Sea area, Hokkaido, Japan. Both areas have large scallop culture industries and long histories of toxins that can cause paralytic shellfish poisoning (PSP) and diarrhetic shellfish poisoning (DSP).

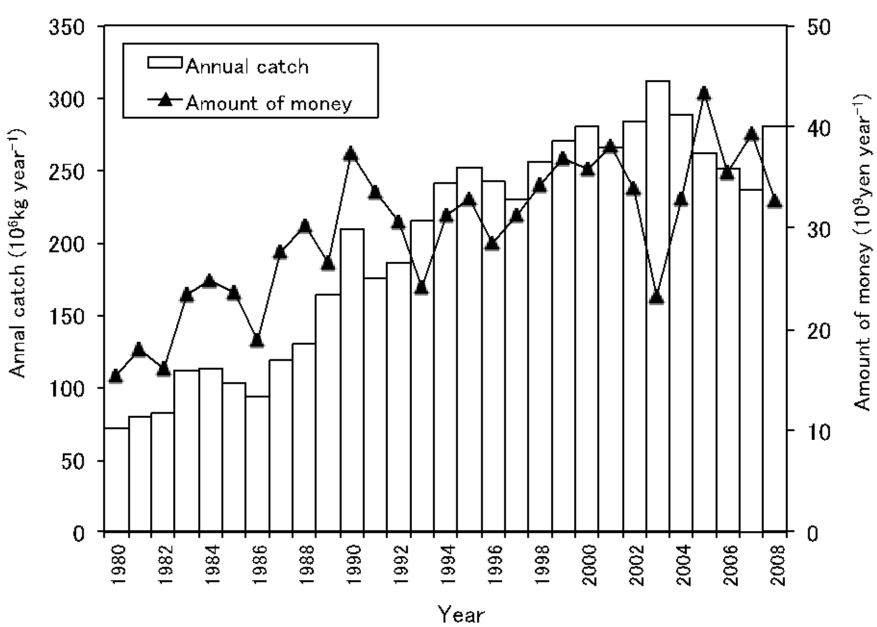

Fig. 2 Annual yields (10^6 kg year^{-1}) and income values (JPY) from scallop aquaculture in the Okhotsk Sea, Hokkaido.

Toxin contamination of scallops in the coastal areas of Hokkaido

Bivalves are filter feeders that process high volumes of seawater in order to collect particulate matter such as phytoplankton and detritus as their food. When toxic phytoplankton cells are present, filter-feeding bivalves accumulate their toxins by feeding. In Japanese coastal waters, contamination of bivalves by paralytic shellfish toxins (PSTs) and diarrhetic shellfish toxins (DSTs) are the most common toxic events (Fukuyo *et al.*, 2002; Imai *et al*., 2006; Imai and Itakura, 2007). The toxicity of market bivalve species is monitored using the mouse bioassay. When toxin concentrations of shellfish exceed the quarantine level (4 MU/g wet weight for PST, 0.05 MU/g wet weight for DST), the harvest of bivalves is stopped and the marketing of commercial bivalves is prohibited by law (Yamamoto and Yamasaki, 1996). This can have serious consequences for the bivalve aquaculture industry in Hokkaido, which has previously suffered from the impacts of PSTs and DSTs (Hokkaido Fisheries Experimental Station, 2000).

In Hokkaido, the monitoring of causative species of PSP began in 1976 together with PST monitoring in 1975 as a response to a bloom of *Gonyaulax* (= *Alexandrium*) species in Lake Saroma in 1974 (Nishihama, 1980; Hokkaido Fisheries Experimental Station, 2000). The first closure of scallop harvesting occurred in Funka Bay in 1978 due to PSTs that exceeded the quarantine level (> 4 MU/g; Hokkaido Fisheries Experimental Station, 2000). Figure 3 shows data from the monitoring of PSTs on the coast of Hokkaido from 1980 to 2011. Concentrations of PSTs in scallops were high until 1991 then showed relatively weak toxicity in subsequent years. The highest PST concentration was detected in 1989, at 2,812 MU/g hepatopancreas. Areas affected by PSTs, mainly the Pacific coast and Funka Bay, generally correspond to waters influenced by the cold Oyashio Current (Figs. 3 and 4). On the other hand, coastal areas affected by the Tsushima Warm Current (the west side of Hokkaido) rarely experience PST closures.

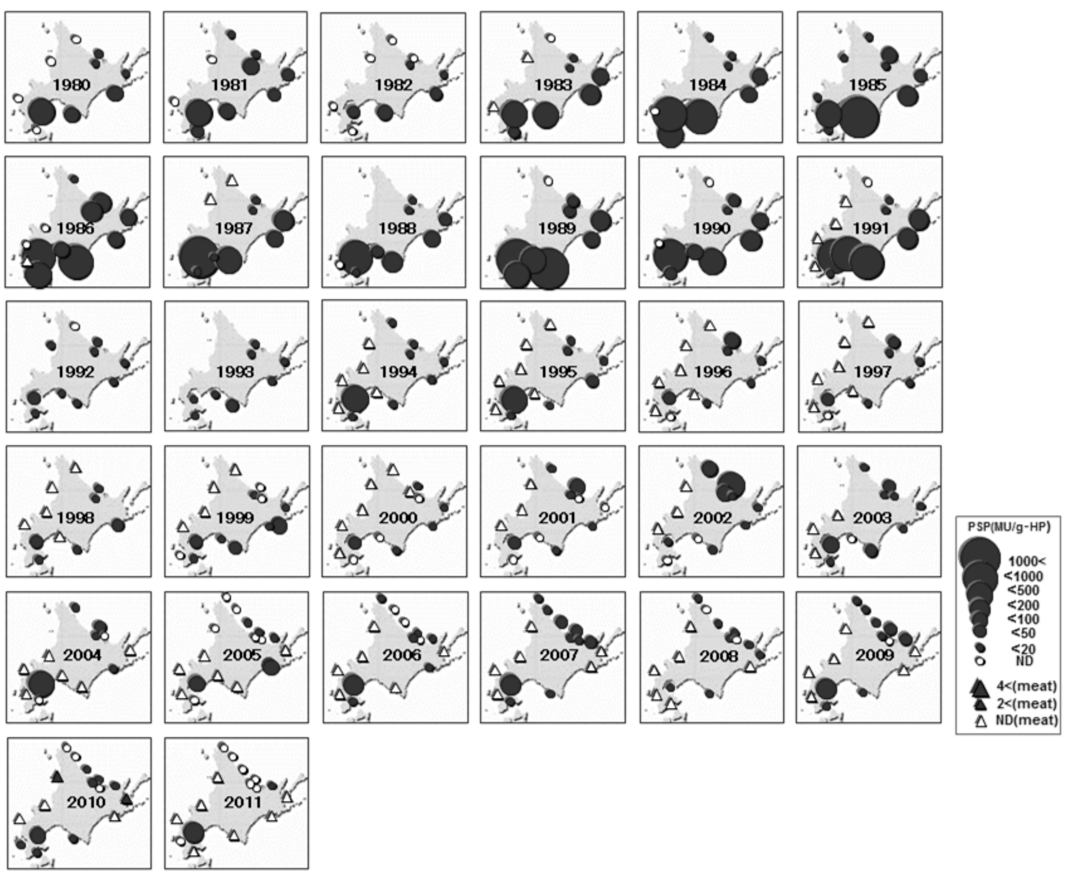

Fig. 3 Historical changes in paralytic shellfish toxins (PSTs) (MU/g hepatopancreas) in cultured scallops along the coast of Hokkaido. MU: mouse unit.

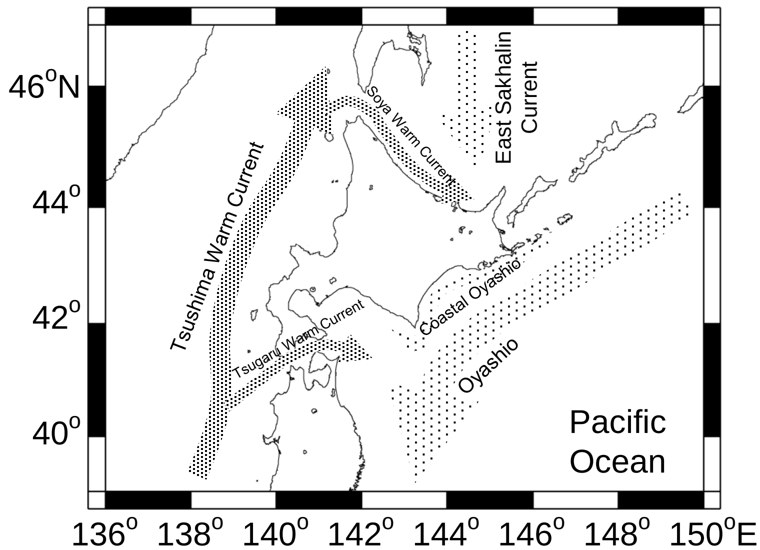

Fig. 4 Schematic paths of the warm currents (Tsushima, Soya and Tsugaru warm currents) and cold currents (East Sakhalin Current, Coastal Oyashio and Oyashio around Hokkaido (Isoda and Kishi, 2003).

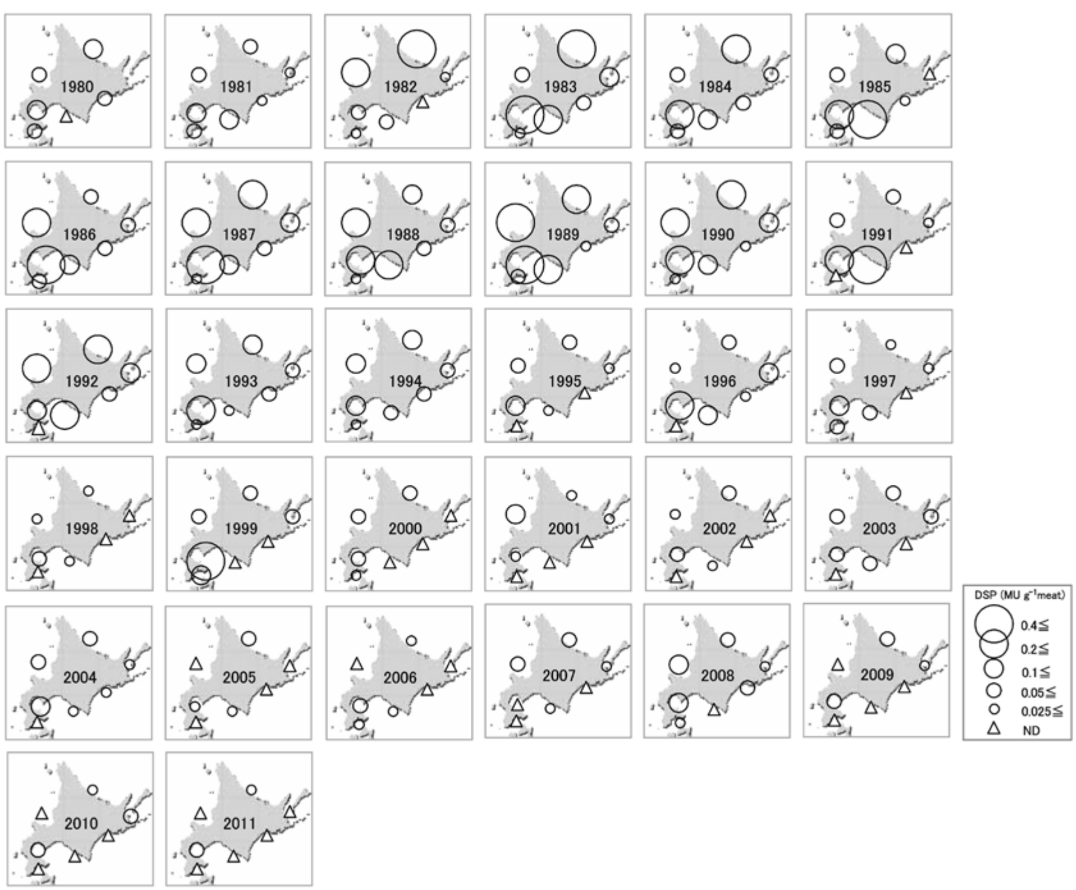

Fig. 5 Historical changes in the toxicity (MU/g meat) of diarrhetic shellfish toxins (DSTs) in cultured scallops along the coast of Hokkaido. MU: mouse unit.

The DSTs, including okadaic acid (OA) and dinophysistoxins (DTXs), were first identified from the samples obtained from a food poisoning incident that occurred in Iwate Prefecture in 1976 (Yasumoto *et al*., 1978). The dinoflagellate, *Dinophysis fortii*, was identified from this event and reported to be the causative organism (Yasumoto *et al*., 1980). In Hokkaido, the monitoring of the DSP-causing organisms, *Dinophysis* spp., began in 1980 together with DST monitoring (Nishihama, 1985; Hokkaido Fisheries Experimental Station, 2000). Figure 5 demonstrates the historical changes of DSTs in cultured bivalves along the coast of Hokkaido from 1980 to 2011. Areas affected by DSTs corresponded to those affected by the Tsushima Warm Current, with Funka Bay and Okhotsk Sea as the major areas of DST events. High DST concentrations in scallops were more frequent until around 1993, after which time they became less toxic.

Adaptation of the scallop harvest to mitigate the impacts of toxic blooms in Funka Bay

Funka Bay is located in the southwestern part of Hokkaido (Fig. 1). The cold Oyashio Current generally impacts the coastline during winter to spring seasons and the Tsugaru Warm Current tends to dominate during summer to autumn seasons (Ohtani and Kido, 1980; Fig. 4). The scallop aquaculture industry in the bay has long suffered from seasonal PST and DST problems, and has frequently experienced harvest closures for several months of the year due to shellfish contamination by these toxins.

In late 1970s, mass mortalities of cultured scallops coincided with the increase in production at various aquaculture sites, such as Mutsu Bay (Aomori Prefecture), Sanriku coast (Iwate and Miyagi Prefecture) and Funka Bay (Hokkaido) mainly due to overcrowding (Kanno and Sato, 1980; Hokkaido Fisheries Experimental Station, 2000). Maintaining adequate densities of farmed scallops in culturing baskets as supportive treatments contributed not only to the decrease in mortality rates but also enhanced the growth rates of the scallops. At present, scallop culture uses procedures depicted in Figure 6 to decrease mortalities and to enhance growth.

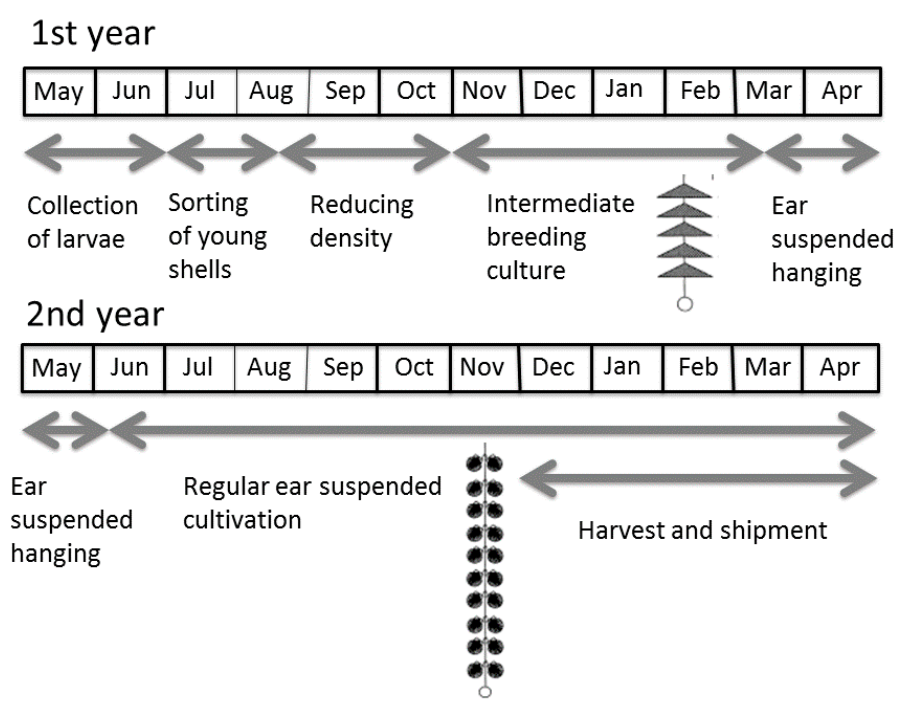

Fig. 6 Annual schedule of scallop cultures in Funka Bay (Yakumo Town). Ear suspended hanging involves drilling a hole in the scallop ear (the protruding margin of shell near where the two shells join) and attaching it to a fixed submerged line for growth.

Most importantly, scallop harvest and shipment are conducted from December to April, just before the beginning of the typical toxin period for scallops in Funka Bay. On the other hand, the scallop culture industry on the Okhotsk Sea coast harvest and ship from late April to mid-December. The shift of harvest and shipment times for scallops in Funka Bay is an excellent strategy to avoid competition between the industries in the Okhotsk Sea and Funka Bay. The strategic adaptation of scallop aquaculture industries to toxic blooms has resulted in successful mitigation of the effects of harmful algal blooms in Funka Bay.

Prediction of PSP toxin contamination of scallops in the Okhotsk Sea

Along the coasts of the Okhotsk Sea, the toxic dinoflagellate *Alexandrium tamarense* has caused PST contamination to scallops once every few years (Fig. 7; Nishihama, 1994; Shimada *et al*., 2010). Therefore, the prediction of PSP toxin events is important for planning the harvesting and shipping of scallops (*e.g*., recommendation of earlier shipping before closure).

Figure 8 presents a hypothetical scenario for occurrences of PSP toxin contamination of scallops in summer along the coast of Hokkaido in the Okhotsk Sea (Shimada *et al*., 2012). *Alexandrium tamarense* cells are usually distributed offshore in low salinity surface water of the Okhotsk Sea (Shimada *et al*., 2010). Since the Soya Warm Current (SWC) flows southeastward and alongshore, it generally dominates in the scallop culture area. *Alexandrium tamarense* is rarely found in the SWC. It is now known that the intrusion of oceanic surface seawater to the coastal region, corresponding to the weakening of the SWC, is associated with the PST contamination of cultured scallops along the coast of the Okhotsk Sea. The strength of the SWC is driven by the sea-level difference (SLD) between Wakkanai and Abashiri (Aota, 1975; Fukamachi *et al*., 2008). Consequently, the following scenario can be presented: PSP occurs when low-salinity water containing *A. tamarense* intrudes into the coastal areas in relation to the weakened SWC due to a decrease of the SLD (Fig. 8).

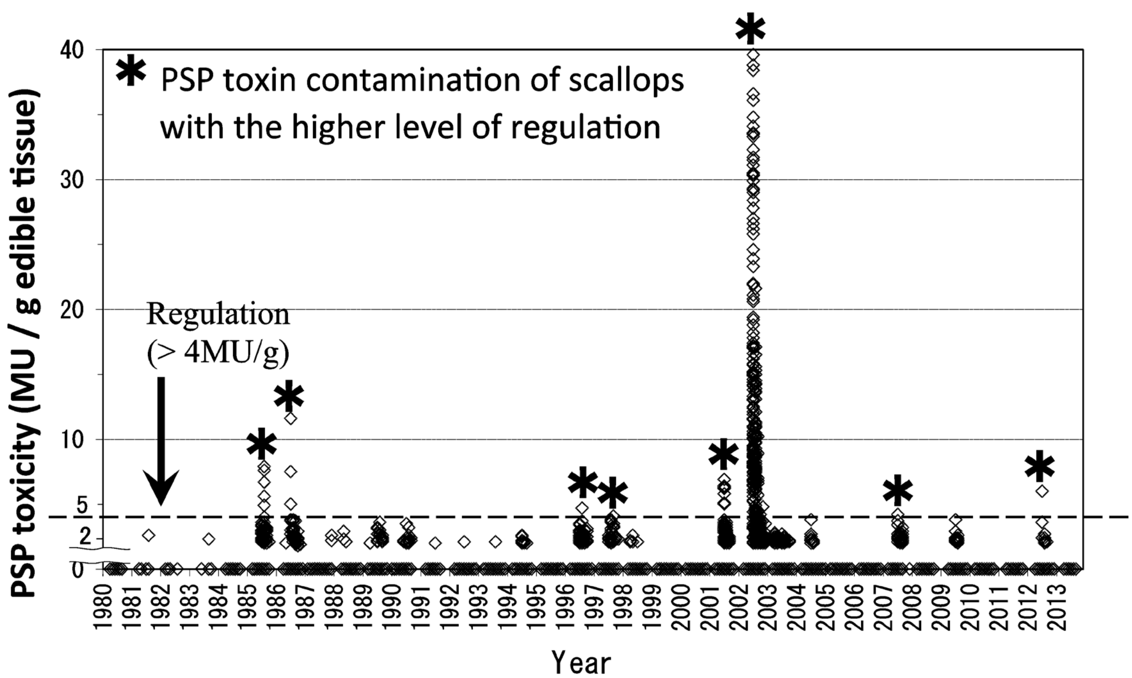

Fig. 7 Paralytic shellfish poison (PSP) toxicity in whole meat of scallops along the Okhotsk Sea coast of Hokkaido since 1980 (data source: Hokkaido Government; Shimada *et al*., 2012). The dashed line indicates the quarantine level for PSTs (4 MU/g). *PSP: occurrence over quarantine level; MU: mouse unit.

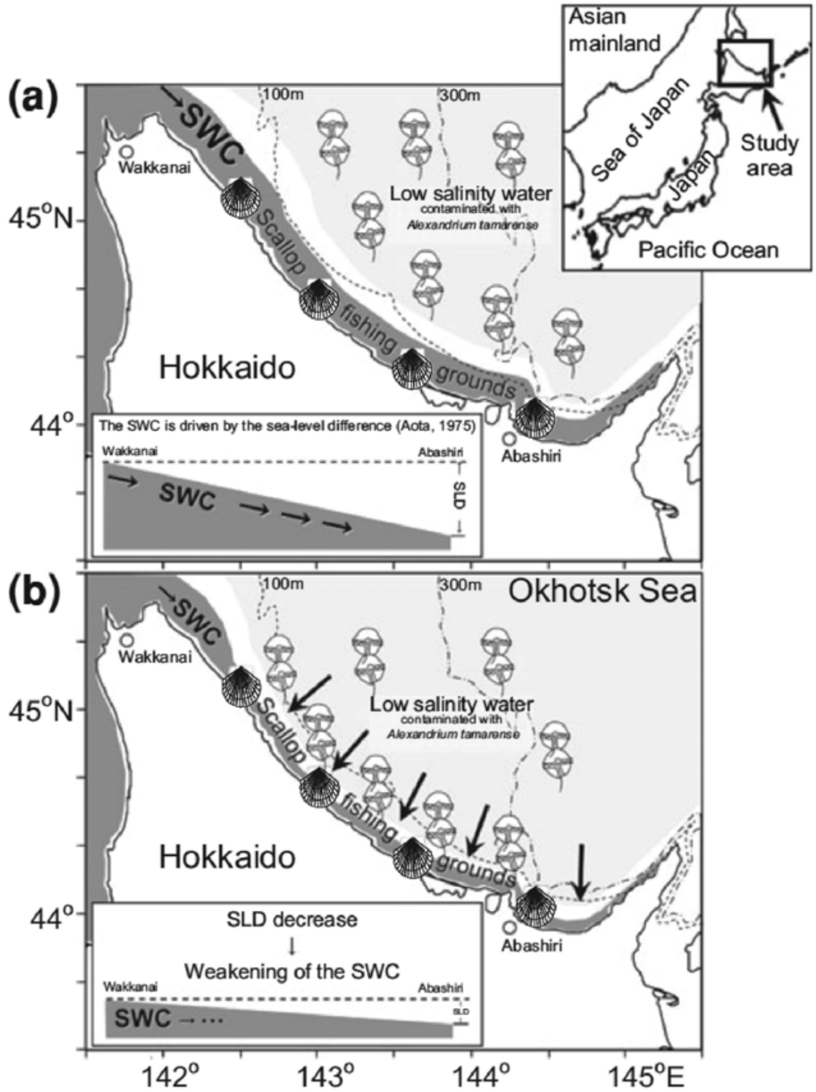

Fig. 8 Schematic path of the Soya Warm Current (salinity > 33.6) and location of the scallop fishing grounds and low-salinity water (salinity < 32.5) in summer by the hypothetical scenarios for (a) normal non-toxic conditions, (b) period of paralytic shellfish contamination of scallops by *Alexandrium tamarense* exposure. SWC: Soya Warm Current; SLD: sea-level difference.

Shimada *et al*. (2012) succeeded in demonstrating the validity of this hypothesis. In mid-July 2004, *A. tamarense* cells in the Okhotsk Sea intruded into the scallop culturing areas just after a decrease of the SLD. In early June 2007, high densities of *A. tamarense* were found in a front offshore of the SWC, and it was predicted that PST contamination of scallops would occur following a decrease of the SLD. In early July, the SLD decreased and *A. tamarense* cells became abundant in scallop culture areas, resulting in eventual PSTs in excess of the quarantine level by mid-July. In contrast, no bloom of *A. tamarense* was detected in offshore waters in late May 2008. The SLD decreased in late June, but no PST events were observed along the coast of Hokkaido.

In conclusion, the following two conditions are needed for PST contamination of scallops on the Okhotsk Sea coast of Hokkaido:
1. Existence of a bloom of *A. tamarense* in offshore surface water;
2. Intrusion of oceanic surface waters containing *A. tamarense* cells into the coastal areas of Hokkaido due to an obvious decrease in the SLD (weakening of Soya Warm Current).

When the above two conditions are satisfied, PST events occur a few weeks later. The PST prediction system can be implemented using the flowchart depicted in Figure 9. For condition 1, the criteria for a bloom of *A. tamarense* should be equivalent to the cell density that causes PSTs to accumulate in scallops over the quarantine level. It is known that *A. tamarense* density of about 100 cells/liter causes frequent quarantine conditions (Hokkaido Fisheries Experimental Station, 2000; Takata *et al*., 2004). Therefore, 100 cells/liter or higher should be the threshold level used to implement early warning (Shimada *et al*., 2012). For condition 2, an obvious decrease of SLD is a reduction from the typical value of about 20 cm to about 10 cm. A decrease in sea surface salinity will also correspond to the weakened SWC and can be a helpful criterion to assess the decrease of SLD (Shimada *et al*., 2012).

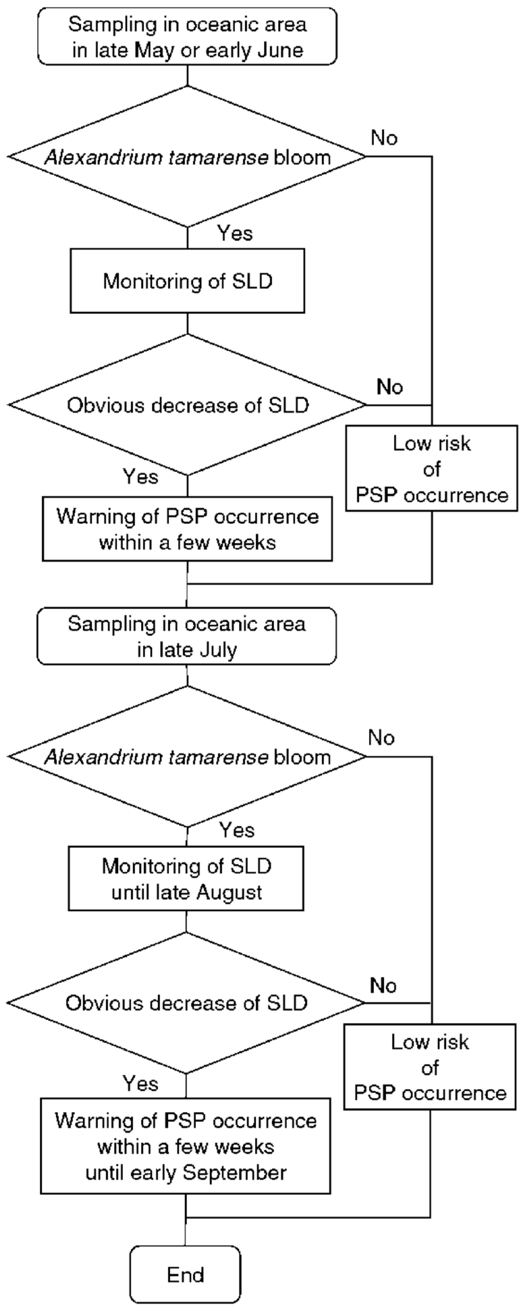

Fig. 9 Flowchart for prediction of PST occurrences in scallops on the Okhotsk Sea coast of Hokkaido, based on sea-level difference (SLD) between Wakkanai and Abashiri.

Overview

When toxin concentrations in shellfish exceed quarantine levels, the commercial harvest of bivalves is stopped on a voluntary basis and shipment of the toxic bivalves to market is prohibited by law (Yamamoto and Yamasaki, 1996). Calculation of economic losses is very difficult; however, temporary workers employed to ship bivalves, such as scallops, actually lose their jobs during the period of quarantine.

In recent years, the prediction of the occurrences of PST contamination of scallops has been successful on the Okhotsk Sea coast (Shimada *et al*., 2012). A future goal is the reduction of fishery damage caused by toxic blooms. Countermeasures against toxic blooms may be used for the prevention of their occurrences. Recently, growth-inhibiting bacteria against the toxic dinoflagellate *Alexandrium tamarense* were isolated from the blades of the seagrass *Zostera marina* (Onishi *et al*., 2014). These bacterial strains revealed strong inhibiting activities against *A. tamarense*. Further, Nishihama (1994) reported that there are large-scale seagrass beds in Lake Saroma, where *A. tamarense* has rarely caused PST problems, according to long-term observations. The existence of growth-inhibiting bacteria in the biofilm of seagrass blade surfaces provides an enticing possibility for biological control of toxic blooms.

References

Aota, M. 1975. Studies on the Soya Warm Current. *Low Temp. Sci.* **A33**: 151–172 (in Japanese with English summary).

Fukamachi, Y., Tanaka, I., Oshima, K.I., Ebuchi, N., Mizuta, G., Yoshida, H., Takayanagi, S. and Wakatsuchi, M. 2008. Volume transport of the Soya Warm Current revealed by bottom-mounted ADCP and ocean-radar measurement. *J. Oceanogr*. **64**: 385–392.

Fukuyo Y., Imai I., Kodama M. and Tamai K. 2002. Red tides and harmful algal blooms in Japan, pp. 7–20 *in* Harmful Algal Blooms in the PICES Region of the North Pacific *edited by* F.J. Taylor and V.L. Trainer, PICES Scientific Report No. 23, North Pacific Marine Science Organization.

Hokkaido Fisheries Experimental Station, 2000. The studies on shellfish poison in the coastal water around Hokkaido. Technical Report No. 3, Hokkaido Fisheries Experimental Station, Yoichi, Hokkaido, 69 pp. (in Japanese).

Imai, I. and Itakura, S. 2007. History of shellfish poisonings and fishery damages in Japan, pp. 9–18 *in* Advanced Researches on Shellfish Poisonings: Current status and Overview *edited by* I. Imai, Y. Fukuyo and S. Hiroishi, Fisheries Science Series 153, Koseisha-Koseikaku, Tokyo (in Japanese).

Imai, I., Yamaguchi, M. and Hori, Y. 2006. Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. *Plankton Benthos Res*. **1**: 71–84.

Isoda, Y. and Kishi, M.J. 2003. A summary of “Coastal Oyashio” Symposium. *Bull. Coast. Oceanogr*. **41**: 1–3 (in Japanese).

Kanno, H. and Sato, H. 1980. Present aspects of commercial scallop culture in Japan, pp. 11–25 *in* Systematic Approach to Mariculture and Utilization of Scallop, Japanese Society of Fisheries Sciences, Fisheries Science Series 31, Koseisha-Koseikaku, Tokyo (in Japanese).

Nishihama, Y. 1980. Environmental factors affecting the occurrence of paralytic shellfish poison in scallop, pp. 40–52 *in* Systematic Approach to Mariculture and Utilization of Scallop, Japanese Society of Fisheries Sciences, Fisheries Science Series 31, Koseisha-Koseikaku, Tokyo (in Japanese).

Nishihama, Y. 1985. Ecology of toxic dinoflagellates in Hokkaido, pp. 47–58 *in* Toxic Dinoflagellate – Implication in Shellfish Poisoning *edited by* Y. Fukuyo, Fisheries Science Series 56, Koseisha-Koseikaku, Tokyo (in Japanese).

Nishihama, Y. 1994. Scallop Fishery in the Okhotsk Sea Coast of Hokkaido. Hokkaido University Press, Sapporo, 218 pp. (in Japanese).

Ohtani, K. and Kido, K. 1980. Oceanographic structure in Funka Bay. *Bull. Faculty Fish., Hokkaido Univ*. **31**: 84–114 (in Japanese with English abstract).

Onishi, Y., Mohri, Y., Tuji, A., Ohgi, K., Yamaguchi, A. and Imai, I. 2014. The seagrass *Zostera marina* harbors growth-inhibiting bacteria against the toxic dino-flagellate *Alexandrium tamarense*. *Fisheries Sci.* **80**: 353–362.

Sakai, K. 1976. Scallop Cultures in Japan. Suisan Hokkaido Kyokai, Sapporo, 750 pp. (in Japanese).

Shimada, H., Nishida, Y., Ito, Y. and Mizushima, T. 2000. Relationship among growth and survival of cultured scallops (*Patinopecten yessoensis* JAY), and environmental conditions in the coastal area off Yakumo, Funka Bay, Hokkaido, Japan. Science Reports of Hokkaido Fisheries Experimental Station 58, pp. 49–62 (in Japanese with English abstract).

Shimada, H., Sawada, M., Kuribayashi, T., Nakata, A., Miyazono, A. and Asami, H. 2010. Spatial distribution of the toxic dinoflagellate *Alexandrium tamarense* in summer in the Okhotsk Sea off Hokkaido, Japan. *Plankton Benthos Res*. **5**: 1–10.

Shimada, H., Sawada, M., Tanaka, I., Asami, H. and Fukamachi, Y. 2012. A method for predicting the occurrence of paralytic shellfish poisoning along the coast of Hokkaido in the Okhotsk Sea in summer. *Fish. Sci*. **78**: 865–877.

Takata, K., Seno, M., Toukubo, Y., Takatsuji, H., Takayama, H. and Ogawa, H. 2004. Difference in accumulation and elimination of paralytic shellfish toxins among oyster, scallop and mussel. *Nippon Suisan Gakkaishi* **70**: 598–606 (in Japanese with English abstract).

Yamamoto, M. and Yamasaki, M. 1996. Japanese monitoring system on shellfish toxins. pp. 19–22 *in* Harmful and Toxic Algal Blooms *edited by* T. Yasumoto, Y. Oshima and Y. Fukuyo, IOC-UNESCO, Paris.

Yasumoto T., Oshima, Y. and Yamaguchi, M. 1978. Occurrence of a new type of shellfish poisoning in the Tohoku district. *Bull. Japanese Soc. Sci. Fish*. **44**: 1249–1255.

Yasumoto, T., Oshima, Y., Sugawara, W., Fukuyo, Y., Oguri, H., Igarashi, T. and Fujita, N. 1980. Identification of *Dinophysis fortii* as the causative organism of diarrhetic shellfish poisoning. *Nippon Suisan Gakkaishi* **46**: 1405–1401.

Economic impacts of harmful algal blooms on fisheries and aquaculture in western Japan – An overview of interannual variability and interspecies comparison

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Abstract

In Japanese coastal waters, fish kills caused by harmful algal blooms (HABs) have occurred mainly in the western part of Japan, in the Seto Inland Sea and the Kyushu coasts. Since the 1970s, the Japanese Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries has been gathering data on HABs, or red tides, in two areas – the Seto Inland Sea since 1970, and the Kyushu coast since 1979 – and has published annual reports. These reports contain detailed statistics on the number of HAB events and the economic losses attributed to each causative species. Based on these reports, here we make interannual and interspecies (causative species) comparisons of the economic impacts of HABs on fisheries and aquaculture in western Japan. In the Seto Inland Sea, the most harmful species causing severe economic losses are *Chattonella* (*C. antiqua*/*marina*/*ovata*), followed by *Karenia mikimotoi*. For example, *Chattonella* caused 7.1 billion JPY (approximately 73 million USD) of economic losses in Harima-Nada in 1972, and *K. mikimotoi* caused approximately 1.3 billion JPY of economic losses in Bungo-Suido in 2012. On the Kyushu coast, *K. mikimotoi* and *Cochlodinium polykrikoides* are the major harmful species, although *Chattonella* has begun to cause severe economic losses in recent years (8.7 billion JPY in Yatsushiro Sea in 2009–2010). This report also describes unrecognized financial losses in coastal communities and some proposed countermeasures to mitigate these economic losses.

Introduction

Two types of harmful algal blooms (HABs) are known in Japan. The first one is noxious algal blooms (so-called "red tides") associated with the mass mortality of marine organisms, especially fish kills in aquaculture cages (Imai *et al*., 2006). The second type of HAB is toxic algal blooms causing toxin contamination to shellfish that can result in either paralytic shellfish poisoning (PSP) or diarrhetic shellfish poisoning (DSP), (Fukuyo *et al*., 2002).

Organizations responsible for monitoring or researching HAB events in Japan include governmental organizations (MAFF: Ministry of Agriculture, Forestry and Fisheries, MEXT: Ministry of Education, Culture, Sports, Science and Technology, MOE: Ministry of the Environment, MHLW: Ministry of Health, Labor and Welfare), local prefectural governments and incorporated administrative agencies (*i.e*., FRA: Fisheries Research Agency, NIES: National Institute for Environmental Studies, NIHS: National Institute of Health Sciences), incorporated foundations (NPEC: Northwest Pacific Region Environmental Cooperation Center) and a number of universities (Fig. 1). Among these organizations, MAFF compiles statistics on HAB events in Japanese coastal waters. To be more specific, the Fisheries Agency of MAFF gathers statistical data on red tides and the Food Safety and Consumer Affairs Bureau of MAFF gathers data on toxic algal blooms.

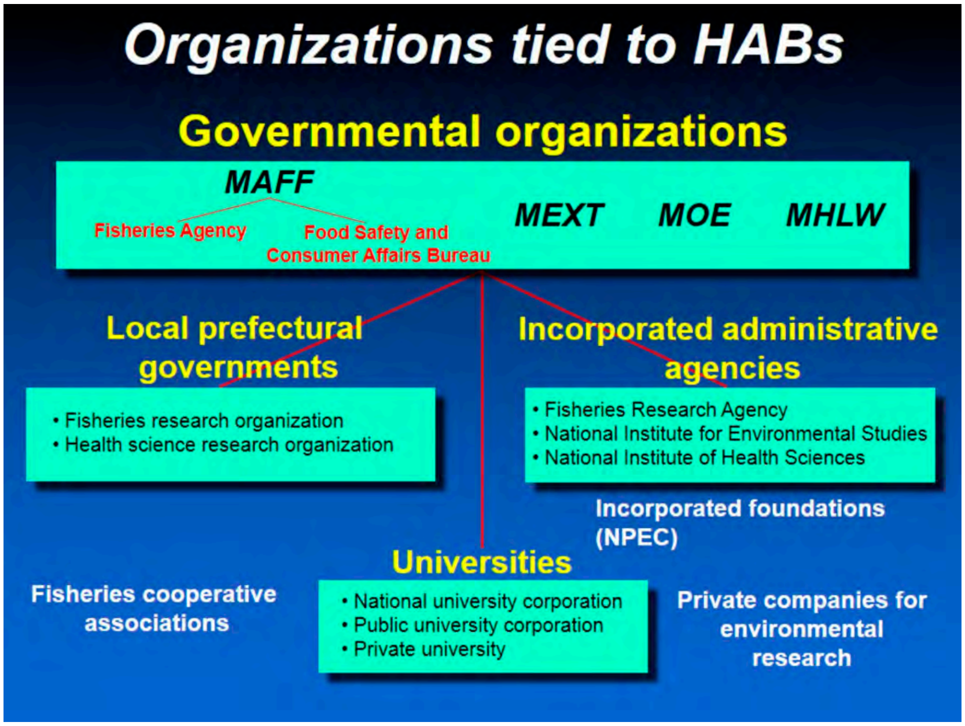

Fig. 1 Organizations tied to harmful algal bloom (HAB) events in Japan. MAFF: Ministry of Agriculture, Forestry and Fisheries; MEXT: Ministry of Education, Culture, Sports, Science and Technology; MOE: Ministry of the Environment; MHLW: Ministry of Health, Labor and Welfare.

As described above, statistical data on HABs, including both red tides and toxic algal blooms, are available in Japan. However, statistical data on the economic impacts of HABs are available only for fish kill events. Shellfish (also finfish) are rarely killed by toxic algal blooms; therefore, it is very difficult to estimate the economic loss due to shipping bans or restrictions caused by outbreaks of the blooms. For this reason, this report focuses on the economic impacts of red tides on aquaculture in Japan.

Japanese marine finfish aquaculture production consists mainly of yellowtail and sea bream. For instance, in 2013, the total Japanese marine finfish aquaculture production was 243,600 tons per year, and the annual production of yellowtail and sea bream was 150,800 tons and 56,600 tons, respectively (MAFF, 2014). Consequently, the production of yellowtail and sea bream accounted for 85% of the total Japanese marine finfish aquaculture production in 2013.

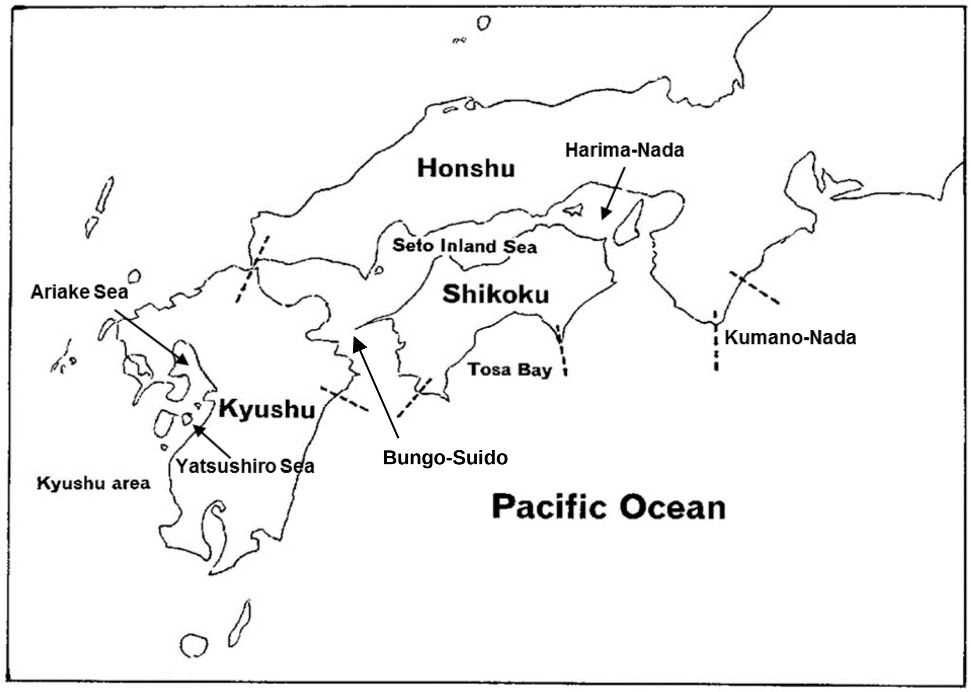

Fig. 2 Map of the western part of Japan where the main yellowtail and/or sea bream aquaculture sites are located.

The main areas of yellowtail and/or sea bream aquaculture are located in the western part of Japan, the Seto Inland Sea and the Kyushu coasts (Fig. 2). Therefore, fish kills caused by red tides occur mainly in these areas. The Japanese Fisheries Agency has gathered data on HABs in these two areas: the Seto Inland Sea since 1970 (Fisheries Agency 1970–present) and the Kyushu coast since 1979 (Fisheries Agency 1979–present), and publishes annual reports (Fisheries Agency, 1970–2008; 1979–2008). These reports contain detailed statistics on the number of HAB events, the economic losses to finfish aquaculture attributed to each event, and the causative species. Guided by those reports, this report makes interannual and interspecies (causative species) comparisons of the economic impacts of red tides on finfish aquaculture in western Japan.

Interannual variability of HAB (red tide) events in the Seto Inland Sea

Before the 1950s, red tide outbreaks were very rare in the Seto Inland Sea. The number of red tide cases drastically increased in the 1960s and the early 1970s, and reached a peak of 299 cases per year by the middle of the 1970s (Fig. 3). After this period, they declined and have remained relatively stable at approximately 100 cases per year. This decrease is thought to be due mainly to governmental regulations regarding 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") which was enforced in 1973 (Fukuyo *et al*., 2002). On the other hand, there is no obvious trend in the number of fish kill events over time. After the 1980s, the number of fish kills ranged from 2 to 19 cases per year in the Seto Inland Sea (Fig. 3).

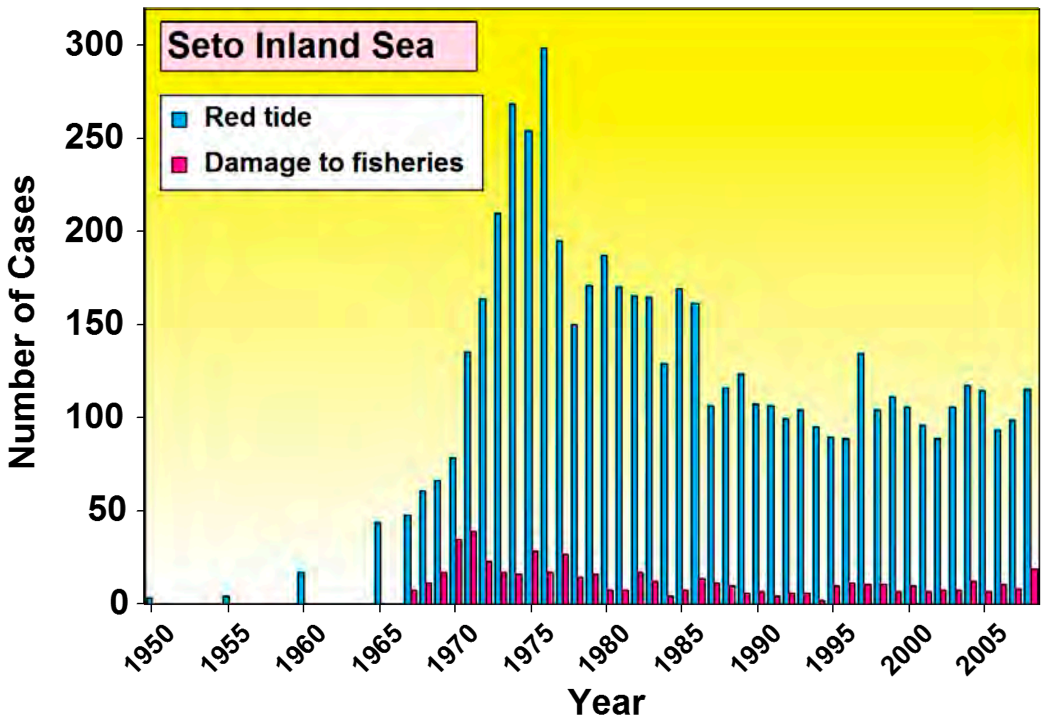

Fig. 3 Number of red tides (blue bars) and fish kill cases (red bars) in the Seto Inland Sea (1950–2008).

Table 1 displays the amount of annual economic loss due to red tides in the Seto Inland Sea. Maximum economic loss of about 7.1 billion Japanese yen (about 73 million USD) was recorded in 1972 when red tides of *Chattonella* spp. caused severe damage to cultured yellowtail in Harima-Nada in the eastern part of the Seto Inland Sea during the summer.

Severe fisheries damage (loss of over 1 billion JPY; about 10 million USD) was observed frequently in the 1970s to 1980s. After 1990, the annual economic loss decreased in comparison to the 1970s and 1980s. However, even in the 2000s severe fisheries damage (loss of over 1 billion JPY) was recorded in this area.

Table 1 Amount of annual economic losses (JPY) due to red tides in the Seto Inland Sea.

Year	Amount (JPY)
1970	0
1971	6,700,000
1972	7,147,060,000
1973	1,350,000
1974	70,150,000
1975	88,000,000
1976	83,605,000
1977	2,970,000,000
1978	3,317,669,000
1979	1,114,678,000

Table 1 Continued.

Year	Amount (JPY)
1980	391,414,000
1981	109,267,000
1982	1,098,221,000
1983	391,414,000
1984	2,880,641,000
1985	1,021,068,000
1986	374,337,000
1987	2,534,454,000
1988	27,923,000
1989	496,951,000
1990	123,570,000
1991	1,547,859,000
1992	18,644,000
1993	184,085,000
1994	806,885,000
1995	963,826,000
1996	142,632,000
1997	579,057,000
1998	3,899,101,000
1999	no data
2000	62,440,000
2001	252,683,000
2002	222,784,000
2003	1,299,224,000
2004	392,342,000
2005	317,388,000
2006	203,421,000
2007	423,660,000
2008	111,973,000

Figure 4 shows the number of fisheries damage events due to each causative HAB species in the Seto Inland Sea (1980–2008). In the Bungo-Suido (Bungo Strait) area of the Seto Inland Sea, *Karenia* spp. (mostly *K. mikimotoi*) caused the majority of fisheries damage after the 1980s.

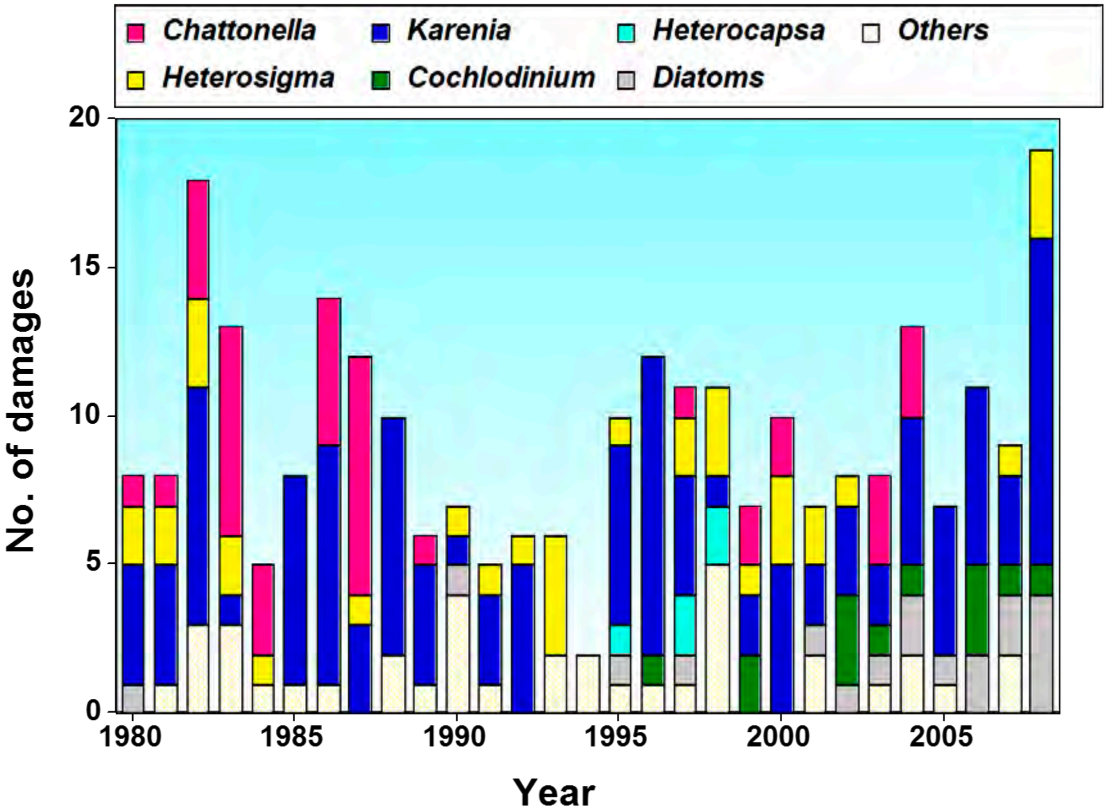

Fig. 4 Number of fisheries damage events due to each HAB species in the Seto Inland Sea (1980–2008).

Although *Chattonella* spp. (*C. antiqua*/*marina*/*ovata*) caused much damage to fisheries in the Seto Inland Sea in the 1980s (and also in the 1970s), the amount of damage generated by the species decreased after 1990. However, from 1995, *Heterocapsa circularisquama* (briefly), *Cochlodinium polykrikoides* and diatoms, including *Coscinodiscus wailesii* and *Eucampia zodiacus*, began to occur frequently (Fig. 4). Diatom blooms (from winter to spring) have led to the exhaustion of nutrients in the water column during the "nori" (*Pyropia yezoensis*, formerly *Porphyra yezoensis*) harvest season. Nutrient deficiency has suppressed the growth of nori, lowered the quality of nori products due to bleaching, and has caused economic damage on the order of billions of Japanese yen (Nishikawa, 2007).

Although it is not fully understood why the composition of damage-causing HAB species changed after the mid-1990s, it has been proposed that decreasing inorganic nutrients, such as inorganic nitrogen (Nishikawa *et al*., 2011), and increasing water temperature (Nishikawa *et al*., 2014; Takizawa *et al*., 2014) in the Seto Inland Sea may play a role.

Interannual variability of HAB (red tide) events in the Kyushu coasts

On the Kyushu coast, there is no obvious trend in the number of red tide cases from 1979 to 2008 (Fig. 5). Table 2 shows the amount of annual economic losses due to red tides on the Kyushu coast. The maximum economic loss of about 4 billion Japanese yen (about 4 million USD) was recorded in 2000 when *Cochlodinium polykrikoides* caused severe damage to cultured yellowtail in Yatsushiro Bay.

Table 2 Amount of annual economic losses (JPY) due to red tides on the Kyushu coast.

Year	Amount (JPY)
1979	11,752,000
1980	32,726,000
1981	70,881,000
1982	142,040,000
1983	4,163,000
1984	15,961,000
1985	889,811,000
1986	29,923,000
1987	61,038,000
1988	49,064,000
1989	318,814,000
1990	1,708,675,000
1991	225,114,000
1992	621,420,000
1993	34,805,000
1994	232,250,000
1995	1,019,490,000
1996	7,529,000
1997	no data
1998	14,788,000
1999	819,779,000
2000	4,335,702,000
2001	146,904,000
2002	725,300,000
2003	829,682,000
2004	234,085,000
2005	98,117,000
2006	20,934,000
2007	33,530,000
2008	180,506,000

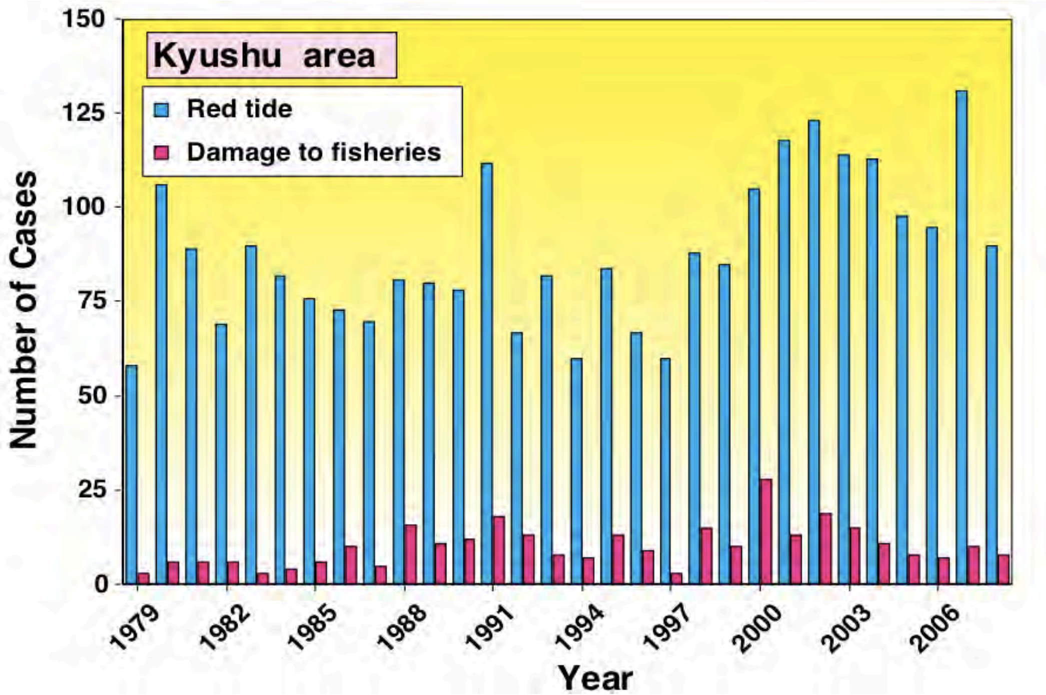

Fig. 5 Number of red tides (blue bars) and fish kill cases (red bars) on the Kyushu coast (1979–2008).

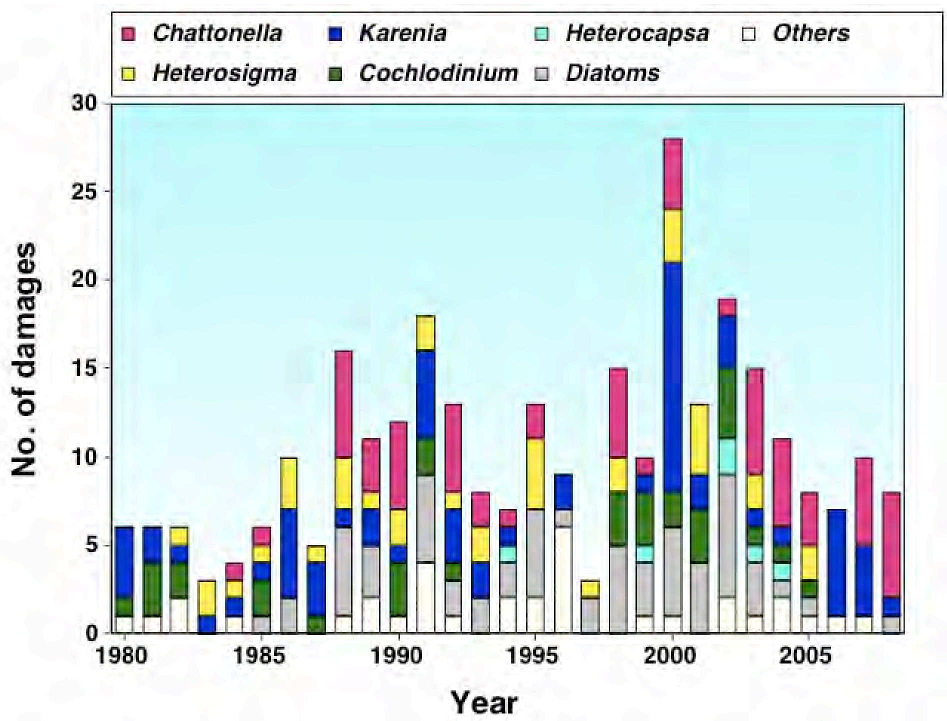

Fig. 6 Number of fisheries damage cases due to each HAB species on the Kyushu coast (1980–2008).

Figure 6 depicts the number of cases of fisheries damage from 1980 to 2008 due to each causative HAB species on the Kyushu coast. *Karenia* (mostly *K. mikimotoi*), *Cochlodinium polykrikoides* and diatoms were the major damage-causing HAB species, although *Chattonella* began to generate severe economic losses after the late 1980s.

Extensive damage by HABs in western Japan

Table 3 shows extensive fisheries damage (≥1 billion JPY) due to red tides in western Japan from 1972 to 2012. In the area, *Chattonella* (*C. antiqua*/*marina*/*ovata*), *Karenia* (mostly *K. mikimotoi*), *Cochlodinium polykrikoides* and *Heterosigma akashiwo* have caused massive fish kills. Additionally, after 1990, *Heterocapsa circularisquama* blooms caused shellfish deaths, and diatoms began to cause bleaching of *Pyropia* (nori) in the same area.

Table 3 Extensive economic damage (≥1 billion JPY) caused by HABs (red tides) in western Japan.

Year	Area	Causative species	Damaged organism	Economic loss (billion JPY)
1972	Harima-Nada	*Chattonella*	Yellowtail	7.1
1977	Harima-Nada	*Chattonella*	Yellowtail	2.7
1978	Harima-Nada	*Chattonella*	Yellowtail	3.3
1984	Kumano-Nada	*Karenia*	Yellowtail, *etc*.	4.6
1991	Aki-Nada, *etc*.	*Karenia*	Red sea bream, *etc*.	1.5
1992	Ago Bay	*Heterocapsa*	Pearl oyster	3.0
1995	Kagoshima Bay	*Heterosigma*	Yellowtail, *etc*.	1.0
1998	Hiroshima Bay	*Heterocapsa*	Oyster	3.9
2000	Yatsushiro Sea	*Cochlodinium*	Yellowtail, *etc*.	4.0
2000–2001	Ariake Sea	Diatoms	Pyropia “nori”	>10*
2009–2010	Yatsusiro Sea	*Chattonella*	Yellowtail, *etc*.	8.7
2012	Bungo-Suido	*Karenia*	Yellowtail, *etc*.	1.3

* Estimated amount (No official information)

Unrecognized financial losses in coastal communities and countermeasures to mitigate these economic losses

As mentioned in the beginning of this report, there are unrecognized financial losses attributed to HABs (defined as toxic phytoplankton blooms). In most cases, however, an accurate estimate of the economic loss due to HABs is difficult to determine (*e.g*., a hiring halt may occur due to shipment closure of cultured shellfish). Also, economic losses by damaged wild aquatic resources (direct and/or indirect influence to the coastal ecosystem) have not yet been quantified. There are also economic losses due to a reluctance by consumers to buy fishery products when HAB events are reported.

In Japan, aquaculture insurance (mutual aid system) mitigates the economic losses due to HABs. Aquaculture insurance is offered under the Fishery Damage Indemnification System in Japan. The System is both a mutual aid system and an important part of the national government’s fishery damage assistance policy (FAO, 2006).

Conclusions

In the Seto Inland Sea, the most harmful species causing severe economic losses are *Chattonella* (*C. antiqua*/*marina*/*ovata*), followed by *Karenia mikimotoi*. *Chattonella* caused a total of 7.1 billion JPY (about 73 million USD) in economic losses in Harima-Nada in 1972, and *K. mikimotoi* caused approximately 1.3 billion JPY in economic losses in Bungo-Suido in 2012.

On the Kyushu coast, *K. mikimotoi* and *Cochlodinium polykrikoides* are the major harmful species, although *Chattonella* has begun to cause severe economic losses in recent years.

From 1995, the dinoflagellates, *Cochlodinium polykrikoides* and *Heterocapsa circularisquama* (briefly), were responsible for shellfish deaths, and diatoms began to cause bleaching of *Pyropia* ("nori") in the Seto Inland Sea and the Kyushu coast.

There has been a change in the composition of damage-causing HAB species after the middle of 1990s in the Seto Inland Sea. Although the reason is not fully understood, it is theorized that changing environmental factors, such as decreasing inorganic nutrients and increasing water temperatures in the winter season, may play a role in the changes of damage-causing HAB species composition.

References

FAO (Food and Agriculture Organization). 2006. Review of the current state of world aquaculture insurance. FAO Fisheries Technical Paper, No. 493. Rome, FAO, 92 pp.

Fisheries Agency. 1970 ~ 2008. Information on the occurrence of red tide in the Seto Inland Sea. Seto Inland Sea Fisheries Coordination Office, Annual Report 1970 ~ 2008 (in Japanese).

Fisheries Agency. 1979 ~ 2008. Information on the occurrence of red tide in the Kyushu coast. Kyushu Fisheries Coordination Office, Annual Report 1979 ~ 2008 (in Japanese).

Fukuyo Y., Imai I., Kodama M. and Tamai K. 2002. Red tides and harmful algal blooms in Japan, pp. 7–20 *in* Harmful algal blooms in the PICES region of the North Pacific *edited by* F.J. Taylor and V.L. Trainer, PICES Scientific Report No. 23, North Pacific Marine Science Organization.

Imai I., Yamaguchi M. and Hori Y. 2006. Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. *Plankton Benthos Res*. **1**: 71–84.

MAFF (Ministry of Agriculture, Forestry and Fisheries). 2014. Statistics of agriculture, forestry and fisheries (in Japanese). http://www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei/pdf/gyogyou_seisan_13.pdf.

Nishikawa, T. 2007. Occurrence of diatom blooms and damage to cultured *Porphyra thalli* by bleaching. *Aquabiology* **172**: 405–410 (in Japanese with English abstract).

Nishikawa, T., Hori, Y., Nagai, S., Miyahara, K., Nakamura, Y., Harada, K., Tada, K. and Imai, I. 2011. Long time-series observations in population dynamics of the harmful diatom *Eucampia zodiacus* and environmental factors in Harima-Nada, eastern Seto Inland Sea, Japan during 1974–2008. *Plankton Benthos Res*. **6**: 26–34.

Nishikawa, T., Hori, Y., Nagai, S., Miyahara, K., Nakamura, Y., Harada, K., Tada, K. and Imai, I. 2014. Long-term (36-year) observations on the dynamics of the fish-killing raphidophyte *Chattonella* in Harima-Nada, eastern Seto Inland Sea, Japan. *J. Oceanogr*. **70**: 153–164.

Takizawa, K., Oka, H., Takimoto S., Nakazato, A. and Motoyama, T. 2014. Trend analysis of monthly water temperature at the eastern coast of Suo Nada, 1987–2010. *J. Natl. Fisheries Univ*. **62**: 117–128.

The economic cost of red tides in China from 2008–2012

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Abstract

More than 330 cases of red tides covering an area of 52,777 km^2, with the economic cost of these disasters totaling nearly 2.23 billion Chinese Yuan (364 million USD), were reported in China from 2008 to 2012. Our coastal surveys show that the southeast coastline of China is an important area for the frequent occurrence of red tides which cause enormous economic losses. The primary months of annual red tides are May and June when the dominant species are *Karenia mikimotoi*, *Skeletonema costatum*, *Noctiluca scientillans*, and *Prorocentrum donghaiense.* The major harmful phytoplankton are *Karenia mikimotoi*, *Cochlodinium geminatum*, *Aureococcus anophagefferen*, and *Prorocentrum donghaiense*.

Introduction

China is a coastal country with 18,000 km of mainland coastline. The total sea area claimed under China's jurisdiction is about 3,000,000 km^2, including the Bohai Sea and the areas in the Yellow Sea, East China Sea and South China Sea[1]. There are more than 1,500 rivers flowing into these seas through broad drainage basins. China's seas also boast of abundant marine biodiversity, with more than 22,600 species documented, and various types of marine ecosystems, such as mangroves, coral reefs, sea grass beds, and coastal wetlands.

In 2011, for example, the coasts of China were believed to be in good condition, as 95% of all sea areas met Seawater Quality Standard Category I standards (SOA, 2011). The marine sediment quality in coastal waters has also been determined generally to be in good condition. However, some of the coastal areas have recently been subjected to adverse impacts from land-based pollution, environmental disasters, and habitat destruction. The occurrence of red tides may cause environmental pressures, such as anomalies in the seawater hydrochemistry and imbalances in marine ecology, with serious impacts on the eco-environment of China's coastal areas.

Monitoring system for harmful algal blooms in China

In order to understand the overall environmental status of the China's sea areas, more than 9,800 survey stations were established in order to obtain over 2.5 million marine environmental data points. This national

[1] Although the South China Sea is not in the PICES convention area, it is being included for completeness in this report, as these are part of China's waters.

monitoring system of harmful algal blooms (HABs) began in 2002 with the establishment of 10 monitoring zones. Today, 19 HAB monitoring and control zones and 16 ecological monitoring and control zones are distributed along the Chinese coast to enhance the understanding of HABs. Monitoring and control zones for HABs were selected mainly in aquaculture areas, ecological protection areas, recreation resorts, and areas where HABs frequently occur.

At present, China's major means of monitoring marine red tides include fixed-point monitoring by ship surveys, satellite remote sensing, and aerial remote sensing. At the same time, monitoring at coastal stations and buoys, with subsequent laboratory testing, is used frequently. Panoramic and land-based monitoring systems greatly enhance the discovery of HABs and emergency response protocols play an important role in mitigating the impacts of red tides.

Algal blooms in China

Red tides are important environmental problems in coastal areas and may do great harm to society and coastal economics. The first record of red tide in China is from 1933 and since that year, more than 1200 HAB events have been recorded. Specifically, there were only 14 cases of red tides before 1979, 75 cases in the 1980s, 226 cases in the 1990s, and nearly 1000 cases from 2000 to 2012 (Fig. 1). The frequency and scale of observed marine red tides reached a maximum during 2003–2006. In addition, poisonous and harmful species have increased in recent years. It appears that the duration and frequency of HABs have increased; furthermore, their scope of influence and harmful effects have also increased.

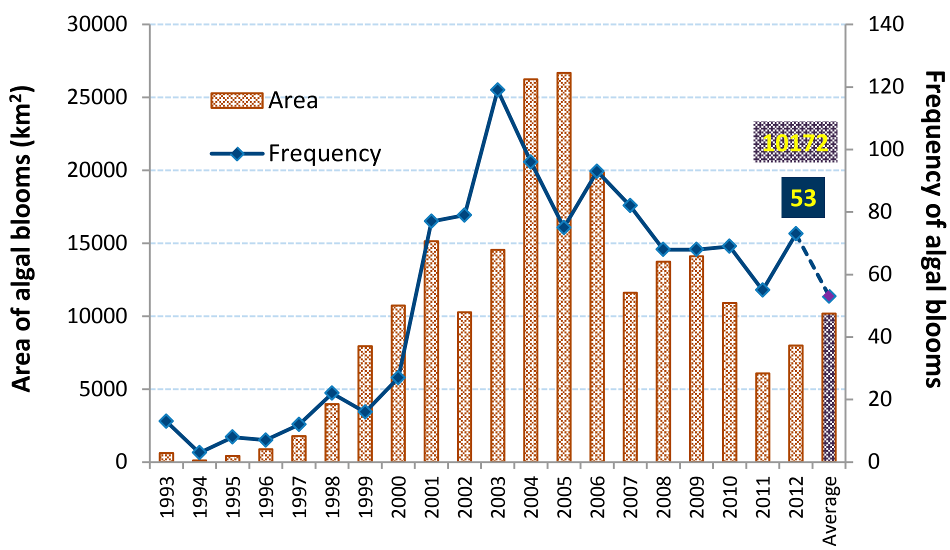


Fig. 1 Harmful algal blooms in China during the past two decades.

The characteristics of marine red tides include their duration, concentration, and spatial extent. Red tides may occur in China during all seasons of the year. In the Bohai and Huanghai sea areas, red tides occur in April–October every year, with the most intense spatial blooms occurring in July–September. In the East China Sea, red tides occur in February–October, with the highest concentration blooms in May–August. In the South China Sea, red tides occur all year round, with the periods of most concentrated blooms occurring mainly in March–May and August–November. The duration of individual red tides can range from 3–5 days to 2 weeks to over 1 month.

In the 1980s, red tides were mainly found in small semi-enclosed bays. Since the 1990s, however, the occurrence of red tides has been recorded mostly in China's nearshore waters. The results of monitoring show that the areas where red tides appear more frequently are located mainly along southeast China Sea and some bays as well as estuaries like Dalian Bay, Jiaozhou Bay, Hangzhou Bay, Shenzhen Bay, Daya Bay, the sea near the Changjiang River mouth, and the Zhujiang River mouth. The area of red tides in the Bohai Sea and the Changjiang River mouth is relatively large while those in the Zhujiang River mouth are relatively smaller, but occur with higher frequency. The scope of individual red tides has expanded from several km^2 to thousands of km^2 over the past two decades.

The characteristics of algal blooms in China from 2008 to 2012

General observations

There was an average of nearly 67 HAB events over an average affected area of 10,556 km^2 in Chinese coastal areas annually from 2008 to 2012 (Fig. 2). The occurrences of marine red tides and affected areas have remained relatively constant over the past 20 years.

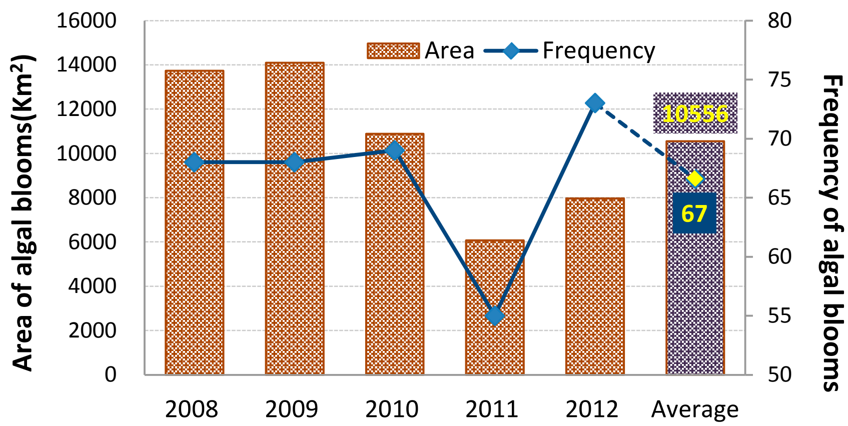


Fig. 2 Distribution of HABs from 2008 to 2012.

Harmful algal blooms in Chinese coastal waters are located mainly in the East China Sea where the number of occurrences and areas are evidently much higher than in the other three sea regions over these past five years (more than 57% of the total red tides and 54% of the total HAB area are in the East China Sea). On average, there were 7 events and an affected area of 2590 km^2 in the Bohai Sea, 11 events and 1950 km^2 in the Yellow Sea, 38 events and 5690 km^2 in the East China Sea, 11 events and 321 km^2 in the South China Sea every year (Figs. 3 and 4). Large-scale HAB events occurred mainly in marine waters adjacent to the Yangtze River estuary and in the southeast coastal waters of China.

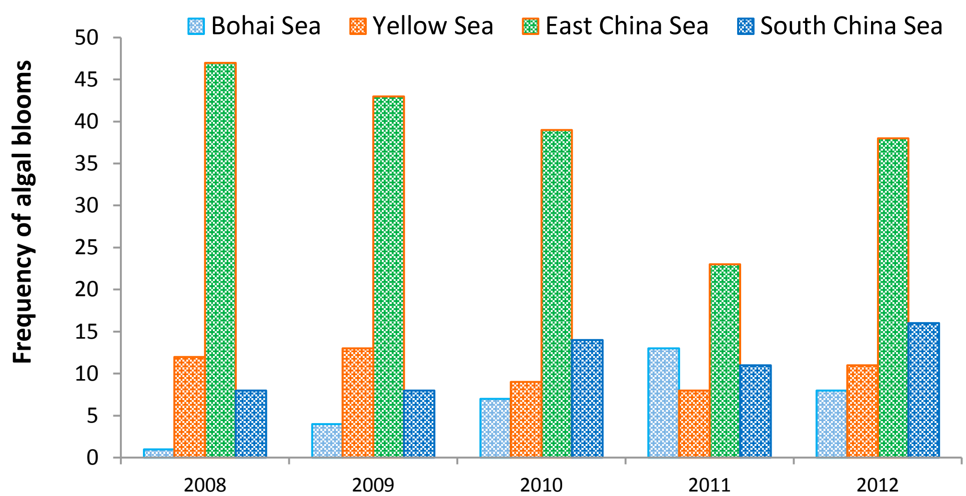


Fig. 3 HAB frequency in 4 areas during 2008–2012.

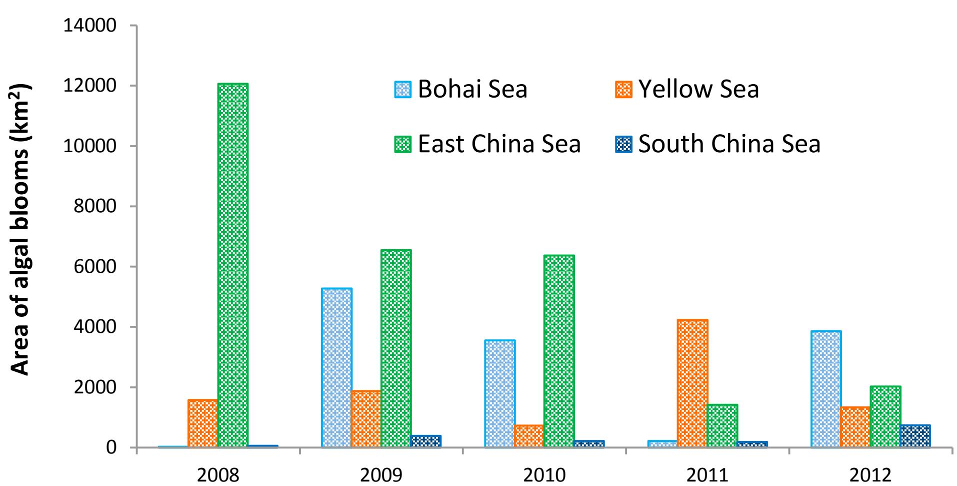


Fig. 4 HAB scale in 4 areas during 2008–2012.

Monthly distribution

The occurrence of HAB events and affected areas showed a normal distribution. The main seasons of the annual events were from April–October, with the majority occurring in May and June (Figs. 5 and 6). The number of occurrences and areas were much higher than in other seasons, with May and June events accounting for 52% and 73%, respectively of the total HAB events over the past five years.

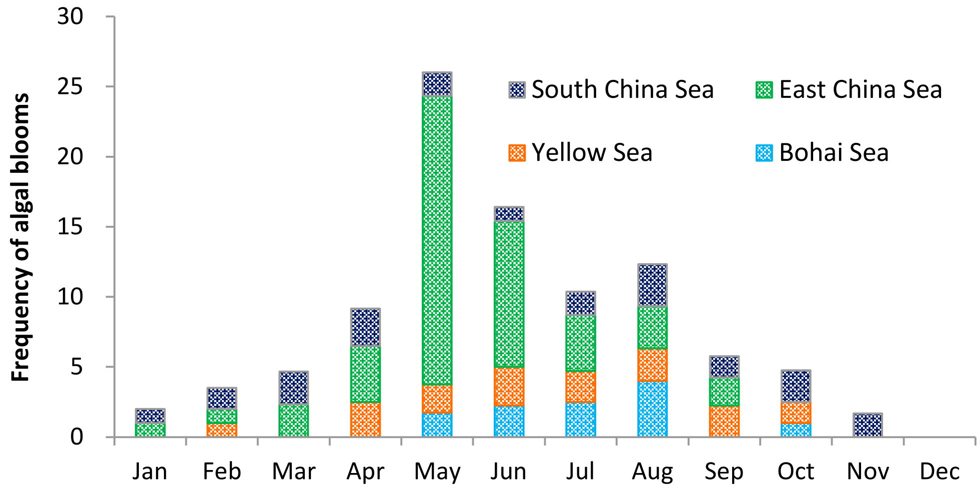


Fig. 5 Monthly distribution of HABs from 2008–2012.

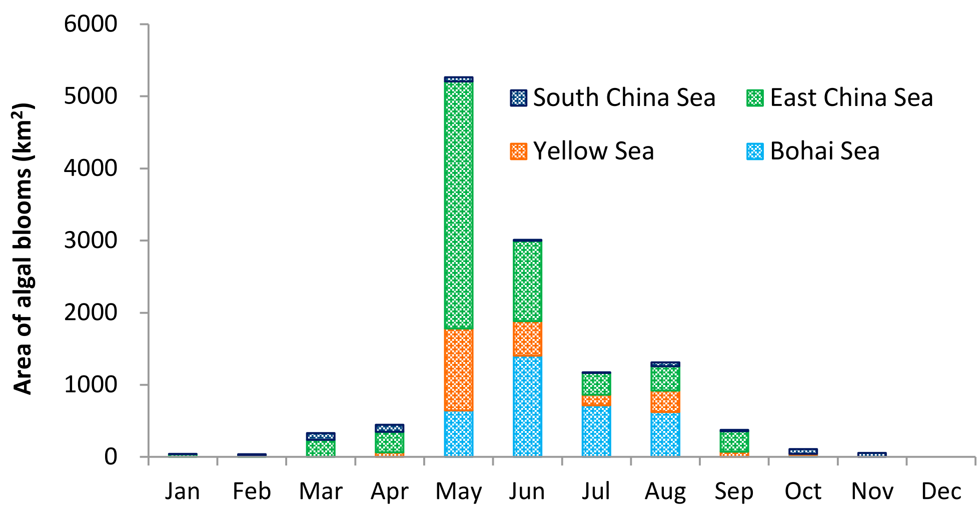


Fig. 6 Monthly distribution of HAB area from 2008–2012.

Disaster-causing species and its toxicity

There are more than 260 species of marine red tide organisms. About 90 species have latent toxins, most belonging to the group *Pyrrophyta* (Sournia, 1995). There are about 40 known genera and 140 species of red tide organisms in China. The dominant species are *Karenia mikimotoi*, *Skeletonema costatum*, *Noctiluca scintillans*, and *Prorocentrum donghaiense*. The major fish-killing organisms are *Karenia mikimotoi*, *Cochlodinium geminatum*, and *Prorocentrum donghaiense*.

In many cases, algal blooms are considered harmless. However, it is when these algal blooms exceed a threshold level that they begin to have negative impacts on the environment and human health. Harmful algal blooms impact coastal fisheries by clogging gills of fish in captivity, depleting oxygen, thereby causing hypoxia, and by production of toxins causing diarrhetic shellfish poisoning (DSP), paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), amnesic shellfish poisoning (ASP), and ciguatera fish poisoning in humans. These red tides generally are of concern only when they are close to shore where they can impact coastal fisheries.

Here, we will describe red tide events that have had negative impacts on the economy in coastal China. In 2008, *Noctiluca scintillans* broke out in Liaoning Province. Although this species does not produce a toxin, it is found to accumulate toxic levels of ammonia which are excreted into the surrounding waters. It caused high mortalities of cultivated shellfish (*Ruditapes philippinarum*, *Meretrix meretrix*) and led to 200 thousand Chinese Yuan (32.6 thousand USD) in economic losses (Table 1).

Table 1 Major disaster-causing HABs events and direct economic losses (million USD) in China's four seas regions.

Date	Region	Species	Area (km^2)	Affected species	Loss (millions USD)
June 2008	Yellow Sea	*Noctiluca scintillans*	500	cultivated shellfish – *Ruditapes philippinarum*, *Meretrix meretrix*	0.03
May 2009	East China Sea	*Noctiluca scintillans*	30	mariculture – *Seriola quinqueradiata*	1.14
May–June 2010	Bohai Sea	*Aureococcus anophagefferen*	3350	cultivated shellfish – *Argopecten irradians*	32.68
July 2010	Bohai Sea	*Mesodinium rubrum*	20	cultivated shellfish – *Argopecten irradians*	0.82
May 2010	East China Sea	*Prorocentrum donghaiense*	30	cultivated fish – *Pseudosciaena crocea*	0.11
June 2010	East China Sea	*Karenia mikimotoi*	7	cultivated fish & juvenile fish	0.01
May–June 2010	East China Sea	*Karenia mikimotoi*, *Prorocentrum donghaiense*	628	cultivated abalone – *Haliotis discushannai*, *Haliotis diversicolor*	329.28
May–June 2011	East China Sea	*Prorocentrum donghaiense*	50	mariculture – *Epinephelus* sp., *Octopus vulgaris*	0.01
August 2011	South China Sea	*Cochlodinium geminatum*	89	cultivated fish fry & juvenile fish – *Ephippus orbis*, *Epinephelus awoara*	0.52

In 2010, *Mesodinium rubrum* covered 20 km^2 and led to 5 million Chinese Yuan (0.82 million USD) in economic losses along Hebei Province, even though this species is rarely linked to damage.

In 2011, economic loss of more than 3.2 million Chinese Yuan (0.52 million USD) was caused by *Cochlodinium*, which spread to a maximum area of 89 km^2 in Guangdong Province, affecting fish fry and juvenile fish (*Lateolabrax japonicas*). Ichthyotoxins produced by *Cochlodinium* have caused major losses in fishery and shell fishery production in many countries. It is believe that this species expanded into Chinese coastal waters beginning in 2006.

In 2012, *Karenia mikimotoi* caused huge damage to the mariculture industries of Zhejiang and Fujian provinces, especially to cultivated abalone. The direct economic loss was more than 2 billion Chinese Yuan (330 million USD).

There are two major disaster-causing species in China. One is *Prorocentrum donghaiense* D. Lu, a very common species along the East China Sea in recent years, which frequently co-occurs with *Karenia mikimotoi*. Some experiments with this species show its specific damage to marine organisms. Another harmful alga is *Aureococcus anophagefferens* Hargraves & Sieburth which causes brown tides. From 2009 to 2012, with a maximum cell density around 10^9 cell/L, it caused huge damage to the scallop culture industry along Hebei Province. The bloom significantly damaged the mariculture industry in this region by causing cessation of feeding and stagnant growth of scallops. For example, in May–June, 2010, it was responsible for 32.7 million USD economic losses.

Economic cost of HABs in China from 2008 to 2012

Direct economic loss from HABs in China's four sea areas

There were more than 330 cases of red tides in China from 2008 to 2012, encompassing a total area of 53,000 km^2, with an economic cost of nearly 2.23 billion Chinese Yuan (364 million USD). These red tides caused great harm to marine fisheries, resulting in enormous economic losses. The hardest hit areas were mainly in southeast Chinese coastal waters where 17 disastrous HABs broke out and led to direct economic loss, accounting for about 91% of the total losses. However, the largest scale HAB events were in the Bohai Sea (Fig. 7).

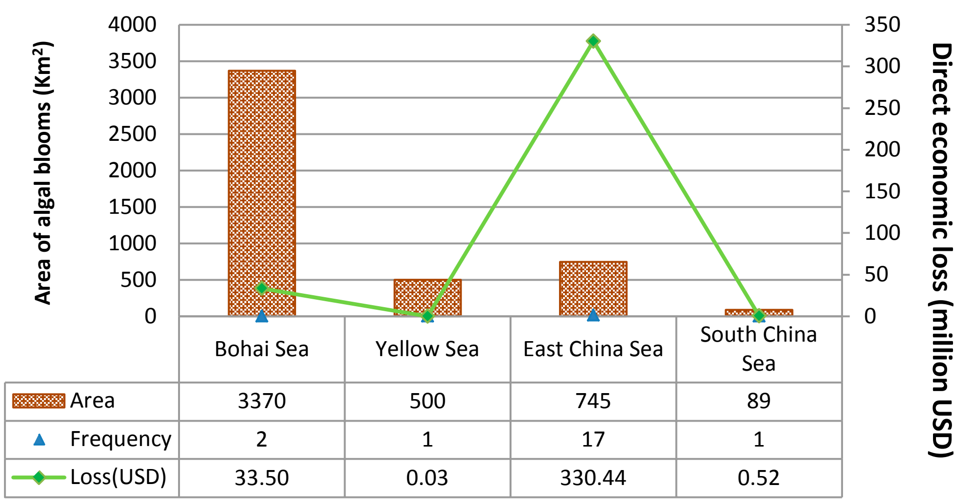
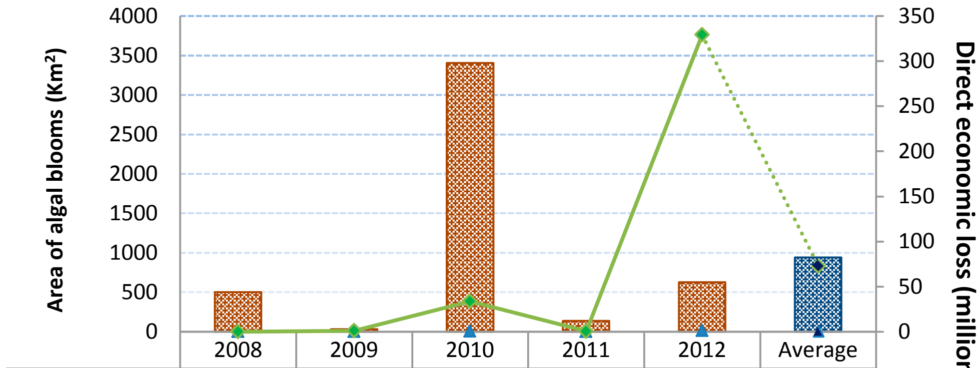


Fig. 7 Direct economic loss of HABs in 4 areas from 2008 from 2012.

Variability of economic loss from 2008 to 2012

Two significant features of economic loss in China are shown in Figure 8. The first is that the largest area of HABs (about 3350 km^2), caused by *Aureococcus anophagefferen*, occurred in May–June 2010 in Qinghuangdao, Hebei Province. The highest direct economic loss, of about 2.02 billion Chinese Yuan (330 million USD), was in 2012 and accounted for about 91% of the total documented losses due to red tides (Fig. 11). The main species responsible for this costly event was *Karenia mikimotoi* which affected cultivated abalone. The average annual loss during 2008–2012 was 446 Chinese Yuan (73 million USD).



	2008	2009	2010	2011	2012	Average
Area	500	30	3407	139	628	940.8
Frequency	1	2	4	2	12	4.2
Loss(USD)	0.03	1.06	33.66	0.53	329.25	73

Fig. 8 Direct economic loss of disasterous HABs during 2008–2012.

Summary

China is a major maritime country. The ocean occupies an important strategic position in China's national economy and social development. However, while marine development and the coastal economy in China are advancing rapidly, several problems impacting the marine environment must be considered. With yearly increases of nutrients and organic compounds polluting the sea, marine red tide disasters have also occurred more frequently. The main disaster-causing species are *Karenia mikimotoi*, *Skeletonema costatum*, *Aureococcus anophagefferen, Noctiluca scintillans*, *Cochlodinium geminatum*, and *Prorocentrum donghaiense.*

There were nearly 70 cases of HABs over approximately 10,560 km^2 annually from 2008 to 2012, accompanied with the total direct economic loss of nearly 450 million Chinese Yuan (73 million USD). The southeast coastal area of China is an important fishery area where red tides occur frequently, causing enormous economic losses. The worst-hit species affected by these red tides are cultivated abalone (*Haliotis discus hannai*, *Haliotis diversicolor*), scallop (*Patinopecten yessoensis*, *Argopecten irradians*, *Chlamys farreri*) and fish (*Lateolabrax japonicas*).

Harmful algal blooms are a global marine issue as well as a major marine disaster in China. Management and disaster mitigation are of great importance in China. Mitigation efforts should be focused on the adverse impact of land-based pollution that can result in environmental disasters and habitat destruction. This should be an area of future research and management.

References

SOA (State Oceanic Administration of China). 2011. *Bulletin of Marine Environmental Status of China in 2011*.

Sournia A. 1995. Red tide and marine phytoplankton of the world ocean: an inquiry into biodiversity *in* Harmful Marine Algal Blooms *edited by* P. Lassus, G. Arzul, E. Erard-Le Denn, P. Gentien and C. Marcaillou-LeBaut, Proceedings of the Sixth International Conference on Toxic Marine Phytoplankton, 1993, Lavoisier, Paris.

Economic losses to the aquaculture industry by harmful algal blooms in Korea since 2001

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Introduction

Since the 1970s, annual aquaculture production (fish, shellfish and macro algae) in Korea has increased steadily each year from around 147,000 metric tons in 1971, to an excess of 700,000 metric tons in 1981, and around 1.2–1.5 million metric tons since 2006 (Yoon, 2008; KOSTAT, 2013). In 2012, finfish production was 7630 metric tons, accounting for about 6% of total aquaculture production (KOSTAT, 2013). In 2012, the total area of finfish cage culture farms in Korean waters was approximately 1,076,309 square meters (KOSTAT, 2013). Most of the cage culture farms are concentrated along the south coast of Korea rather than the east and west coasts due to conditions that are beneficial to aquaculture in the south, including the protection of semi-closed bays and islands and moderate tidal ranges. This archipelagic environment makes it an ideal place for the installation of cages. With the development of advanced aquaculture technology, a number of important aquaculture species have become lucrative in Korea since the late 1980s, including olive flounder, *Paralichthys olivaceus*, Korean rockfish, *Sebastes schlegeli*, sea bream, *Pagrus major* and *Acanthopagrus schlegeli*, and grey mullet, *Mugil cephalus*, which have been important aquaculture species since the late 1980s (Lim, 2006). The highest yields of aquacultured fish are olive flounder (51%), followed by Korean rockfish (29%), grey mullet (7%), sea bream (5%) and sea bass (2%; KOSTAT, 2013). Cage cultures are much more common than land-based cultures for Korean rockfish, sea bream and sea bass along the southern coast (Lim, 2006; Yoon, 2008; KOSTAT, 2013).

Harmful algal blooms (HABs) have become more frequent in Korean waters since the 1990s, although less dense blooms were sporadic until the 1980s. In particular, blooms by the fish killing dinoflagellate, *Cochlodinium polykrikoides*, have become annual and persistent occurrences since the mid-1990s, after the first event was recorded in Jinhae Bay in 1982 (Kim, 1997; Lee *et al.*, 2013b). The first fish kill by HABs (by *Karenia mikimotoi*) in Korea occurred in 1981, resulting in fisheries losses of 1.7 million USD. In 1992, *Gyrodinium* sp. caused fisheries losses of 5 million USD (NFRDI, 2010). Since then, *C. polykrikoides* caused fish kills with fisheries losses of 7 million USD in 1993 and 60 million USD in 1995 (the largest fish kill). Through the 2000s and 2010s, *C. polykrikoides* was the single most important fish killing species causing damage to aquaculture farms in Korea (Fig. 1).

Fig. 1 Caged fish kill caused by a *Cochlodinium* bloom in Korea.

The main factors leading to fish kills by *C. polykrikoides* blooms have been reported to be associated with structural and functional changes at the gill filament/tissue level (inactivation of enzymes, decrease of partial blood pressure and distortion of the epithelium, *etc*.) resulting in suffocation by the decrease in oxygen exchange in the fish gills (Kim *et al.*, 1999; Kim *et al.*, 2000; Kim *et al.*, 2001; Kim *et al.*, 2002a; Kim *et al.*, 2002b). These observations suggest that finfish flesh does not become toxic by *C. polykrikoides* blooms and does not cause human health concerns.

The National Fisheries Research and Development Institute (NFRDI) and fisheries extension service stations under local governments have their own HAB monitoring networks covering the entire Korean coastline. The stations were established in 1995 to monitor massive fish kills by *C. polykrikoides* blooms. In addition, special monitoring programs targeting *Cochlodinium* are in place before, during, and after blooms on the south coast where there have been frequent and dense blooms since 2000. This monitoring program is aimed primarily at early prediction and warning of *Cochlodinium* blooms based on biological and hydrological data collected through field surveys at 2-week intervals from June to October. A HAB clearinghouse at NFRDI collects all available biological and hydrological data from both monitoring institutes and coastal environment observation buoys deployed near aquaculture farms, and collates available meteorological and remote sensing data to synthesize, analyze and publish a daily HABs newsletter. The newsletter, describing causative organisms, cell densities, affected and warning areas, is disseminated to fishermen and HAB agencies by automated telephone response system, short message service (SMS), satellite TV, fax, and via a webpage. NFRDI has adopted a HABs warning system for fishermen and aquaculturists consisting of two levels: red tide attention (<300 cells/ml) and red tide alert (<1,000 cells/ml).

In this report, characteristics of HAB occurrences and economic losses in association with *C. polykrikoides* blooms from 2001 to 2012 are provided, which might be helpful for researchers and policymakers to understand and mitigate the fisheries impact by HABs in Korea.

Methods

Data on HAB events were collected through both a regular HABs monitoring program at 98 sites along the entire Korean coast (Fig. 2), and a special *Cochlodinium* monitoring program for 30 sites on the south coast where there have been frequent and dense blooms. Data on HAB causative species, cell density, areas affected by blooms, hydrological (CTD) measurements and water quality (nutrients) were collected by the regular HABs monitoring and special *Cochlodinium* monitoring programs, conducting monthly from March to November and every the other week from June to October, respectively. The relative bloom intensity of *Cochlodinium* (0–10 points) was calculated based on a summary value determined from the following: cell density (0–3 points), bloom duration (0–3 points), area affected by bloom (0–3 points) and direct fisheries losses (0–1 point). Data on direct fisheries losses due to *Cochlodinium* blooms were gathered from statistics reported by the local government and/or Ministry of Oceans and Fisheries (MOF, 2012). Additional costs were calculated based on the expenses for HAB control by clay (sum of purchase, transportation and dispersal) by local governments who are in charge of HAB mitigation during blooms. However, indirect economic losses by HABs (*e.g*., purchasing and running of mitigation equipment, fuel and labour for mitigation activities, retarded fish growth resulting from reduced or no feeding during blooms, reduction of fisheries consumption and decrease of marine recreational activities) were not included in this report.

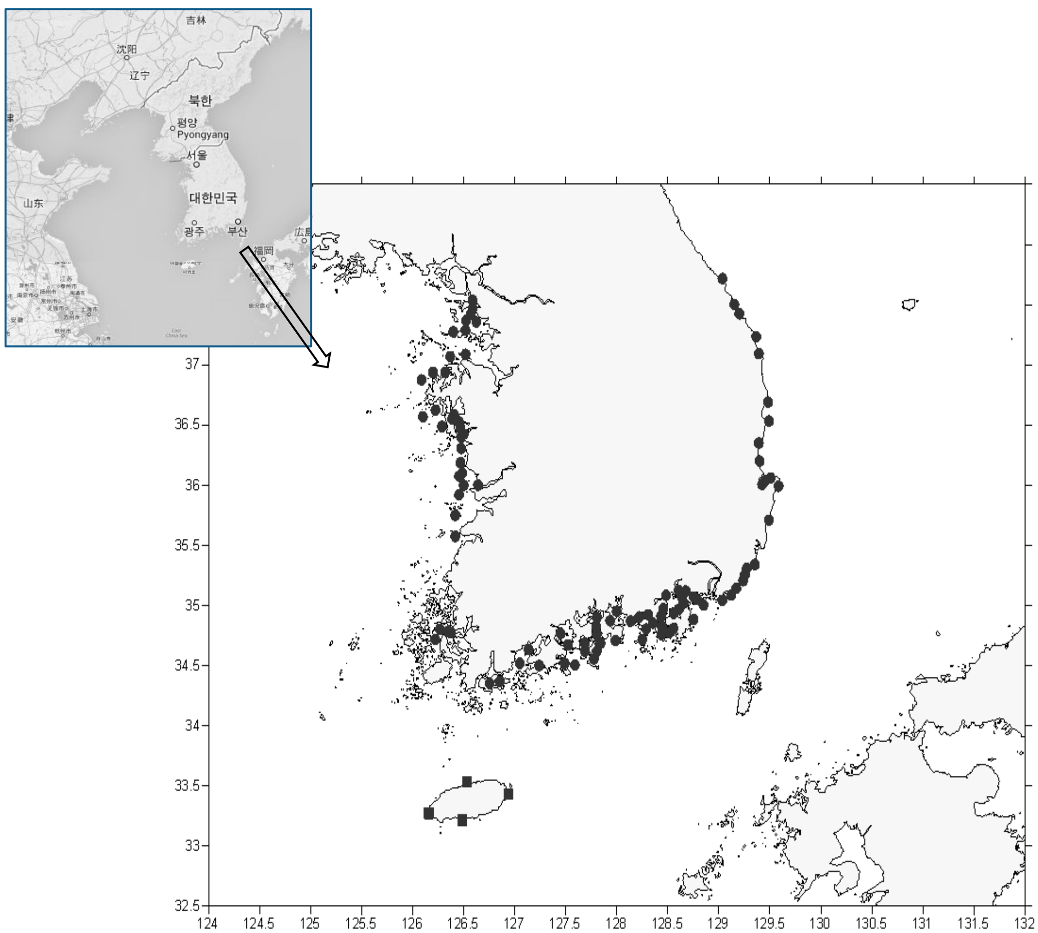

Fig. 2 Map showing regular HAB monitoring locations along the Korean coastline.

Results

HAB events and bloom intensity of Cochlodinium during 2001–2012

A total of 470 HAB events were recorded, of which 155 events were caused by fish killing species that occurred along the entire Korean coast from 2001 to 2012 (Fig. 3). HAB events caused by non-fish killing species (67%) were much higher than those by fish killing species (*Cochlodinium polykrikoides* and *Chattonella* spp.) during this period. Overall, the number of HAB events has decreased gradually since the latter half of the 2000s, and the decrease was closely associated with a decrease in *C. polykrikoides* blooms. In particular, the number of *C. polykrikoides* blooms in 2010 was very low (3 events), with no bloom observed in 2011. From the latter half of the 2000s, the most frequent red tides were caused by *C. polykrikoides*, *Heterosigma akashiwo*, *Noctiluca scintillans*, *Skeletonema coastatum*, *Akashiwo sanguinea*, *Prorocentrum minimum*, *Gonyaulax polygramma*, *Mesodinium rubrum*, *Prorocentrum dentatum/donghaiense*, *Chatonella antiqua* and *C. marina,* among which *C. polykrikoides* was the only species that led to fish kills during the period.

On the other hand, the intensity of *C. polykrikoides* blooms was comparatively high in 2007 (9.5 relative bloom intensity), 2003 (9.2), 2001 (8.5), 2005 (8.0) and 2002 (7.9); low in 2009–2011 (2–0), 2006 (3.9), 2004 (4.8) and 2008 (5.9). In particular, the bloom intensity in 2007 and 2003 was remarkably high at more than 9.2 of a possible 10 total relative bloom intensity points (Fig. 4).

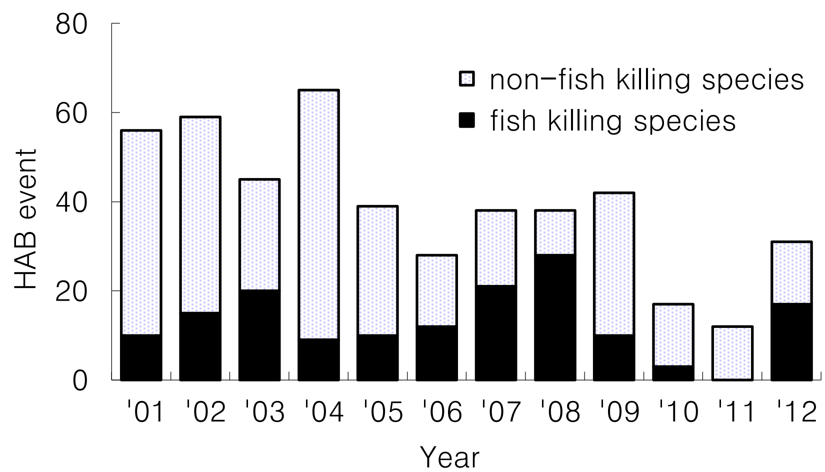

Fig. 3 Number of HAB events on Korean coasts during 2001–2012.

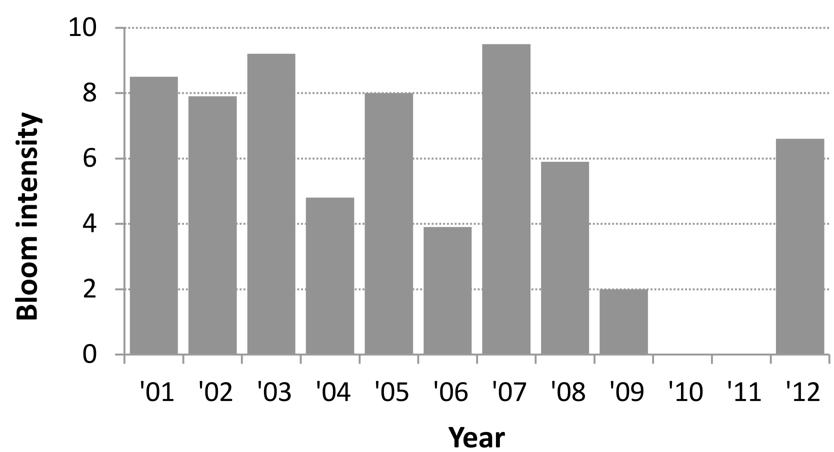

Fig. 4 Intensity of *Cochlodinium* blooms on Korean coastlines during 2001–2012.

Direct economic losses due to HABs

Fish kills by HABs in Korea from 2001 to 2012 were caused only by *C. polykrikoides* blooms. Direct fisheries losses to aquaculture farms due to *C. polykrikoides* blooms are shown in Figure 5. Total direct losses due to *C. polykrikoides* blooms from 2001 to 2012 were 53.22 billion Korean Won (equivalent to about 52 million USD). Direct fisheries losses were relatively high in 2003 (22.3 billion KRW), 2007 (11.5 billion KRW) and 2001 (8.4 billion KRW), with low or no losses in 2004–2006 and 2008–2011. In particular, there were about 13 million individual finfish and shellfish mortalities in 2003. Overall, high fisheries losses occurred in years when the bloom intensity of *C. polykrikoides* was comparatively high (< 9 points).

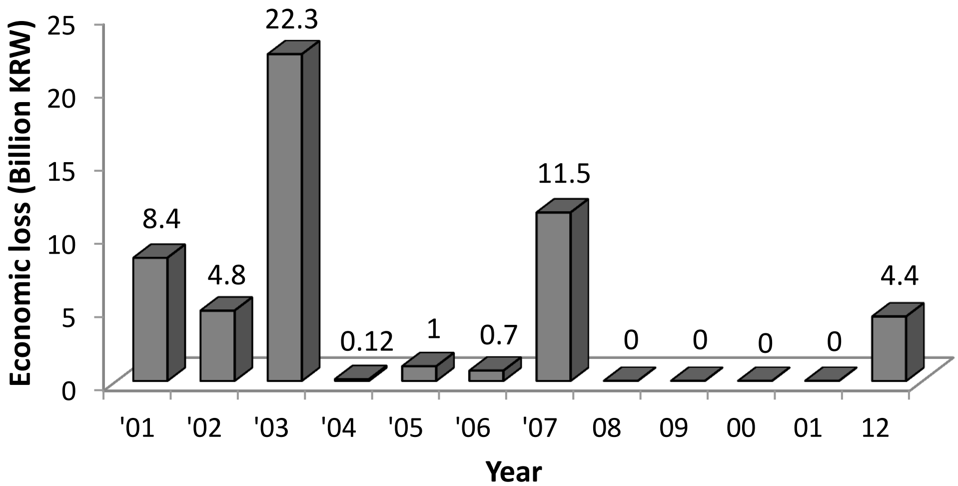

Fig. 5 Direct losses to aquaculture farms due to *Cochlodinium* blooms from 2001–2012.

Associated economic losses due to HABs

Bloom mitigation measures include several techniques such as: direct control of harmful algae by physical, biological and chemical methods, injection of liquefied oxygen into the culture tanks/cages to increase dissolved oxygen levels, thereby preventing suffocation of fish, and withholding feeding to minimize the oxygen requirement for fish (NFRDI, 2005; Park *et al.*, 2013). Clay dispersal is the major HAB mitigation technique in Korea, primarily because yellow clay is relatively inexpensive with high removal efficiency and is easy to apply in the field without serious impacts on aquatic organisms (Yu *et al.*, 2004; Seo *et al*., 2008; Lee *et al.*, 2013a).

In this report, additional economic losses by HABs were calculated to include the expenses for clay control activities by local governments who are in charge of mitigation during blooms. In 2012, it was estimated that local governments spent approximately one billion Korean Won (equivalent to about one million USD) for clay control activities (mostly for purchase, transport/shipping and field dispersal of clay).

Aquaculturists' expenses to minimize fish kill against HABs go towards purchasing/running mitigation equipment (bubblers, oxygen suppliers including liquefied oxygen, algae filtration units, motors for deep water pumping into cages, *etc*.), and mitigation activities to dilute and control algal patches by boats. Moreover, it is inevitable for aquaculturists to have economic losses due to retarded fish growth resulting from reduced or no feeding during HABs. Income to fisheries villages is also reduced due to the decrease in numbers of visitors participating in marine recreational activities along the coasts, including sports fishing during HAB events. Accordingly, such indirect economic losses should be considered in the estimation of total economic losses due to HABs. However, indirect economic losses were not included in this report even though they may be considerable.

Summary

From 2001 to 2012, direct fisheries losses to aquaculture farms by HABs exceeded 53 billion Korean Won (equivalent to about 52 million USD). *Cochlodinium polykrikoides* was responsible for fish kills in Korea during this period. High fisheries losses occurred in 2003 and 2007 when the bloom intensity of *C. polykrikoides* was remarkably high. It was estimated that local governments spent approximately one billion Korean Won (equivalent to about one million USD) for clay control activities in 2012.

References

Lee, C.K., Kim, W.S., Park, Y.T. and Jo, Q. 2013a. Effect of yellow clay on oxygen consumption rate of Korean rockfish, *Sebastes schlegelii*. *J. Kor. Soc. Mar. Environ. Safety* **19**: 241–247.

Lee, C.K., Park, T.G., Park, Y.T. and Lim, W.A. 2013b. Monitoring and trends in harmful algal blooms and red tides in Korean coastal waters, with emphasis on *Cochlodinium polykrikoides*. *Harmful Algae* **30S**: S3–S14.

Lim, H.K. 2006. Korean aquaculture: Status and future directions. Aquaculture Research Team, Report. National Fisheries Research and Development Institute, Republic of Korea.

Kim, H.G. 1997. Recent harmful algal blooms and mitigation strategies in Korea. *Ocean Res*. **19**: 185–192.

Kim, C.S., Jee, B.Y. and Bae, H.M. 2002a. Structural alterations in the gill of the red sea bream, *Pagrus major*, exposed to the harmful dinoflagellate *Cochlodinium polykrikoides. J. Fish. Sci. Tech*. **5**: 75–78.

Kim, C.S., Lee, S.G., Lee, C.K., Kim, H.G. and Jung, J. 1999. Reactive oxygen species as causative agents in the ichthyotoxicity of the red tide dinoflagellate *Cochlodinium polykrikoides*. *J. Plankton Res*. **21**: 2105–2115.

Kim, C.S., Lee, S.G. and Kim, H.G. 2000. Biochemical responses of fish exposed to a harmful dinoflagellate *Cochlodinium polykrikoides*. *J. Exper. Mar. Biol. Ecol*. **254**: 131–141.

Kim, C.S., Lee, S.G., Kim, H.G. and Lee, J.S. 2001. Screening for toxic compounds in the red tide dinoflagellate *Cochlodinium polykrikoides*: Is it toxic plankton? *Algae* **16**: 457–462.

Kim, D., Oda, T., Muramatsu, T., Kim, D., Matsuyama, Y. and Honjo, T. 2002b. Possible factors responsible for the fish-killing mechanism of the red tide phytoplankton, *Chattonella marina* and *Cochlodinium polykrikoides*, pp. 245–268 *in* Coastal Environmental Ecosystem Issues of the East China Sea *edited by* A. Ishimatsu, and H.J. Lie, TERRAPUB and Nagasaki University, Tokyo and Nagasaki.

KOSTAT (Statistics Korea). 2013. Statistics of finfish production in Korea. Korean Statistical Information Service (http://kosis.kr/statisticsList).

MOF (Ministry of Oceans and Fisheries). 2012. Counter plan for red tide mitigation. 2012 meeting report of MOF for HAB measure. Seoul, Korea.

NFRDI (National Fisheries Research and Development Institute). 2005. Guideline for HAB mitigation in the field. 15 pp. Busan, Korea.

NFRDI. 2010. Monitoring, management and mitigation of red tide. Annual Report of NFRDI on red tide of Korea. Busan, Korea.

Park, T.G., Lim, W.A., Park, Y.T., Lee, C.K. and Jeong, H.J. 2013. Economic impact, management and mitigation of red tides in Korea. *Harmful Algae* **30**S: S131–S143.

Seo, K.S., Lee, C.K., Park, Y.T. and Lee, Y. 2008. Effect of yellow clay on respiration and phytoplankton uptake of bivalves. *Fish. Sci*. **74**: 120–127.

Yoon, G.H. 2008. Aquaculture in Korea. *Aquaculture News* **34**: 16–17.

Yu, Z., Sengco, M.R. and Anderson, D.M. 2004. Flocculation and removal of the brown tide organism *Aureococcus anophagefferens* (Chrysophyceae), using clays. *J. Appl. Phycol*. **16**: 101–110.

Harmful algal blooms on the Russian east coast and their possible economic impacts

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Introduction

Harmful algal blooms (HABs) have serious economic impacts on fisheries and cause harm to people's health in countries of the PICES region, including the northern Russian Pacific region. A monitoring program aimed to analyze the presence of HAB species in the coastal waters of Primorsky Krai and screen for phycotoxins in shellfish was launched in 2007. Data from this monitoring program revealed a real threat of diarrhetic shellfish poisoning, from measurements of okadaic acid and dinophysistoxins in shellfish in excess of their guidance limit. Nevertheless, there is no effective governmental monitoring of HABs and phycotoxins in Russia, although there is a law on appropriate concentrations of phycotoxins in seafood. There are no routine measurements of phycotoxins as part of a sanitation program and as a consequence, these toxins are not diagnosed or recorded by medical or sanitary organizations. These are the primary reasons for not having formal data on the economic impacts of HABs, as well as their harm on people's health in Primorsky Krai and for the whole Far Eastern region of Russia. In this report, we will make a first attempt to estimate the potential economic impacts and harm to people's health caused by HABs based on analysis of data obtained by the Center for Monitoring of Harmful Algal Blooms and Biotoxicity in Coastal Waters, Institute of Marine Biology of the Far Eastern Branch of the Russian Academy of Science (IMB FEB RAS; see www.imb.dvo.ru/misc/toxicalgae/index.htm).

Toxic microlgae and phycotoxins in the coastal waters of Primorsky Krai

Research on HABs started at the beginning of the 1990s at the Institute of Marine Biology FEB RAS (Konovalova, 1993; Orlova *et al*., 2002). However, potentially harmful microalgae were detected previously by phytoplankton monitoring programs (Ostroumoff, 1924; Kisselew, 1950; Gail, 1959). Microalgal toxins are known to concentrate in shellfish, and can cause the toxic syndromes paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP) and diarrhetic shellfish poisoning (DSP) when ingested by people. The microalgae that produce these toxins are not only common but are capable of causing dense blooms in the Far Eastern Seas of Russia, including the coast of Primorsky Krai (Orlova, 2014). Microalgae isolated from Russian waters have been shown to have the ability to produce toxins in culture (Orlova *et al*., 2007; Orlova *et al*., 2008), and contamination of bivalves by paralytic shellfish toxins (PSTs) was detected in Aniva Bay (Mogilnikova *et al*., 2007). Cases of DSP are believed to be common for Primorsky Krai; however, cases of DSP intoxication have not been confirmed by sanitary control officials. Symptoms of DSP, including nausea, vomiting and diarrhea have been reported by many people after eating mussels and clams during summer months (S.I. Maslennikov, V.V. Ivin, D.I. Vyshkvartsev, E.V. Lebedev and others, pers. comm.). This is a common situation in many coastal regions, but due to the complexity in diagnosing DSP, and the difficulty in establishing causal links between the consumption and contamination of shellfish by phycotoxins, cases of confirmed DSP are rarely reported. A massive poisoning event was registered in 2012 in the Khasan recreational area in Primorsky Krai, when 30 tourists were hospitalized with symptoms of diarrhea and vomiting. Their first symptoms were felt after eating seafood purchased from one of the beach shops (http://primamedia.ru/news/14.08.2012/221993/). Etiologies of intestinal infections have not been defined, but according to the Russian Federal Sanitary Control Service, a rise in incidence of intestinal diseases associated with seafood is recorded annually in Primorsky Krai during the period from mid-August to mid-September.

Monitoring for toxin-producing microalgae and phycotoxins in bivalves has been conducted by the Center for Monitoring of Harmful Algal Blooms and Biotoxicity of Russian Far Eastern Coastal Waters since 2007. Toxin concentrations, both in samples of mussels and microalgae cultures isolated from Peter the Great Bay, were quantified by Enzyme Linked Immunosorbent Assay (ELISA) and high performance liquid chromatography (HPLC) methods. Monitoring in the coastal waters of Primorye from 2007 to 2012 revealed the presence of 30 known biotoxin-producing species that can form blooms (Table 1). Potentially toxic species belong to four groups of phytoplankton: *Bacillariophyta*, *Dinophyta*, *Haptophyta* and *Raphidophyta*. Diatoms of the genus *Pseudo-nitzschia* are producers of domoic acid, which causes ASP, and species of the genera *Dinophysis* and *Prorocentrum*, capable of producing diarrhetic toxins, were observed in the study area. Species of the genus *Alexandrium*, known as producers of saxitoxins that cause PSP, also were found. Monitoring revealed the potentially toxic species *Protoceratium reticulatum*, *Gonyaulax spinifera* and *Lingulodinium polyedra* which can produce yessotoxins. Raphydophytes, haptophytes and diatoms of the genus *Chaetoceros* are known fish killers.

ASP causative species

Pseudo-nitzschia is one of the most widespread and abundant microalgae groups capable of toxin production in the coastal waters of Primorsky Krai. Seven potentially toxic *Pseudo-nitzschia* species, *P. calliantha*, *P. delicatissima*, *P. fraudulenta*, *P. multiseries*, *P. multistriata*, *P. pungens* and *P. seriata* were found in Primorsky Krai coastal waters (Stonik *et al*., 2011a; Stonik and Orlova, 2013). Blooms of *P. calliantha*, *P. multiseries*, *P. multistriata* and *P. pungens* have been observed in summer and autumn months with abundances exceeding 1 million cells/L and constituting 75–98% of the total density of the phytoplankton assemblage (Orlova *et al*., 1996; Stonik *et al*., 2011a). Analysis of domoic acid (DA) by HPLC was performed on a culture of *P. multiseries* (clone PM02, analyzed at day 27 in culture). This culture, which was isolated from the coastal waters of Vladivostok, showed an extremely high concentration of DA, at 7000 ng/ml (Orlova *et al*., 2008). Concentrations of DA (up to 0.5 pg/cell), determined using the "ASP direct ELISA" kit (Biosense Laboratories AS, Norway, AOAC official method 2006.02), were measured in cultures of 4 species: *P. calliantha*, *P. delicatissima*, *P. multistriata* and *P. pungens*, (Stonik *et al*., 2011b; Stonik, unpubl. data). The monitoring of DA concentrations in mollusks collected from Amursky, Ussuriisky, Golden Horn and Vostok bays from 2009 to 2013 showed that concentrations in tissues of the bivalves *Mytilus trossulus*, *Crenomytilus grayanus* and *Mizuhopecten yessoensis* in summer, autumn, and winter ranged from 0.01 to 0.5 mg DA/kg, well below the permissible regulatory limit of 20 mg/kg (Stonik and Orlova, 2012). No human poisonings due to DA in shellfish have been reported. The relatively high concentrations of several *Pseudo-nitzschia* species able to produce DA suggest the potential threat of ASP in Primorsky Krai.

PSP causative species

Dinoflagellates known to produce PSP toxins were observed in Peter the Great Bay. Species of *Alexandrium* produce saxitoxin and its analogues, which are transferred up food chains, causing intoxication of people and massive mortalities of aquatic warm-blooded animals. Four potentially harmful species were identified in the coastal waters of Primorsky Krai (Table 1). The abundances of these species can reach more than 500 cells/L in the summer–autumn period. When the concentration of these microalgae reaches threshold concentrations in the European Union (EU), the Sanitary Control Services in the EU prohibit the harvest and consumption of shellfish in the region. Maximum concentrations of *Alexandrium* in the coastal waters of Vladivostok can reach up to

10,000 cells/L, well above the EU threshold value. Strains of potentially toxic species of *A. tamarense*, obtained by germinating resting cysts from the marine sediments of Primorye, were screened for biotoxins by HPLC. Results showed that all isolated strains contained saxitoxin and its derivatives as well as high concentrations of C1, C2, neosaxitoxin and gonyautoxin-5 (Orlova *et al*., 2007).

Table 1 Toxic microalgae in the coastal waters of Primorye.

Species	Type of poisoning	Toxin	Maximum concentration of microalgae (thousands cells/L)	Reference
Bacillariophyta				
Chaetoceros concavicornis Mangin	FM*	–	10	Shevchenko *et al*., 2006
Chaetoceros convolutus Castracane	FM	–	1	Shevchenko *et al*., 2006
Pseudo-nitzschia pungens (Grunow ex P.T. Cleve, 1897) Hasle	ASP	DA	11,000	Orlova *et al*., 1996
Pseudo-nitzschia multiseries (Hasle, 1974) Hasle	ASP	DA	11,000	Orlova *et al*., 1996
Pseudo-nitzschia calliantha Lundholm, Moestrup & Hasle	ASP	DA	2,700	Orlova *et al*., 2008
Pseudo-nitzschia delicatissima (P.T. Cleve, 1897) Heiden	ASP	DA	200	Stonik *et al*., 2011a
Pseudo-nitzschia fraudulenta (P.T. Cleve, 1897) Hasle	ASP	DA	450	Stonik *et al*., 2011a
Pseudo-nitzschia multistriata (Takano, 1993) Takano	ASP	DA	1,500	Stonik *et al*., 2011a
Pseudo-nitzschia seriata (P.T. Cleve, 1883) H. Pera-gallo in H. & M. Peragallo	ASP	DA	230	Stonik *et al*., 2011a
Dinophyta				
Alexandrium acatenella (Whedon & Kofoid, 1936) Balech	PSP	STX	0.2	Konovalova and Selina, 2010
A. ostenfeldii (Paulsen, 1904) Balech & Tangen	PSP	STX, SP	0.2	Konovalova and Selina, 2010
Alexandrium tamarense (Lebour, 1925) Balech	PSP	STX	10	Orlova *et al*., 2007
Alexandrium pseudogonyaulax (Biecheler) Horiguchi ex Yuki et Fukuyo	CT	GA	5.6	Morozova *et al*., 2002
Dinophysis acuminata Claparède & Lachmann	DSP	OA, DTX–1,2	11	Orlova *et al*., 2013
Dinophysis acuta Ehrenberg	DSP	OA, DTX–1,2	0.2	Orlova *et al*., 2002
Dinophysis caudata Saville-Kent	DSP	OA, PTX–2	0.1	Konovalova and Selina, 2010
Dinophysis fortii Pavillard	DSP	OA, DTX–1, PTX–2	3	Orlova *et al*., 2002
Dinophysis norvegica Claparède & Lachmann	DSP	OA, DTX–1	5	Konovalova and Selina, 2010

Table 1 Continued.

Species	Type of poisoning	Toxin	Maximum concentration of microalgae (thousands cells/L)	Reference
Dinophyta				
Dinophysis rotundata Claparède & Lachmann	DSP	DTX–1	0.1	Konovalova and Selina, 2010
Dinophysis sacculus Stein	DSP	OA	0.1	Konovalova *et al*., 1989
Gonyaulax spinifera (Claparède & Lachmann, 1859) Diesing	DSP?	YTX	0.5	Konovalova and Selina, 2010
Lingulodinium polyedra (F. Stein) J.D. Dodge	DSP?, FM	YTX	0.2	Gail, 1950; Konovalova and Selina, 2010
Prorocentrum lima (Ehrenberg, 1860) Stein	DSP	OA, DTX-1,2,4 FAT, PR	0.2	Konovalova and Selina, 2010
Prorocentrum minimum (Pavillard, 1916) Schiller	FM, IM	–	8,000	Stonik, 1994
Protoceratium reticulatum (Claparède & Lachmann, 1859) Bütschli	DSP?	YTX	10	Orlova *et al*., 2009
Raphidophyta				
Chattonella marina (Subrahmanyan) Hara & Chihara	FM	ROS	15,000	Simakova *et al*., 1990
Fibrocapsa japonica Toriumi et Takano	FM	ROS	1.5	Selina, 1993
Heterosigma akashiwo (Y. Hada) Y.Hada ex Y. Hara & M. Chihara	FM	ROS	309,100	Orlova *et al*., 2002
Haptophyta				
Pseudohaptolina birgerii (G. Hällfors & Hiemi) Stonik, Efimova & Orlova	FM?	ROS?	275,000	Orlova *et al*. (in press)
Chrysochromulina sp.	FM	ROS	–	Konovalova *et al*., 1989

*Abbreviations: ASP – amnesic shellfish poisoning; DSP – diarrhetic shellfish poisoning; PSP – paralytic shellfish poisoning; FM – fish mortality; IM – invertebrate mortality; CT – cytotoxicity, FAT – fast acting toxins; DA – domoic acid; YTX – yessotoxins; STX – saxitoxins; SP – spirolids; GTX – goniotoxins; NSTX – neosaxitoxin; GA – goniodomin A; OA – okadaic acid; DTX – dinophysistoxins; PTX – pectenotoxin; PR – prorocentrolide; ROS – reactive oxygen species.

DSP causative species

Routine monitoring of phytoplankton showed that species of the genus *Dinophysis*, known to produce DSTs, are common and abundant in the summer–autumn period in the coastal waters of Primorsky Krai. Eleven species of *Dinophysis* and *Prorocentrum* (Table 1), known worldwide as DSP producers, were found in the region of investigation. Total abundance of dangerous species of *Dinophysi*s in the coastal waters of Primorsky Krai can reach several thousand cells per liter of water (Fig. 1) in the summer period. This is 10 times higher than the EU regulatory limit (Andersen, 1996).

During the period of investigation, several blooms of *D. acuminata* were observed. In 1993, a bloom of *D. acuminata* was detected, at a concentration of 6.2×10^4 cells/L in the central part of Amursky Bay (I.V. Stonik, pers. comm.). In June 2006, a bloom of *D. acuminata*, at a concentration of 6.3×10^5 cells/L, was recorded in an artificial lagoon in Amursky Bay (A. Begun, pers. comm.).

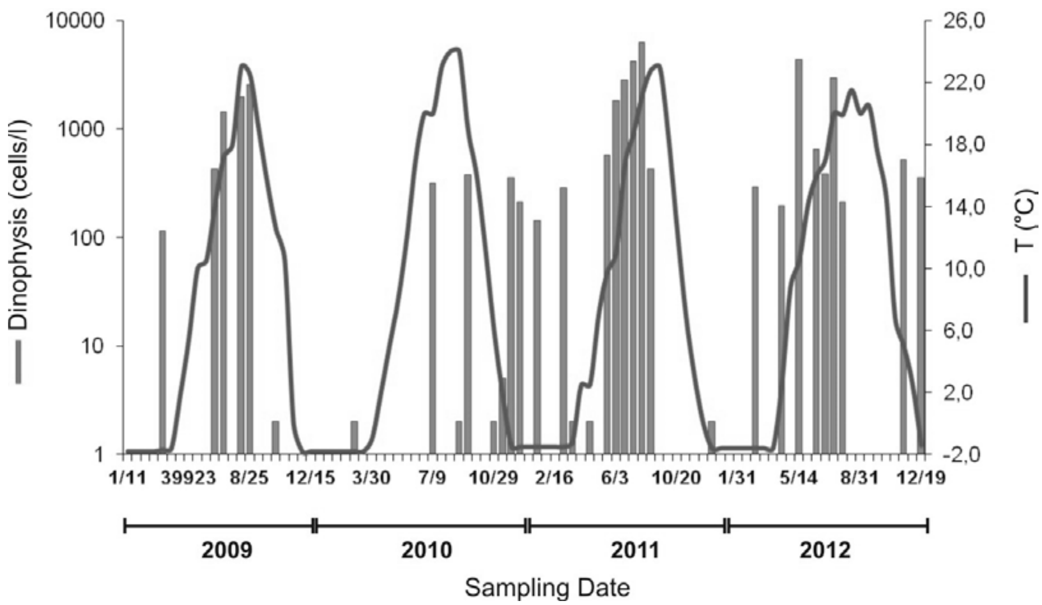

Fig. 1 Water temperature and total *Dinophysis* abundance in Vladivostok coastal waters.

As a result of high *Dinophysis* cell densities, concentrations of toxins in bivalves have also exceeded the regulatory guidance limit. The maximum concentration of DSTs in mussels was 22.92 μg/100 g (Fig. 2; Orlova *et al*., 2013). Qualitative analysis revealed the toxin profile, which has DTX–1 as a major toxin isoform (94–100%) with okadaic acid (0–6%) as a minor isoform. Trace amounts of yessotoxin (YTX), pectenotoxin-2 (PTX–2) and azaspiracid-2 (AZA–2) also were observed. This documents the detection of PTX–2 and AZA-2 in Russian waters for the first time.

Gonyaulax spinifera, *Protoceratium reticulatum* and *Lingulodinium polyedra* have been identified in Peter the Great Bay. These microalgae are known YTX producers (Table 1). Other potential YTX producers recently have been observed in low abundance in the region of investigation. The most abundant is *P. reticulatum*, which can reach a density of up to many thousands cells per liter.

In summary, the human consumption of bivalves may cause diarrhetic and amnesic poisoning. The absence of defined phycotoxin control measures in mariculture facilities may have irrecoverable consequences for the fisheries and tourist economies as well as people's health.

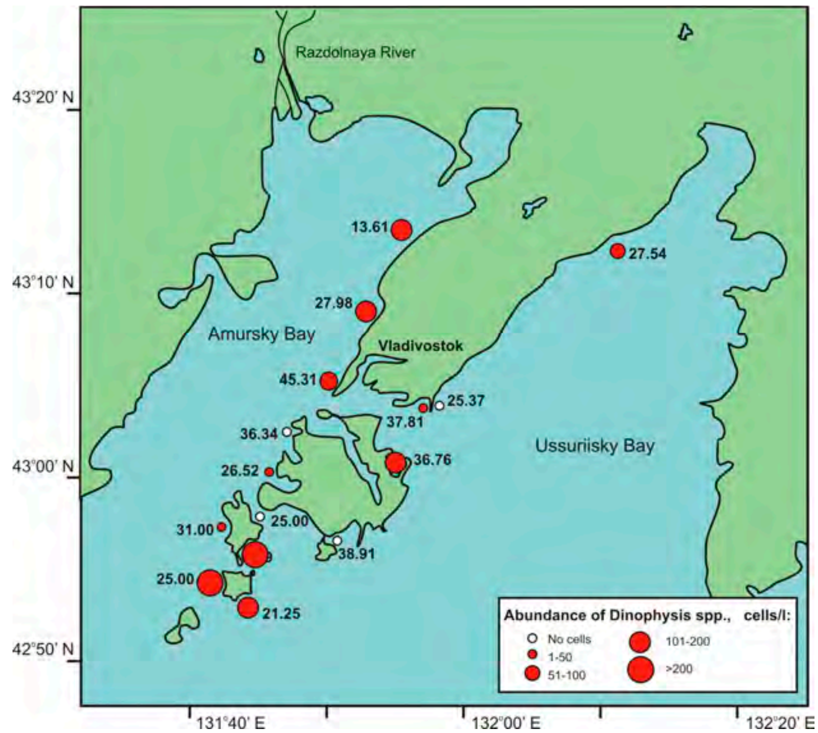

Fig. 2 Spatial distribution of *Dinophysis* (circles, cells/L) and DSTs (numbers, µg/100 g; EU regulatory closure level is 16 µg/100 g) in the coastal waters of Vladivostok. Concentrations of DSTs were determined by Abraxis ELISA.

Species responsible for fish and invertebrates mortalities

In Primorsky Krai, 8 species responsible for massive fish and invertebrate kills have been identified. Those microalgae belong to four taxonomic groups: *Bacillariophyta* (2 species), *Dinophyta* (1 species), *Haptophyta* (2 species) and *Raphidophyta* (3 species).

Two species of diatoms causing concern are *Chaetoceros convolutus* and *C. concavicornis*, organisms which are widespread in Primorsky Krai coastal waters from January through May at densities up to 10,000 cells/L. These diatoms are included in summer bloom-forming assemblages (Konovalova *et al*., 1989).

The dinoflagellate *Prorocentrum minimum* has been considered potentially toxic to humans via ingestion of its toxins accumulated in shellfish, although reported associations between *P. minimum* blooms and human toxicity are rare (Tangen, 1983; Taylor *et al*., 2003). *P. minimum* was found from April to December in the coastal waters of Primorye, and may form strong blooms in the summer, with maximum concentration up to 8×10^6 cells/L in August (Stonik, 1994).

Raphidophyte flagellates are well known for their allelopathy and ichthyotoxic blooms which pose a serious global threat to fish farming (Imai and Yamaguchi, 2012). There are three potentially toxic raphidophyte genera in Primorye: *Chattonella*, *Fibrocapsa* and *Heterosigma*. *Heterosigma akashiwo* is a harmful bloom-forming alga that inhabits temperate coastal waters around the world and can cause kills of both wild and cultured fish. Fish have been observed to die when *H. akashiwo* concentrations exceed millions of cells per liter (Taylor and Haigh, 1993). *H. akashiwo* is the most common bloom-forming raphidophyte in the coastal waters of Primorsky Krai. This species was found from April to September. The maximum concentration ("yellow tide") of *H. akashiwo* up to 100 million cells/L was observed in June 2010 in the coastal waters of Vladivostok when water temperatures reached 22ºC.

Chattonella marina is known as a bloom-forming fish killing species. This species was observed in the coastal waters of Primorye from July to October when water temperature ranged from 14–22ºC. Red tides caused by *Chattonella marina* were observed in Amursky Bay in October 1987, followed by fish deaths (Simakova *et al*., 1990).

Haptophytes are a major component in marine pico- and nanoplankton communities, occurring in all seas as important primary producers (Thomsen *et al*., 1994). Blooms of haptophytes cause fish kills (Edvardsen and Paasche, 1998) and may have a major impact on ecosystems. The two potentially toxic genera *Pseudohaptolina* and *Chrysochromulina* sp. were found in the coastal waters of Primorsky Krai (Table 1). *Chrysochromulina* sp. is common but not abundant in the coastal waters of Primorsky Krai (Konovalova *et al*., 1989). The brown tide haptophyte *Pseudohaptolina birgerii* (G. Hällfors and Hiemi) Stonik, Efimova and Orlova (basyonim *Chrysochromulina birgerii* G. Hällfors and Hiemi) was observed in early spring (March–April), with a maximum concentration of 275×10^6 cells/L, under ice in the coastal waters of Vladivostok.

These results demonstrate that almost the whole territory of Peter the Great Bay is under threat of HAB development and toxin poisoning in the summer–autumn period. The concentrations of toxins in shellfish and densities of dangerous microalgae species are comparable with recommended thresholds for fish farms and harvest closures in the EU and Asia-Pacific countries. Consumption of bivalves during observed blooms may cause DSP, PSP or ASP. Absence of phycotoxin control in mariculture facilities may have irrecoverable consequences for the economy and people's health. The following activities pose the biggest risk of phycotoxin exposure to consumers:

- *Purchase of phycotoxin-poisoned seafood products*
  Potentially toxic seafood products can be purchased in shops, at local markets, from unauthorized distributors, and from salespeople. Seafood from local sea farms is widely distributed throughout the region without a requirement for sanitary certification.

- *Restaurants and cafes*
  In local cafes and restaurants, seafood dishes may be cooked from products purchased from local sea farms or from salespeople. There is no requirement to have a sanitary certification that the seafood is phycotoxin-free (GOST R ISO 22000: 2007).

- *Through dietary supplements from seafood*
  Seafood is a known source of biologically active substances. In Primorsky Krai, there are several companies that produce dietary supplements from seafood stock materials. Extracts are prepared from mussels purchased from local sea farms. Certification that the seafood is phycotoxin-free is not required.

- *Individual seafood harvest*
  In the summer period, it is popular for people to harvest and cook seafood from Peter the Great Bay for consumption on the beach. A license for seafood harvest is not required.

Hygienic requirements of seafood safety in the Russian Federation

The main documents regulating the allowable levels of phycotoxins in products are the Federal Law #52 "Sanitary and epidemiological welfare of the population" and the "Charter of the Russian Federal Sanitary Control Service", which define the rules and standards of phycotoxin presence in different products.

In terms of seafood, and especially bivalves, guidance limits differ depending on the nature of the toxins and type of seafood. A Commission, specified in the Federal Law #52, has developed several documents with the general name "Sanitary Regulations and Norms #2.3.4.050-96 and 2.3.2.2401-08", specifically for fish harvest and farming. These contain regulations about phycotoxins and specify that for DSP toxins, the total concentrations of all derivatives should not exceed 160 µg/kg mussel tissue. For ASP toxins, the concentration should not exceed 20 mg/kg mussel tissue and 30 μg/kg crab meat. For PSP toxins, the concentration should not exceed 80 μg/100g shellfish. These standards are similar to the EU regulatory toxin levels based on European research (European Union Reference Laboratory for Marine Biotoxins (EU-RL-MB)). For different population groups, regulations are different. It is specified that in case of children's health, the regulations should be more stringent. According to the Federal Law #52, fish and seafood prepared for pre-school and school-age children's nutrition must contain no phycotoxins.

Even though monitoring programs are dictated according to Federal Law, the effectiveness of this program is a serious issue. A major problem is the lack of research and field studies needed for the establishment of effective Sanitary Regulations and Norms for Russia. For example, in the current Federal Law #52, the ELISA test-kit "DSP-Check" by Parapharm Laboratories Co., Ltd., Japan, is recommended for okadaic acid determination. However, only the ELISA test-kit "Okadaic Acid ELISA" manufactured by Abraxis, USA, is available but difficult to purchase for a reasonable cost because there is the only one licensed distributor (Kovcheg Technologies) of these kits in Moscow. Even so, none of the recommended ELISA kits are suitable for measuring the DSTs in Primorsky Krai because the major toxin, DTX–1, has only 50% cross-reactivity with the antibody used in the kit. The use of ELISA in DST determination will, therefore, underestimate the toxin concentrations in shellfish, putting people's health at great risk. Results of our research reveal that the Russian Sanitation Program for the sanitary control of shellfish produced and sold for human consumption needs to be altered with appropriate guidance for testing methods for DSTs. The current standard regulatory protocol for DSTs in the EU and USA is liquid chromatography mass spectroscopy, a method that should be implemented in Russia.

Aquaculture – Products, scale and regions

The Far Eastern region is proud to be the main fishery region in Russia. The fish yield is more than 2.5 million tons per year, which is 60% of all Russian fish catches. Around the world, fish farming and fish production aquaculture account for 50% of the total yield. However, in comparison with Asian and European countries, fish farming does not play a crucial role in Russian markets and accounts for only for 5% in total fish production due to the fact that most fish are harvested from the wild. The Far Eastern region of Russia is in a leading position in fish farming due to high resource potential, good climate conditions, and easy access to bays. Development of fish farming facilities is one of the goals of the region (Maslennikov, 2008).

The total ratio of Far Eastern production to the total production in the whole country is salmon (99%), flatfish (more than 90%), herring (more than 40%), crab (100%), bivalves (about 60%), trepang (100%) and algae (about 90%). The development of fish farming started in 1972 in the southern part of Primorsky Krai. In the mid-1970s, the methods of artificial cultivation of clams, mussels, oysters and *Laminaria* were developed, taking into account the cultivation conditions of the Far Eastern region with the help of Japanese and Korean experts. Before 2000, there was a period of long stagnation in fish farm production in the region but after that year, the production rate grew exponentially, increasing more than 10-fold in 5 years (Fig. 3).

Nowadays, Primorsky Krai is an absolute leader in aquaculture farming in Russia. In August 2010 there were 34 facilities, having a total production area of 12 thousand hectares (Fig. 4). Taking into account resource potential, it would be possible to expand aquaculture facilities up to 376 thousands hectares, which is more than 30 times larger than the current facilities (Markovtsev, 2008; Maslennikov, 2008).

The current level of aquaculture does not appear to have any influence on the environment, does not compete with any other sector of agriculture, and is not a subject of limitations for water usage and land parcels. However, as we can see from the experience of countries with developed aquaculture, such problems may become serious issues if development is allowed to occur without planning. In Primorsky Krai, facilities are spread unequally along the coastline. More than 70% of the fish farms are located in the southern part of the region.

The specialization of aquaculture facilities is changing from the south to the north in the region (Fig. 4; Gaivan *et al*., 2012). The southern areas are suitable for clam and mussel cultivation, whereas the more northern parts are specialized in *Laminaria* production. Many farms grow multiple species. The most common combination is mussels, clams and *Laminaria*.

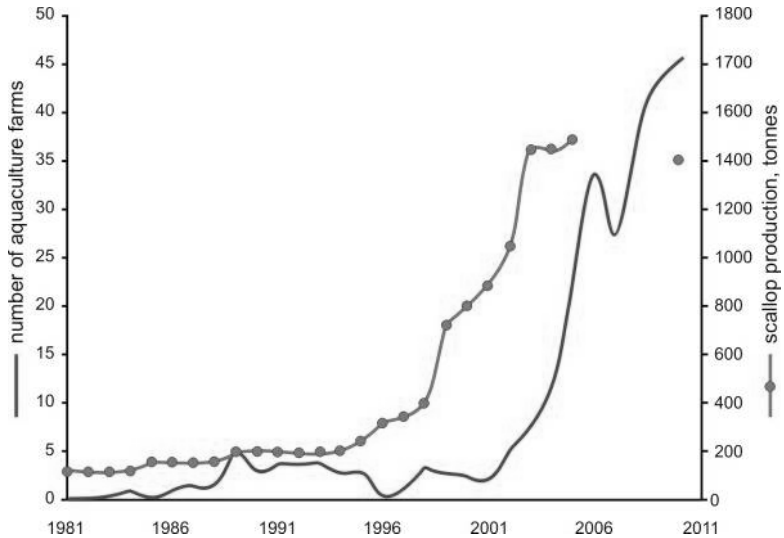

Fig. 3 Dynamics of aquaculture production in Primorsky Krai over the past 30 years.

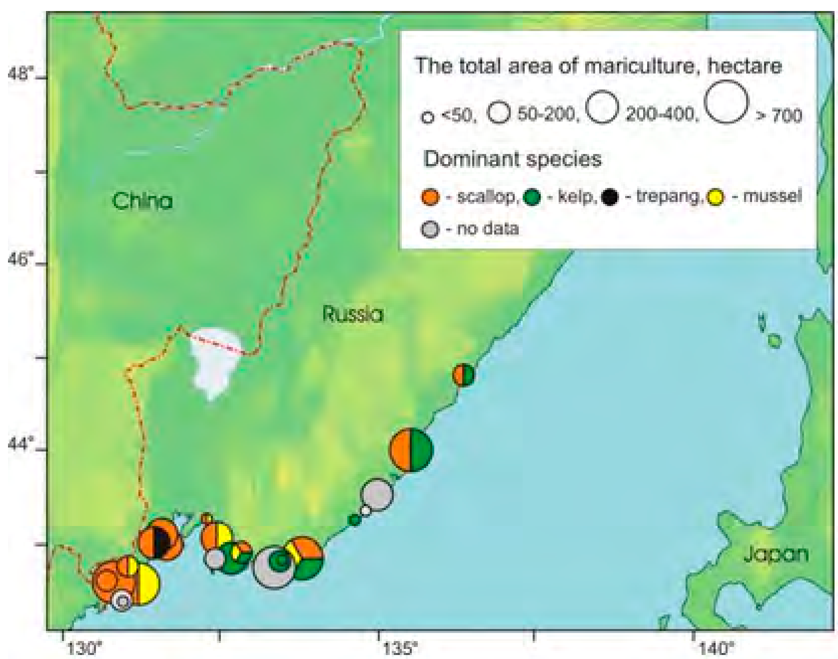

Fig. 4 Location and specialization of aquaculture facilities in Primorsky Krai.

Increasing numbers of aquaculture facilities have led to increased seafood production during the last decade. In 2006, aquaculture facilities produced 500 tons of clams, 820 tons of *Laminaria* and 42 tons of mussels. In 2010, a record 1736.5 tons of clams were grown. *Laminaria* constituted 10–40% of the total production, whereas mussels and oysters constituted about 2%, with sea cucumber less than 1% (Table 2).

Table 2 Amount of aquaculture production in 2010 (Fishery complex of Primorsky Krai, 2012).

Cultivated species	2010
Total production	3509.2
Japanese scallop, *Mizuhopecten yessoensis*	1736.5
Kelp, *Laminaria japonica*	1540.4
Blue mussel, *Mytilus trossulus*	150.6
Sea urchin, *Strongylocentrotus intermedius*	63.6
Sea cucumber, *Apostichopus japonicus*	10.2
Pacific oyster, *Crassostrea gigas*	7.9

A feature of the harvest and processing of mussels is that its harvest time is very short: quality mussels can be collected from April to early May. In April, the mussel spawning season changes the taste of the product. In the remaining period of the year, mussels are not harvested.

An economic estimate of losses due to phycotoxin poisoning resulting in withholding the seafood product from circulation suggests a figure of up to 10 million dollars USD (clams – $8.65 million USD, mussels – $0.1 million USD) per year, given the purchase price of clams at $5.7 USD/kg and mussels at $3 USD/kg.

How important are shellfish as an important source of protein to people in remote areas (not accessible to grocery stores)?

Based on marketing research by the consulting company, "AMICO", seafood is one of the most rapidly expanding markets in Russia. The annual growth of the seafood market is 30–40% (AMICO, 2007).

Surprisingly, currently there is little demand for aquaculture products in the local market of Primorsky Krai. The total consumption of seafood products is about 10% of total fish harvest (Table 3).

Table 3 Fish production (tons) in Primorsky Krai in 2010–2012 (Analytical Reports Primorskstat, 2012).

Type of seafood	2010	2011	2012
Live, fresh or frozen fish	56,494	76,839	83,363.9
Non-frozen invertebrates	4,841	6,494	7,905.4
Other seafood products	531	1,581	1,642.1

A survey of Primorsky Krai citizens (Gaivan *et al*., 2012) showed that seafood is not considered a main dietary product (Fig. 5). About 1/3 of the population does not consume seafood products at all, and about 45% of respondents indicated that they consume seafood products just a few times a year. The reason is the high price of these products.

The majority of people who eat seafood products relatively often prefer the cheapest product – *Laminaria*. The second most popular product is the clam. In the remote areas, where the indigenous ethnic groups live, the main source of protein is fish and the amount of seafood consumed is even lower than the Primorsky Krai average.

It is also interesting to compare the cultural traditions of seafood consumption. In South Asian countries, 60% of the clam is eaten (mantle, gonads, muscle) but in Russia, only muscle (10–14%) is considered edible. Muscle is known to be the organ where the least amount of phycotoxins is found (Gaivan *et al*., 2012). A similar situation is noted for mussel consumption in Russia. In general, traditional seafood consumption patterns in Russia help to minimize the threat of phycotoxin poisoning.

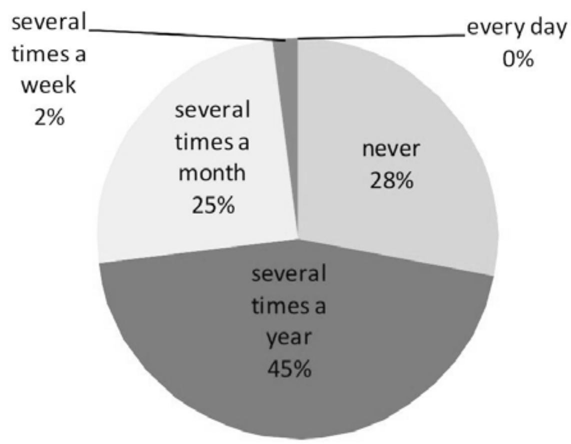

Fig. 5 Results from the survey question, “How often do you eat seafood?”. Primorsky Krai citizens survey ratio (Gaivan *et al*., 2012).

How big are the recreational shellfish areas? Are any shellfish sold for commercial purposes?

Primorsky Krai is one of the favorite tourist destinations in Russia. The majority of tourists come from the nearest regions: Khabarovsky Krai and Jewish Autonomous Region. The tourist season in Primorsky Krai is from the end of June until the beginning of October, when beach-related recreation is common. The main recreational zone is located in the southern part of the region (Fig. 6, recreation area 3). There are more than 34 beach zones with 32 resorts (7 are year-round resorts), 1 health resort, 12 children camps, and 8 campgrounds. All of these facilities together are capable of accommodating 230,000 tourists at the same time.

Based on data from the Department of International Cooperation and Development of Tourism of Primorsky Krai Administration, in 2012 the number of beach tourists in Primorye was 600 thousand people (http://primorsky.ru/authorities/executive-agencies/departments/tourism/). The Nakhodka coastal area is the most popular place for summer tourism (200 thousand tourists per summer). Another popular destination is the Khasan recreational area (Fig. 6, recreation area 1), where every year 60 thousand tourists spend their summer vacations.

Almost all tourists consume food in local cafes and restaurants near their resorts or cook seafood collected from the beaches. Seafood served in the restaurants is often harvested from the nearest bay and is not subjected to obligatory certification. Cases of poisoning are common; however, determining the reasons for intoxication and etiology are not common due to the lack of toxin testing. Thus there is a risk of poisoning beach tourists (more than half a million people) during the summer.

Another way people become intoxicated is by consuming mollusks that are driven ashore during storms and typhoons. Those convulsions of nature do not occur often, but during these events the number of mollusks that come ashore is comparable with the annual yield of a small aquaculture farm. One example of such a cataclysm happened in August 2012 after typhoon “Bolaven”, when several tons of aquatic organisms were washed up, the majority of which were bivalves. People actively collected these mussels for consumption (Fig. 7).

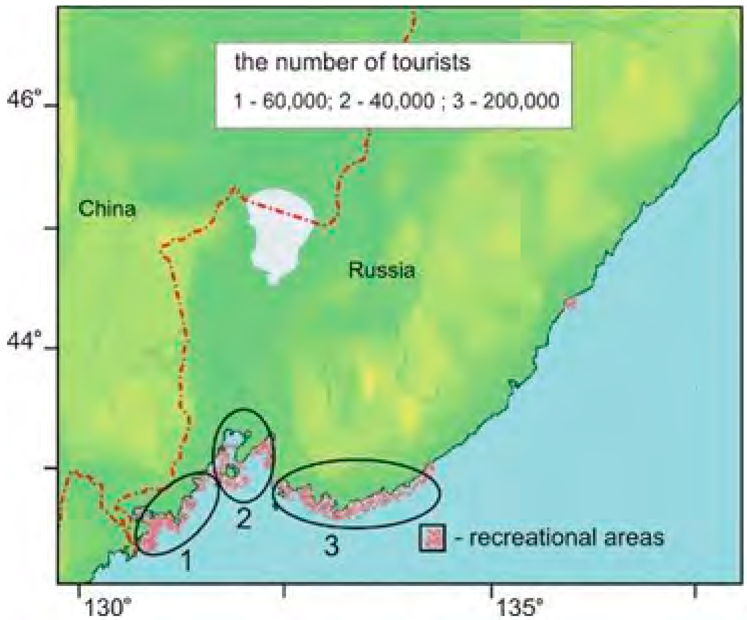

Fig. 6 Map of recreational zones in Primorsky Krai with number of tourists in 2012.

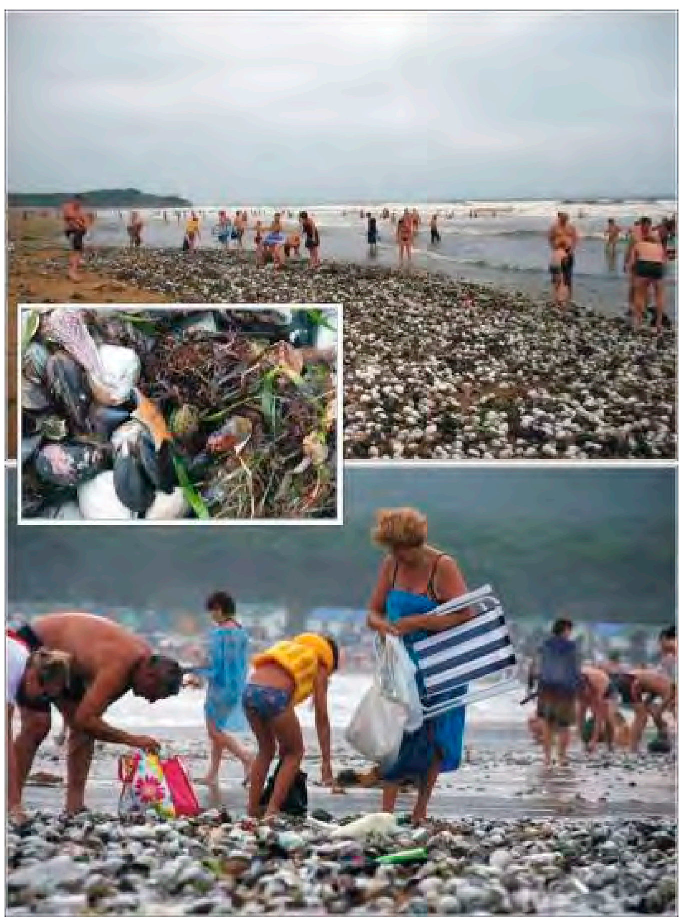

Fig. 7 Lazurnaya Bay (biggest beach near Vladivostok) after typhoon "Bolaven" (http://ptr-vlad.ru/2012/08/31/posle-tayfuna-bolevan-na-plyazh-shamory-vybrosilo.html).

Potential damage to the fish breeding field in Primorsky Krai caused by HABs

Phytoflagellates are among the most ichthyotoxic species known, responsible for potentially high economic losses due to fish kills in Primorsky Krai coastal waters. Cases of massive mortalities of released hatchings in the coastal waters have been registered in some fish farms in Primorsky Krai. In 1993, massive mortalities of juvenile fish were reported at the Ryazanovsky fish farm. Research results showed that water samples collected during this period contained unidentified small flagellates (1.1 million cells/L) and the raphidophytes (0.9 million cells/L) *Chattonella* sp. and *Heterosigma akashiwo.* It is known that fish farms that cultivate different fish species by cage culture methods suffer the most harm from ichthyotoxic algae blooms. However, because currently there are no fish farms in Primorsky Krai which use this technology for fish breeding, there are no projected losses to date from raphidophyte HABs.

However, there is a real threat for the fish-farming companies specializing in salmon hatchling cultivation for the purposes of maintaining biological diversity and increasing salmon yields in coastal waters. Annual release of Pacific salmon smolts usually begins in mid-April. The number of smolts released can reach up to 30 million individual fishes (Fig. 8). Therefore, there is potential harm from ichthyotoxic blooms to young fish. For example, the most vulnerable fish farm is "Lidovsky" in the north of Primorsky Krai (Fig. 8), where the cycle of fish breeding includes incubation and feeding of hatchlings in tanks followed by further growth in natural maturation ponds. If it is assumed that the prime cost for 1 salmon hatchling is $1 USD, then the total economic loss of 100% hatchlings will be $30 million USD.

Fig. 8 Annual release of young salmon by fish farms in Primorsky Krai.

Potential damage to the natural ecosystems of Primorsky Krai caused by HABs

Cases of massive mortality of aquatic animals, including fish, crabs, prawns, starfish, seals (*Phoca largha*), and whales (*Balaenoptera acutorostrata*) are registered annually. The environmental prosecutor's office conducts an investigation of each case, which includes screening for pesticides, oil products or heavy metals. However, in the majority of cases, the reason for death remains unknown. We assume that HABs are a potential contributor to some mortality events, but there has been no research to prove this. The following are events that obtained intense media coverage.

- *September 15, 2008*
  The massive mortality of candlefish (*Osmerus mordax*) on the western part of a Russian island was reported. There were no signs of oil pollution. The assumed reason for the fish kill was chemical or biological pollution (http://news.vl.ru/vlad/2008/09/15/gibel/).

- *May 26, 2011*
  Near the coast of Vladivostok, a massive kill of flathead mullet (*Mugil cephalus*) was reported. The total number was hard to calculate. Fish sample analysis showed no evidence of pesticides, oil products or heavy metals. Histological and chemical analysis of dead fish did not reveal the reasons of death. However, it was noted that water samples contained a lot of organic matter and the concentration of phytoplankton was elevated (http://www.km.ru/v-rossii/2011/06/14/ekologiya-i-okhrana-prirodnykh-bogatstv-rossii/nedostatok-kisloroda-stal-prichin).

- *September 10, 2011*
  Hundreds of anchovies (*Engraulis japonicus*), as well as starfish and small crabs, were driven ashore near the Kungasny Peninsula in Vladivostok. The reason for that case was not identified but it was not a consequence of an oil spill in the Amursky Bay (Fig. 9).

- *June 2, 2013*
  In the northern part of Amursky Bay, the body of an adult seal (*Phoca largha*) was discovered (Fig. 10) together with 2000 individual dead flathead mullet (*Mugil cephalus*). The reason for the deaths remains unknown.

Fig. 9 Masses of dead fish on Kungasnii Peninsula (http://newsland.com/news/detail/id/779801/).

Fig. 10 Body of an adult seal *Phoca largha* in Amursky Bay (http://www.newsvl.ru/photos/2013/06/05/112859/).

Conclusions

Even though the impact of harmful algal blooms appears small due to a lack of developed technologies for fish farming and the small role of seafood in people's diets, the cases of fish and sea mammal mortality and acute intoxication of people after the consumption of mollusks show evidence of a real threat to both the economy and human health.

The absence of a federal monitoring program for HABs and phycotoxins is a huge disadvantage, which leads to an underestimation of the actual scale of the negative impact of HABs in ecosystem health, economic losses to aquaculture, and harm to human health. The absence of obligatory screening for phycotoxins prevents the effective analysis of possible reasons for massive fish mortalities in the region. Currently, the Russian Federal Sanitary Control Service has no guidance for PTXs, AZAs and YTXs. In addition, there is no recommendation for microalgae monitoring in regions with the most fish farms. These are just some of the drawbacks to the current legislation directing HAB monitoring efforts in Russia.

The only permanent monitoring program in the Far East of Russia is organized by the Center for Monitoring of Harmful Algal Blooms and Biotoxicity in Coastal Waters, IMB FEB RAS. The initial purposes for the creation of the Center were to:

- Provide permanent monitoring of potentially harmful microalgae, which cause HABs and can produce toxic substances harmful to marine animals and humans;
- Investigate toxin biodeposits (seawater, benthos);
- Monitor resting cysts as potential initiators of HABs;
- Develop analytical methods to help predict HABs;
- Participate in developing analytical methods for toxin identification and application of these methods for providing a healthy environment;
- Educate school and university students, as well as authorities, about the problem of HABs and phycotoxins.

Important results from Center work include the description of several harmful species, investigation of the periods of their massive development, and the study of mechanisms of toxin transport to marine animals.

These results have importance for local residents and for the global science community. The significance of these results for scientists all over the world is an enhanced understanding of microalgae migration patterns, with analysis of how various environmental conditions can influence the toxicity of microalgae. These Russian Far Eastern data may be used for global predictions and estimations. On the local level, this information is used to raise people's awareness about the severity of HAB problem and to prevent possible intoxications. Each summer, information is provided by Center workers to the mass media about the possibility of poisoning by eating uncertified seafood, which helps people understand the risk of shellfish harvest.

The Center also plays a huge educational role in preventing the illness of people caused by phycotoxins. Center staff give lectures at science festivals, organize seminars for school students of different ages, provide consultations for sanitary officers and representatives of people's health protection organizations, and participate in local conferences where scientists, administrators and business representatives meet to discuss environmental problems. Multiple analytical reports on HABs have been prepared by the Center showing the absolute need for developing an effective phycotoxin food safety monitoring program which should help not only protect people from possible intoxication, but also will improve the competitiveness of Russian seafood products on the international market. This, in turn, would be very beneficial for the development of fish farms and the regional economy.

The Center for Monitoring of Harmful Algal Blooms and Biotoxicity in Coastal Waters, IMB FEB RAS is taking all possible actions to improve the current protocols for toxin testing. Collaboration with sanitary control authorities resulted in signing an agreement to establish a mutually beneficial research program, which aimed to change the recommended screening method for DSP from ELISA to LS/MS and to make the connection between microalgae monitoring and the prevention of phycotoxin poisoning. This is a complex process that is best achieved through cooperation between science, medical organizations and government. We hope that our research program will be a critical first step in understanding the distribution of toxins and the causative species, providing a framework for the better understanding and detection of potential threats from phycotoxins.

References

AMICO. 2007. Seafood marketing research. 64 pp. (in Russian).

Analytical Reports Primorskstat, Fishery Primorsky Krai. 2012. 318 pp. Available online at http://hubofdata.ru/dataset/esimo_ru_poi_159.

Andersen, P. 1996. Design and Implementation of Some Harmful Algal Monitoring Systems. IOC Tech. Ser. No. 44, UNESCO, Paris, 102 pp.

Edvardsen, B. and Paasche, E. 1998. Bloom dynamics and physiology of *Prymnesium* and *Chrysochromulina*, pp. 193–208 *in* The Physiological Ecology of Harmful Algal Blooms *edited by* D.M. Anderson, A.D. Cembella and G.M. Hallegraeff, NATO ASI Series Vol. G 41, Springer Verlag, Berlin.

European Union Reference Laboratory for Marine Biotoxins (EU-RL-MB). Agencia Espoñola de Seguridad Alimentaria y Nutrición (AESAN), Vigo, Spain. EU-Harmonized Standard Operation Procedure for Determination of Lipophilic Marine Biotoxins in Molluscs by LC MS/MS, Version 4. 2011. Available online at http://www.aesan.msps.es/CRLMB/docs/docs/metodos_analiticos_de_desarrollo/EU-Harmonised-SOP-LIPO-LCMSMS_Version4.pdf (accessed on 10 May 2013).

Fishery complex of Primorsky Krai, 2011/Primorskstat. 2012. 318 pp. (in Russian).

Gail, G.I. 1959. Phytoplankton of the Sea of Japan. *Izvestiya TINRO* **33**: 3–177 (in Russian).

Gaivan, E.A., Zemtsov, S.P. and Mazurova, A.A. 2012. Mariculture of Primorye. Potential Development of the Industry within the Aqua Territorial Regional Systems. Lap Lambert Academic Publishing GmbH & Co., Germany, 146 pp.

GOST R ISO 22000. 2007. System of food safety management. Requirements for any organization involved in the development of food products. 36 pp. (in Russian).

Imai, I. and Yamaguchi, M. 2012. Life cycle, physiology, ecology and red tide occurrences of the fish-killing raphidophyte *Chattonella*. *Harmful Algae* **14**: 46–70.

Kisselew, I.A. 1950. Pantsirnye zhgutikonostsy (Dinoflagellates). Izdatelstvo AN SSSR, Moscow, Leningrad, 279 pp.

Konovalova, G.V. 1993. Toxic and potentially toxic dinoflagellates from the Far East coastal waters of Russia, pp. 275–279 *in* Toxic Phytoplankton Blooms in the Sea *edited by* T.J. Smayda and Y. Shimizu. Elsevier, Amsterdam.

Konovalova, G.V. and Selina, M.S. 2010. Dinophyta *in* Biota of the Russian Waters of the Sea of Japan *edited by* A.V. Adrianov, Dalnauka 8, Vladivostok, 351 pp. (in Russian).

Konovalova, G.V., Orlova, T.Yu. and Pautova, L.A. 1989. Guide on Phytoplankton of the Sea of Japan. Dalnauka, Vladivostok, 173 pp. (in Russian).

Markovtsev, V.G. 2008. Mariculture and ecological aspects its development in Primorye. Dalnevostochnii Region. *Ribnoe Hozyaistvo* **3**: 4–9 (in Russian).

Maslennikov, S.I. 2008. Coastal marine bioresources of Far East of Russia and its rational use in terms of ecology and economy, pp. 89–125 *in* Energy and Environment in Slavic Eurasia: Toward the Establishment of the Network of Environmental Studies in the Pan-Okhotsk Region *edited by* T. Shinichiro, Hokkaido University, Sapporo.

Mogilnikova, T.A., Motilkova, I.V. and Konovalova, N.V. 2007.Toxic phytoplankton and phykotoxins in scallop tissue *Mizuhopecten yessoensis* (Jay) in coastal waters of Sakhalin Island (Aniva Bay). *Trudi SakhNIRO* **9**: 207–222 (in Russian).

Morozova, T.V., Orlova, T.Yu. and Selina, M.S. 2002. Phytoplankton in the scallop culture area in Minonosok Bight (Pos'eta Bay, Sea of Japan). *Russian J. Mar. Biol*. **28**: 94–99.

Orlova, T.Yu. 2014. Diversity of potentially toxic microalgae on the east coast of Russia, pp. 77–91 *in* Marine Biodiversity and Ecosystem Dynamics of the North-Western Pacific Ocean *edited by* S. Song, A.V. Adrianov, K.A. Lutaenko and S. Xiaoxia, Science Press, Beijing.

Orlova, T.Yu., Zhukova, N.V. and Stonik, I.V. 1996. Bloom-forming diatom *Pseudo-nitzschia pungens* in the Amurskiy Bay (the Sea of Japan): morphology, ecology and biochemistry, pp. 147–150 *in* Harmful and Toxic Algal Blooms *edited by* T. Yasumoto, Y. Oshima and Y. Fukuyo, Intergovernmental Oceanography Commission of UNESCO, Paris.

Orlova, T.Yu., Konovalova, G.V., Selina, M.S., Stonik, I.V., Morozova, T.V. and Shevchenko, O.G. 2002. Harmful algae blooms on the eastern coast of Russia, pp. 47–73 *in* Harmful Algal Blooms in the PICES Region of the North Pacific *edited by* F.J. Taylor and V.L. Trainer, PICES Scientific Report No. 23, North Pacific Marine Science Organization.

Orlova, T.Yu., Selina, M.S., Lilly, E.L., Kulis, D.M. and Anderson, D.M. 2007. Morphogenetic and toxin composition variability of *Alexandrium tamarense* (Dinophyceae) from the east coast of Russia. *Phycologia* **46**: 534–548.

Orlova, T.Yu., Stonik, I.V., Aizdaicher, N.A., Bates, S.S., Leger, C. and Fehling, J. 2008. Toxicity, morphology and distribution of *Pseudo-nitzschia calliantha*, *P. multistriata* and *P. multiseries* (Bacillariophyta) from the northwestern Sea of Japan. *Botanica Marina* **51**: 297–306.

Orlova, T.Yu., Stonik, I.V. and Shevchenko, O.G. 2009. Species composition of planktonic microalgae in Amursky Bay, Sea of Japan. *Russian J. Mar. Biol*. **35**: 48–61.

Orlova, T.Yu., Stonik, I.V., Popkova, P.A., Morozova, T.V., Trainer, V.L., Moore, L. and Eberhart, B.-T.L. 2013. Diarhetic shellfish toxins in Primorye, Russian Federation. p. 217. Program and Abstracts PICES-2013, Communicating forecasts, uncertainty and consequences of ecosystem change, October 11–20, 2013, Nanaimo, BC, Canada.

Orlova, T.Yu., Stonik, I.V., Efimova, K.V., Yakovleva, I.M., Ponomareva, A.A., Kharlamenko, V.I. and Begun, A.A. Brown tide caused by *Pseudohaptolina birgerii* (G. Hällfors & Hiemi) Stonik, Efimova & Orlova *comb. nov.* (Haptophyta) under ice in Amursky Bay in the Sea of Japan. *Harmful Algae* (in press).

Ostroumoff, A. 1924. *Noctiluca miliaris* in Symbiose mit grunen. *Algen. Zool. Anz*. **68**: 162.

Selina, M.S. 1993. Raphydophyta from Peter the Great Bay. *Algologia* **3**: 60–65.

Shevchenko, O.G., Orlova, T.Yu. and Hernandez-Becerril, D.U. 2006. The genus *Chaetoceros* (Bacillariophyta) from Peter the Great Bay, Sea of Japan. *Botanica Mar.* **49**: 236–258.

Simakova, N.K., Orlova, T.Yu. and Selina, M.S. 1990. "Red tide", caused by raphydophytes *Chattonella* sp. in Amursky Bay, Sea of Japan. *Russian J. Mar. Biol*. **5**: 77–78.

Stonik, I.V. 1994. Potentially toxic dinoflagellate *Prorocentrum minimum* in Amursky Bay, the Sea of Japan. *Russian J. Mar. Biol*. **20**: 416–420.

Stonik, I.V. and Orlova, T.Yu. 2013. The species composition and quantitative distribution of the diatom genus *Pseudo-nitzschia* H. Peragallo, 1990 in Russian waters of the Sea of Japan and the Sea of Okhotsk. *Russian J. Mar. Biol*. **39**: 238–245.

Stonik, I.V., Orlova, T.Yu. and Lundholm, N. 2011a. Diversity of *Pseudo-nitzschia* H. Peragallo from the western North Pacific. *Diatom Res*. **26**: 121–134.

Stonik, I.V., Orlova, T.Yu., Chikalovetz, I.V. and Chernikov, O.V. 2011b. Diatoms from the northwestern part the Sea of Japan as producers of domoic acid, p. 41. Abstracts of 9th IST Asia Pacific Meeting on Animal, Plant and Microbial Toxins, International Society on Toxinology, IST, September 4–8, 2011, Vladivostok, Russia.

Stonik, I.V. and Orlova, T.Yu. 2012. Population dynamics and toxicity of the diatom species of the genus *Pseudo-nitzschia* in Peter the Great Bay, the northwestern part of the Sea of Japan, p. 311. Program and Abstracts PICES-2012, Effects of natural and anthropogenic stressors in the North Pacific ecosystems, October 12–21, 2012, Hiroshima, Japan.

Tangen, K. 1983. Shellfish poisoning and the occurrence of potentially toxic dinoflagellates in Norwegian waters. *Sarsia* **68**: 1–7.

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, pp. 705–771 *in* Toxic Phytoplankton Blooms in the Sea *edited by* T.J. Smayda and Y. Shimizu, Elsevier Science, New York.

Taylor, F.J.R., Fukuyo, Y., Larsen, J. and Hallegraeff, G.M. 2003.Taxonomy of harmful dinoflagellates, pp. 389–482 *in* Manual on Harmful Marine Microalgae *edited by* G.M. Hallegraeff, D.M. Anderson and A.D. Cembella, UNESCO Publishing, Paris.

Thomsen, H.A., Buck, K.R. and Chavez, F.P. 1994. Haptophytes as components of marine phytoplankton, pp. 187–208 *in* The Haptophyte Algae *edited by* J.C. Green and B.S.C. Leadbeater, Clarendon Press, Oxford.

Economics of razor clam fishery closures due to harmful algal blooms in Washington State

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Abstract

Several times in the last two decades Washington State recreational and commercial razor clam fisheries have been interrupted by closures due to the spread of harmful algal blooms (HABs) that threaten the health of humans. The closures due to HABs, and measures to avoid human contact with HABs, can have economic consequences in at least four categories: (1) the economic costs of illness and death caused by HABs, (2) the economic impacts to coastal incomes and employment due to fishery closures, (3) the net economic loss suffered by clammers due to fishery closures, and (4) costs of monitoring and enforcing closures due to HABs. There have been a few studies focused on the economic cost of sickness due to HABs (category 1) dealing with costs associated with sickness and death in the United States from ciguatera fish poisoning. In this paper we focus on the categories 2 and 3, using a survey completed in April of 2008 on four recreational clamming beaches on the Pacific coast of Washington State, and related information concerning a small commercial fishery for razor clams. Our estimates of coastal income impacts focus on a range of possibilities, from single beach closures of one recreational dig over a 3- to 4-day "clam opener" to full four-beach closures for the entire year. Economic impacts on the recreational razor clam fishery range from a loss of 3 to 339 full-time job equivalents and from $110 thousand to $10.57 million[1] in coastal income loss, depending upon the extent of the closures. Similar estimates for the Quinault Indian Nation commercial fishery range from close to $117 thousand for a half-year single beach closure to $1.42 million for a full-year all beach closure. Closure of the smaller commercial fishery on the Willapa Spit could cause a coastal income loss of up to $514 thousand for a year-long closure. These are estimated changes in coastal community incomes associated with reduced clamming opportunities. Here, we estimate the amount that recreational clammers would be willing to pay to reduce beach closures to one or less per year. Based upon responses to a survey conducted in April 2008, this value is estimated at $662 thousand. This estimate of the net economic benefit of the available razor clam recreational fishery greatly exceeds the $150 thousand currently allocated for the phytoplankton monitoring system that provides early warning of HAB events, under the Olympic Region Harmful Algal Bloom (ORHAB) partnership. Using weekly microscope analysis of phytoplankton in water samples collected from razor clamming beaches, the ORHAB program has prevented coastwide closures of the razor clam fishery since 2005.

Introduction

The Washington State razor clam supports a large recreational fishery, averaging about 250,000 digger trips per year to the southwest Washington counties where tourist and fisher spending (*e.g.*, motels, food, gasoline,

[1] All monetary values in U.S. dollars (USD).

souvenirs) has a significant economic impact on the coastal communities. There is also a modest-sized commercial razor clam fishery off the Washington coast. The Pacific razor clam (*Siliqua patula*) is an exceptionally meaty shellfish ranging from California to Alaska. However, the largest population of harvestable razor clams is found in Washington State. In Washington waters, razor clams are found primarily on the intertidal coastal beaches that are exposed from a +3 foot level to a –2 foot tide level. The Washington Department of Fish and Wildlife (WDFW) divides the coastal harvest areas into five major management zones (Fig. 1):

(1) Long Beach: from the Columbia River north to the mouth of the Willapa Bay,
(2) Twin Harbors: from Willapa Bay north to the south jetty at the mouth of Grays Harbor,
(3) Copalis Beach: from the north jetty at the mouth of Grays Harbor to the Copalis River,
(4) Mocrocks Beach: from the Copalis River to the south boundary of the Quinault Indian Reservation,
(5) Kalaloch Beach: from the South Beach campground north to the Olympic National Park Beach Trail 3.

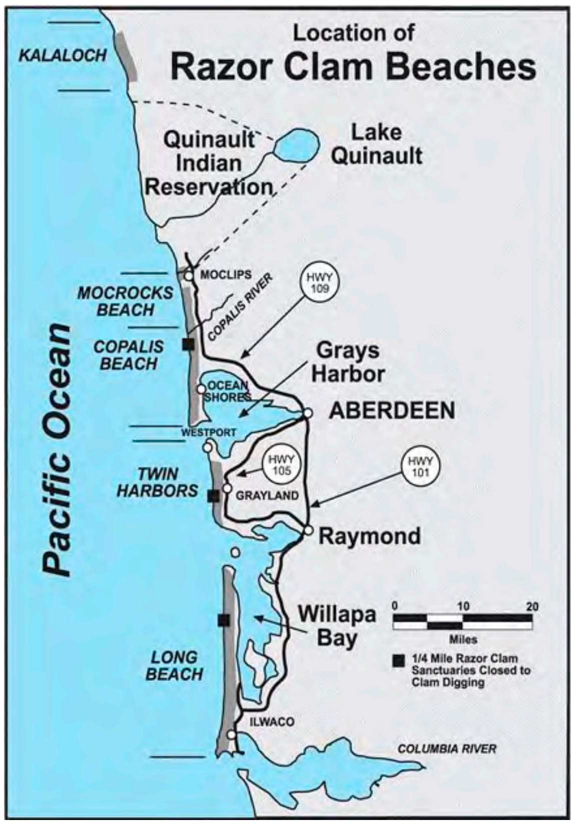

Fig. 1 Map of Washington State razor clam beaches.

During certain times of the year, marine toxins, produced by some species of harmful algae are filter fed by razor clams and concentrated in their tissues. When ingested, these toxins can cause illness and, at very high concentrations, can be fatal to humans. The WDFW, in cooperation with the Washington Department of Health (DOH), samples clams on a routine basis for HAB management purposes. If high toxin levels from HABs are detected, razor clam seasons are delayed or closed.

The Olympic Regional Harmful Algal Bloom (ORHAB) program, a multiagency partnership, was established in the year 2000 to provide early warning of HAB events on the Washington Pacific coast based on optimized phytoplankton and rapid toxin-testing. In 2005, ORHAB transitioned from five years of funding from NOAA's National Center for Coastal Ocean Science to funding from Washington State, through legislation

(RCW 77.32.555) that established $150,000 annual funding for the program through a surcharge to shellfish and seaweed licenses. Specifically, the surcharges to license fees were as follows: three dollars per resident and nonresident for annual shellfish and seaweed licenses, $2 for annual resident and nonresident (Chadsey *et al*., 2011) razor clam licenses, and $1 for a three-day razor clam license. These funds were applied toward salaries of HAB specialists at the WDFW who monitor the Washington State southern beaches (Twin Harbors and Long Beach) and the University of Washington's Olympic Natural Resource Center which monitors the central beaches (Kalaloch Beach and Ocean Shores) and oversees the program. The Quinault Indian Nation, the Quileute Tribe, and the Makah Tribe have also participated in the program, although their contributions have not been supported through the tax on state license fees.

The amount of support that should be devoted to monitoring and determination of HAB risk is constantly debated by funding agencies. One issue is whether the economic benefit of improved HAB monitoring and protection of seafood safety exceeds its costs. There are at least four categories of economic impacts of HAB outbreaks that must be considered in order to fully assess their impacts and the value of monitoring:

(1) the economic costs of illness and death caused by HABs,
(2) the economic impacts to coastal incomes and employment due to fishery closures,
(3) the net economic loss suffered by clammers due to fishery closures, and
(4) costs of monitoring and enforcing closures due to HABs.

Each research area applies specific methodologies and concepts, and careful utilization of these economic studies requires a basic understanding of the economic concepts. This section briefly reviews the concepts and findings of some published studies.

There have been a few studies focused on category 1, the economic costs of sickness due to HABs. For example, Hoagland and collaborators (Hoagland *et al*., 2002) discussed the costs of ciguatera fish poisoning in the U.S. In another example, the costs of illness for hospital emergency department treatment for illness associated with *Karenia brevis* blooms in Sarasota County, Florida, were estimated at $0.5 to 4.0 million (Hoagland *et al*., 2009). In an expanded analysis (Hoagland, *et al*., 2014), the annual costs were estimated at $60 thousand to $700 thousand annually. No such studies have been pursued concerning the cost of HAB-related illnesses in Washington State.

The local income and employment economic impacts (category 2, economic impacts) are usually driven by reduced commercial fishery harvest, reduced aquaculture harvest, and/or reduced participation in, and expenditures on, marine recreation. As explained by Radtke *et al*. (1987), a simple estimate of economic impact can be calculated using a regional economic model (typically an Input-Output model) to calculate the "direct impact" of reduced fishing or recreational activity, the "indirect impacts" caused by reduced purchases of supplies and inputs by the directly impacted sectors, and the "induced impact" resulting from decreased purchases of consumer goods and services due to the combined direct and indirect reductions in regional incomes. The Input-Output (I-O) model is a simple linear model of regional economy that documents the aggregate outputs of each economic sector, the inter-sectoral transactions, and the resulting regional incomes (Miernyk, 1965). A regional I-O model (developed by Beyers, *et al*., 2008) was used to estimate changes in regional income, regional employment, and overall gross expenditures in the Washington coastal counties where clams are harvested.

However, while these local economic impacts can be relevant to policy makers, the income and employment impacts are not strictly measures of economic benefits or costs. This is because reduced clamming in the coastal counties will typically result in the money not spent at the coast being spent elsewhere, leaving the broader State or Northwest regional expenditures and incomes about the same. So, the beach-oriented local economic impact is informative about economic effects on beach-clamming counties, but is not an accurate measure of the net economic loss associated with beach closures. A measure of net economic loss due to lost clamming could be represented by the amount that clammers would be willing to pay to avoid closures.

Category 3, net economic loss to clammers due to closures, reflects the value that clammers place on the activity, over and above the costs of clamming. This is the net benefit concept typically addressed in a cost-benefit analysis. Both recreational clammers and commercial operations can be expected to experience some net economic benefits of clamming, or some benefits of reduced closures due to more precise monitoring of HAB occurrences. An estimate of this value for recreational clamming was based upon data collected in a survey of Washington coastal clammers executed in 2008. The final economic impact, category 4, costs of monitoring and enforcing closures of the clam fishery, assesses the benefit and cost of monitoring HABs compared to the estimated value of reduced closures. This issue is explored by Jin and Hoagland (2008), but has rarely been addressed. Economic impact categories 2, 3, and 4 will be discussed in detail below for the Washington State razor clam fishery.

Regional impacts of HABs due to reduced recreational fishing

A recent study by Dyson and Huppert (2010) estimated the regional impacts of a various types of closures at the four Washington coast razor clam beaches due to *Pseudo-nitzschia* blooms. For example, it was estimated that a full season closure of all the beaches would cause an $11.36 million per year reduction in coastal county incomes due to reduced recreational activity, and a nearly $2 million per year reduction in incomes due to lack of tribal and non-tribal commercial harvest of razor clams. Much lower impacts are estimated for single beach or shorter lasting closures. For example, an annual closure of the popular Long Beach peninsula razor clam fishery would have a regional income impact of negative $4.4 million. If the closure included only one clam fishery opening (typically 2–5 days), the negative income impact would be $1.4 million (Dyson and Huppert, 2010, p. 30). These are hypothetical impacts that could be used in assessing the effects of avoiding beach closures through better monitoring of HABs.

To calculate the economic impacts of closures in the Washington coastal razor clam fisheries, the reduced harvest is translated into a reduction in value of clams harvested based upon recent average annual values, and then these are converted to estimated coastal income impacts based upon regional input-output (I-O) models. For the recreational fisheries, a regional I-O model for the Grays Harbor and Pacific county region is based upon the I-O coefficients from the existing Washington State input-output model.

We collected data documenting the level of expenditure by recreational razor clammers using a mail-back survey questionnaire distributed by the WDFW during a recreational clam fishery opening on April 19–20, 2008. For the smaller commercial razor clam fisheries on the southern Washington coast, we utilized the existing Fishery Economic Assessment Model commonly used by the Pacific Fishery Management Council to gauge impacts of fishery closures in the Willapa Spit and Quinault tribal commercial fisheries.

To implement either of the I-O models for recreational or commercial fisheries, we had to determine how the fishers are likely to react to beach closures. For recreational fisheries, we made assumptions about how clammers change their patterns of beach visits and expenditures in response to closure of ocean beaches. The simplest approach assumes that any planned beach visits during a closure would be cancelled and the economic impact would be proportional to the reduced recreational expenditures in the beach area. The more complicated approach utilizes information gained in the razor clam survey to estimate the proportion of clammers that would visit the beach even if the fishery is closed, and to estimate the proportion to clammers that would shift from a particular beach to a different beach when a specific beach, or group of beaches, is closed. These latter estimates of impact incorporate more subtle behavior which is typical of recreationists' choice sites to visit. In both the simpler and more complicated approaches to estimating impacts of recreational closures, the expenditures per clammer per day were taken from the April 2008 razor clam survey. The size and nature of the survey are illustrated in Table 1.

The overall coastal income impact of razor clam trip expenditures in Pacific and Grays Harbor counties in 2008 is estimated to be $13.5 million. As shown in Table 2, the estimated economic impacts on labor income in the two-county region for closures of a single scheduled opening of a single recreational beach ranges from $110 thousand (at Mocrocks Beach) to $1.2 million (at Long Beach) as indicated. For a full year closure of the individual beaches, the estimated income impacts range from $350 thousand to $4.40 million. A full-year all-beach closure has an estimated labor income impact of $10.57 million. This latter estimate is less than the overall estimated impact of expenditures by razor clammers ($13.5 million) because some clammers indicate they would continue to visit the beaches for recreation even when the clam fishery is closed.

Table 1 Participation data, selected survey data, and average expenditures per party for four razor clamming beaches (Mocrocks Beach, Copalis Beach, Twin Harbors, and Long Beach) on Washington's outer coast. Expenditures are in 2008 dollars.

	Mocrocks	**Copalis**	**Twin Harbors**	**Long Beach**
	Fishery participation in 2008			
Annual participants	22,247	42,376	65,253	112,442
Days open	11	13	39	22
Average no. of clammers/day	2022	3260	1673	5111
	Survey overview and averages			
No. of respondents	66	53	51	70
No. of people/party	4.09 (0.27)	4.42 (0.47)	3.46 (0.30)	3.81 (0.30)
No. of clammers/party	3.71 (0.23)	3.98 (0.39)	3.10 (0.21)	3.29 (0.23)
% staying overnight	36%	65%	64%	67%
No. of nights spent	1.06 (0.14)	1.44 (0.15)	3.06 (0.84)	2.62 (0.39)
No. of days clammer/trip	1.21	1.35	1.99	1.41
Miles traveled, one way	116 (13)	127 (11)	111 (14)	106 (18)
% who cancelled a trip in past due to HABS	45%	35%	34%	40%
	Average $ spent per party per trip			
Hotel	85.67	115.77	73.10	84.27
Camping	9.36	6.19	18.18	14.48
Restaurant	57.42	78.44	75.04	87.45
Groceries	29.71	38.37	65.50	62.50
Gas and oil	69.49	107.15	111.43	116.14
Ferry tolls	1.18	0.23	0.66	0.00
Other transport	1.16	0.96	0.80	10.61
All other	14.79	28.75	25.21	37.21
Total expenditure	$268.77	$375.87	$368.91	$412.67

Table 2 Local (two-county) economic impacts due to HABs-related beach closures for (a) one opening (typically 2–5 days) and (b) a full year. Expenditures, sales impact, and income are in millions of 2008 dollars, and employment is number of full-time equivalent jobs affected.

(a) One-Opening Closure

Beach	Sales foregone ($)	Total sales impact ($)	Employment impact	Labor income impact ($)
Mocrocks Beach	0.19	0.29	3	0.11
Copalis Beach	0.36	0.54	6	0.20
Northern beaches*	1.10	1.64	20	0.60
Twin Harbors	0.88	1.19	14	0.43
Long Beach	2.31	3.29	38	1.20
Southern beaches	2.69	3.77	44	1.37
All four beaches#	4.02	5.75	67	2.10

(b) Full Year Closure

Beach	Sales foregone ($)	Total sales impact ($)	Employment impact	Labor income impact ($)
Mocrocks	0.63	0.94	11	0.35
Copalis	1.37	2.05	24	0.75
Northern beaches	3.98	5.26	65	1.93
Twin Harbors	2.20	2.97	35	1.08
Long Beach	8.52	12.07	140	4.40
Southern beaches	15.95	21.85	253	7.97
All four beaches	20.42	28.97	339	10.57

* Northern beaches = Mocrocks + Copalis; Southern beaches = Twin Harbors + Long Beach.
# The impacts on separate beaches will not add up to the impact on combined beaches for north or south beach summaries. Similarly, the total for north plus south beaches will not equal the total for the coastal region because when one beach closes, the number of fishing days occurring at the other beaches is affected. Clammers shift from beach to beach in response to closures, *e.g.*, if Mocrocks is closed, some of the clammers will shift to Copalis or one of the southern beaches.

Regional impacts of commercial fisheries

The economic impacts of commercial fisheries on the Pacific coast have long been evaluated using the Fisheries Economics Assessment Model (FEAM) developed by The Research Group of Corvallis, Oregon, for the Pacific Fishery Management Council (PFMC). This is a well-developed I-O model adapted to the coastal fisheries using extensive interviews and surveys of coastal fishing businesses in California, Oregon and Washington. The fisheries-specific information provided the basis for adding rows (industries) to the 1998 IMPLAN model, a commonly-used national and state-level I-O model (see Minnesota IMPLAN Group at http://www.implan.com/).

To assess the income impacts of the commercial razor clam fisheries, we focused on the FEAM model developed for PFMC's 2003 Final Environmental Impact State for proposed groundfish plan amendments (PFMC, 2003). The detailed model developed for the southwest coast of Washington was obtained from PFMC to assess the impact of the Quinault tribal fishery on Copalis and Mocrocks beaches and the commercial fishery on the Willapa Spit. The specific FEAM fisheries sector relevant to the clam fishery is titled "clams and mussels". We inserted a five-year average harvest, harvest revenue, and wholesale revenue (in 2007 dollars) for the two fisheries into the FEAM model to generate the estimated coastal income impacts in Table 3.

The five-year period chosen for the Quinault fishery consisted of the years 2003–2007. The resulting impact represents an estimate of the annual average income generated in the coastal region by fully open Quinault commercial razor clam fisheries. To assess impacts of closures due to HABs, we would need to judge the likely length of the closures and the impact that these will have on the ability of the fisheries to take the annual harvestable amounts of clams in the two geographic areas. Since the tribal fishery (like the recreational fishery) occurs during low tides between September and June 1 each year, a lengthy closure is likely to limit the ability to harvest the total amount of clams available. As shown in Table 4, resulting coastal income impacts range from almost $117 thousand for a half-year single beach closure to $1.4 million for an all-year all beach closure.

Table 3 Five-year average coastal income impact of commercial razor clam fisheries**.**

(a) Quinault Tribal Fishery

2003–2007 average harvest with beach price of $1.25 and wholesale price of $4.24	
Total weight of clams (pounds)	376,623
Landed value (beach price)	$470,779
Value-added by processor	$1,126,103
Wholesale value	$1,596,882
Coastal income impact	$1,421,225

(b) Willapa Spit Fishery

2002 plus 2004–2007 average harvest with landed price of $1.46 and wholesale price of $4.24	
Total weight of clams (pounds)	136,264
Landed value	$198,971
Value-added by processors	$378,814
Wholesale value	$577,759
Coastal income impact	$514,206

Table 4 Economic impacts of various types of closures of the Quinault commercial fishery. Based upon average annual harvest of during 2003–2007.

Closure Type	Harvest decline (pounds)	Negative Income Impact ($)
Year-long, all northern beaches	376,623	1,421,225
Year-long, Copalis Beach	165,407	624,180
Year-long, Mocrocks Beach	149,224	563,112
Year-long, Point Grenville	61,992	233,933
Half-year, all northern beaches	188,312	710,614
Half-year, Copalis Beach	82,704	312,090
Half-year, Mocrocks Beach	74,612	281,556
Half-year, Point Grenville	30,996	116,967

The Willapa Spit razor clam fishery is managed by the WDFW using licenses and seasons. It typically begins in May or June after the recreational fishery is completed. Historically, the clams harvested in this fishery were frozen and sold for bait in the winter Dungeness crab fishery. In recent years, a growing percentage of the clams are being used for human consumption, and these are bringing a higher price. Before and during the commercial fishery, the clams are tested for biotoxins to assure safety for human consumption. Domoic acid outbreaks can occur during May–June. For example, the May–June period was closed in 2003 for this reason. The fishery was re-opened in August but the harvest was much reduced as fewer people participated. Many of the usual participants were engaged in other, more lucrative fisheries (*e.g.*, albacore tuna) at that time, or they could not adjust other work commitments to participate in the delayed clam fishery. Hence, the impact shown in Table 5 is based upon the five-year average harvest and revenue during 2002 plus 2004–2007 for the Willapa Spit fishery. The year 2003 was left out of the calculation for Willapa Spit because the fishery was closed during the usual fishing period of June–July due to a HAB outbreak. To calculate the coastal income impacts, we used the average price paid to harvesters (based on WDFW data) and, since we had no direct information on the wholesale value for the Willapa fishery, we assumed that these clams would bring the same average wholesale price as the Quinault razor clams. As shown in Table 5, we estimate the negative income impact of a full closure (May–September) as $514,206, and the negative impact of a spring closure (May–June) as $448,266.

The commercial fishery is clearly a smaller economic driver of the coastal economies than the recreational fishery. Nevertheless, the overall impacts of two fisheries likely represent significant contributions to the communities involved in those fisheries. Closures of portions or of the whole tribal commercial clam fishing season is reckoned to cause negative economic impacts to coastal incomes proportional to the reductions in the fishery seasons.

Table 5 Economic impacts of various types of closures at Willapa Spit in the southern Washington coastal region. May–September closure impact is based upon average annual harvest and value during five recent fishing years (2002 and 2004–2007). May-–June closure impact is based upon the difference between the five-year average and 2003 harvest and value.

Closure scenario	Harvest decline (pounds)	Negative income impact ($)
Spring–Summer closure (May–September)	136,264	514,206
Spring closure (May–June)	118,790	448,266

Assessing the recreational value of reduced beach closures

The last item in the 2008 survey was a question eliciting respondent "willingness to pay" (WTP) for reduced razor clam closures. This was the first attempt to estimate the value of reduced beach closures to recreational clammers. The purpose of estimating was to have a benefit measure that could be compared to the cost of HAB monitoring at razor clam beaches. A single question on the survey addressed this issue:

12. If the State had additional funds available to test for algae blooms more often, it might be possible to reduce the number of beach closures to 1 or less per year. To benefit from the additional HAB testing, would you be willing to pay more than the current price of $8.21 for an annual resident Razor Clam permit?

□ No □ Yes → **If so, how much more would you be willing to spend?**

□ $2 □ $4 □ $6 □ $8 □ $10 □ $15 □ $20 □ $25 □ $30

The question was completed by 220 respondents, 84 of whom checked "No", while 126 checked "Yes". As shown in Table 6, the average amount of WTP for all responders was $5.17 more than the current price of $8.21.

We wanted to estimate an average WTP across the population of clammers at large – that is, an average per clammer, not per clammer trip. The survey data represent a proportional sample of participants on a few days in April 2008. Hence, the individuals are represented in the sample in proportion to their level of participation. A clammer who participated 10 times a year is represented 10 times more in the sample than a clammer who participated only once per year. A reasonable approach to estimating a value per individual rather than per trip is to calculate a weighted average where the weights are inversely proportional to the number of trips per individual for the year.

The weight adjustment for value per clammer *versus* value per respondent was developed (lower part in Table 6. The weights applied to observations at each level of participation (from 1 trip up to 20 trips for the year) were first calculated simply as the inverse of the trip number. Then these were each divided by the sum of the inverse numbers, yielding the set of weights that add up to 1 over the range of trips taken by the clammers. These weights were multiplied by the average values observed within each trip category (1 through 20) resulting in the overall average value shown in Table 7. Similarly, the average number of trips by clammers was calculated from the sample using the same weights applied to the survey answers regarding the number of trips taken during the 2007–2008 season by the respondents. A summary of the results is displayed in Table 7.

Table 6 Results from question 12 on "Willingness to Pay" to fund research that would help the State reduce the number of closures to no more than 1 per year.

		Number of trips (i)											
Answer	**All**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**15**	**20**	**SUM**
No	84	29	19	12	10	4	6	0	2	2	0	0	**84**
Yes	126	48	30	17	8	8	8	1	1	4	1	1	**126**
Sum of Yes $		325.0	276.0	185.00	72.0	105.0	38.0	2.0	2.0	35. 0	2000	25.0	1,085.0
Avg Yes $	8.61	6.77	9.20	10.88	9.00	13.13	4.75	2.00	2.00	8.75	20.0	25.0	
Avg All $	**5.17**	4.22	5.63	6.38	4.00	8.75	2.71	2.00	0.67	5.83	20.0	25.0	

Weighting each value for number of trips component											**Sum**
w=(Yes + No)/210	0.3667	0.2333	0.1381	0.0857	0.0571	0.0667	0.0048	0.0143	0.0286	0.0048	0.0048	
wt1 = w*(1/i)	0.3667	0.1167	0.0460	0.0214	0.0114	0.0111	0.0007	0.0018	0.0029	0.0003	0.0002	**0.5790**
wt*=wt1/Sumwt1	0.6333	0.2015	0.0795	0.0370	0.0197	0.0192	0.0012	0.0031	0.0049	0.0005	0.0004	1.0000
wt*x Avg All	$2.67	$1.14	$0.51	$0.15	$0.17	$0.05	$0.00	$0.00	$0.03	$0.01	$0.01	**$4.74**
wt*x No. Trips	0.6333	0.4030	0.2385	0.1480	0.0987	0.1151	0.0082	0.0247	0.0493	0.0082	0.0082	**1.74**

Table 7 Summary of estimated Willingness to Pay (WTP) for reducing closures to no more than 1 per year.

Weighted average WTP value per angler	$4.74
Weighted average trips per clammer	1.74
Total number of clammer-days during 2007–2008 clamming sea on	242,318
Divided by weighted average of number of trips = number of individuals	139,631
Number of individuals × avg. value = total WTP to avoid closures	$662,205

These estimates are based upon a relatively small sample of clammers during a single season. However, the estimates seem reasonable, and they should help to assess whether or not the cost of maintaining or increasing the costs of ORHAB monitoring would be justifiable on a cost-benefit basis. The WTP estimate of $662 thousand exceeds the current cost of ORHAB monitoring which currently is fixed at $150 thousand from the State legislature. These funds are provided from a tax to Puget Sound shellfish and seaweed licenses and Pacific coast razor clam licenses. The average annual funds from the surcharge to licenses is >$500 thousand. All funding above and beyond the $150 thousand to ORHAB goes to the WDOH for biotoxin monitoring. As ORHAB program costs for salaries and supplies continue to increase, a proposal has been made to approach the legislature for an additional surcharge that is justified by the WTP data presented here.

Conclusions

The economic impacts of closures in the Washington coastal razor clam fisheries have been estimated based upon assumed reductions in the harvests due to full-year and partial-year closures of the recreational and commercial fisheries. In each case, the reduced harvest is translated into a reduction in value of clams harvested based upon recent average annual values, and then these are converted to estimated coastal income impacts based upon regional input-output (I-O) models. For the recreational fisheries, we developed, with major assistance from Prof. William Beyers (University of Washington), a regional I-O model for the Grays Harbor and Pacific county region based upon the I-O coefficients from the existing Washington State input-output model. Data documenting the level of expenditure by recreational razor clammers were collected using a mail-back survey questionnaire distributed by the WDFW during a recreational clam fishery opening on April 19–20, 2008. For the smaller commercial razor clam fisheries on the southern Washington coast, we utilized the existing Fishery Economic Assessment Model (FEAM) commonly used by the Pacific Fishery Management Council to gauge impacts of fishery closures in the Willapa Spit and Quinault tribal commercial fisheries.

The overall coastal income impact in Pacific and Grays Harbor counties of razor clam trip expenditures in 2008 is estimated to be $13.5 million. The estimated economic impacts on labor income in the two-county region for closures of a single scheduled opening of a single recreational beach ranges from $110 thousand (at Mocrocks Beach) to $1.20 million (at Long Beach). For a full year closure of the individual beaches, the estimated income impacts range from $350 thousand to $4.4 million. A full-year, all beach closure has an estimated labor income impact of $10.57 million. This latter estimate is less than the overall estimated impact of razor clam expenditures ($13.5 million) because some clammers claim they would continue to visit the beach for recreation even if the clam fishery is closed.

The commercial fishery is clearly a smaller economic driver of the coastal economies than the recreational fishery. Nevertheless, the overall impacts of these two fisheries ($1.42 million for the Quinault tribal fishery and $514 thousand for the Willapa Spit fishery) likely represent significant contributions to the communities involved in those fisheries. Closures of portions, or all of the tribal commercial clam fishing season will cause negative economic impacts to coastal incomes proportional to the reductions in the fishery seasons. The impact of a partial Willapa Spit fishery closure is more complicated because the fishing participants typically plan on shifting to other fisheries after the usual May–June season. Hence, a shut-down in May–June, even if the fishery is opened later in the summer, will tend to cause a reduction in the economic contribution of the fishery, perhaps as much as $448 thousand.

Beyond the coastal beaches focused on in this paper, shellfish harvesting trips to Puget Sound beaches are estimated at 125,000 per year by the Washington State Department of Fish and Wildlife, providing a net economic of $5.4 million to the region (Washington Shellfish Initiative publication, 2011). Washington State leads the country in aquaculture of clams, oysters and mussels with an annual value of >$107 million. Recently, new emerging HAB problems, including the first documented case of diarrhetic shellfish poisoning (DSP, Trainer *et al*., 2013), are challenging the State monitoring programs with the requirement of a large number of additional shellfish samples to be analyzed in order to protect public health. A phytoplankton monitoring program, modeled after ORHAB, was established in 2006 to assist the WDOH by providing an early warning of HABs. This program, called SoundToxins, is jointly managed by the Northwest Fisheries Science Center and Washington State SeaGrant and is composed solely of volunteers from the general public, shellfish farms, environmental learning centers, and Native Tribes. It is increasingly challenging to maintain SoundToxins without dedicated funding. In particular, because the current shellfish surcharge brings in funding from licenses sold for recreational harvesting in Puget Sound, a proposal will be made to include SoundToxins in the permanent funding for monitoring HABs Statewide.

In summary, phytoplankton monitoring provided by programs such as ORHAB and SoundToxins help reduce the number of beach closures to shellfish harvesting. The economic value of reduced closures made possible by the current State allocation for monitoring by the ORHAB partnership exceeds the $150 thousand cost of monitoring the HABs. Without monitoring, beaches would likely be closed to shellfish harvesting more often and for longer periods. In this paper, we estimate that razor clam diggers are willing to pay $625 thousand to avoid frequent closures of the recreational razor clam fishery on the Pacific coast of Washington. The commercial fishery would experience reduced closures as well, a factor that is not included in the WTP estimate above. Greater attention should be paid toward optimizing important phytoplankton monitoring programs that have successfully mitigated significant human health impacts and reduced the length of closures of beaches to Washington State shellfish harvesters.

Acknowledgements We thank Scott Mazzone, Marine Fish and Shellfish Biologist of the Quinault Indian Nation, for reviewing an earlier draft of this manuscript and for providing helpful comments.

References

Beyers, W., Lefberg, I. and Lin, T. 2008. The 2002 Washington Input-Output Model. Office of Financial Management, State of Washington. Available online at http://www.ofm.wa.gov/economy/io/2002/default.asp.

Chadsey, M., Trainer, V.L. and Leschine T.M. 2011. Cooperation of Science and Management for Harmful Algal Blooms: Domoic Acid and the Washington Coast Razor Clam Fishery. *Coast. Mngmt.* **40**: 33–54.

Dyson, K. and Huppert, D.D. 2010. Regional economic impacts of razor clam beach closures due to harmful algal blooms (HABs) on the Pacific coast of Washington. *Harmful Algae* **9**: 264–271.

Hoagland, P., Anderson, D.M., Kaoru, Y. and White, A.W. 2002. The economic effect of harmful algal blooms in the United States: estimates, assessment issues, and information needs. *Estuaries* **25**: 819–837.

Hoagland, P., Jin, D., Polansky, L.Y., Kirkpatrick, B., Kirkpatrick, G., Fleming, L.E., Reich, A., Watkins, S.M., Ullmann, S.G. and Backer L.C. 2009. The costs of respiratory illnesses arriving from Florida Gulf Coast *Karenia brevis* blooms. *Environ. Health Perspect.* **117**: 1239–1243.

Hoagland, P., Jin, D., Beet, A., Kirkpatrick, B., Reich, A., Ullmann, S., Fleming, L.E. and Kirkpatrick, G. 2014. The human health effects of Florida red tide (FRT) blooms: An expanded analysis. *Environ. Intl.* **68**: 144–153.

Jin, D. and Hoagland, P. 2008. The value of HAB predictions to the commercial shellfish fishery in the Gulf of Maine. *Harmful Algae* **7**: 772–781.

Miernyk, W.H. 1965. The Elements of Input-Output Analysis. New York: Random House, 156 pp.

PFMC (Pacific Fishery Management Council) 2003. Pacific Coast Salmon Plan (as revised through Amendment 14). Adopted March 1999. Portland, OR.

Trainer, V.L., Moore, L., Bill, B.D., Adams, N.G., Harrington, N., Borchert, J., da Silva, D.A.M. and Eberhart, B.T.L. 2013. Diarrhetic shellfish toxins and other polyether toxins of human health concern in Washington State. *Mar. Drugs* **11**: 1–22, doi:10.3390/md110x000x.

Radtke, H., Dewees, C.M. and Smith, F.J. 1987. The fishing industry and Pacific coastal communities: Understanding the assessment of economic impacts. Pacific Sea Grant College Program. University of California. Marine Advisory Program Publication - UCSGMAP-97-1.

Washington Shellfish Initiative. 2011. From the website: http://www.psp.wa.gov/shellfish.php.

Economic impacts of harmful algal blooms in the NOWPAP region

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About NOWPAP

The Northwest Pacific Action Plan (NOWPAP) is part of the Regional Seas Programme of the United Nations Environment Programme (UNEP), which aims to address the accelerating degradation of the world's oceans and coastal areas. The program goals are sustainable management and use of the marine and coastal environment through engagement of neighboring countries in comprehensive and specific actions to protect their shared marine environment. China, Japan, Korea and Russia are member states of NOWPAP and four Regional Activity Centres (RACs) implement activities for marine environmental conservation in the NOWPAP region.

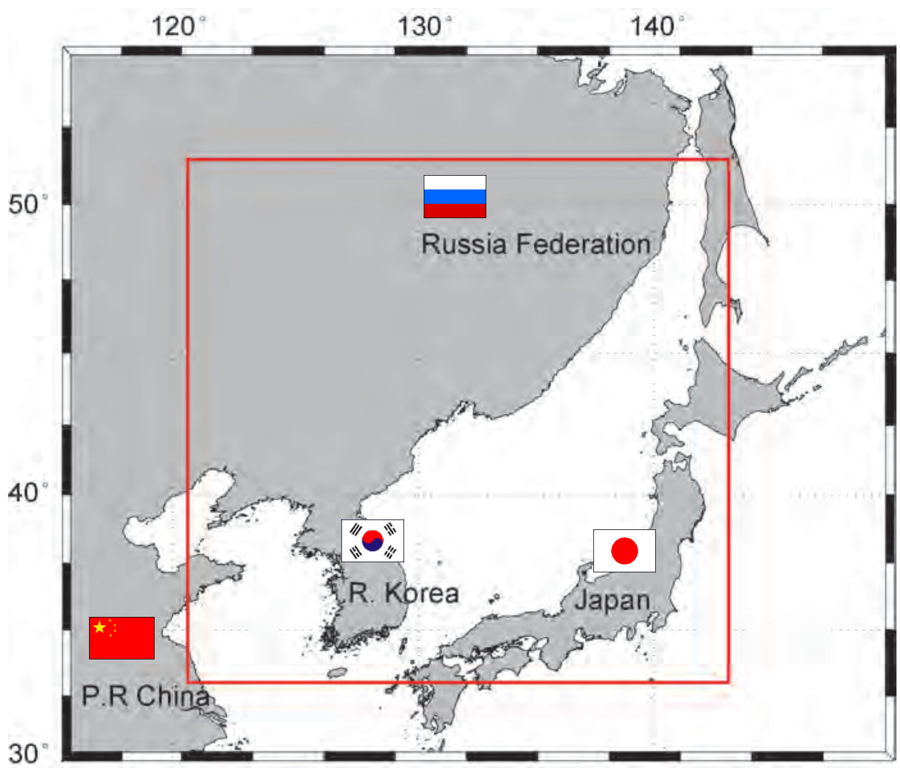

Fig. 1 NOWPAP geographical scope.

The Special Monitoring and Coastal Environmental Assessment Regional Activity Centre (CEARAC), one of four RACs of NOWPAP, is responsible for coordination of regional activities for assessment of the state of the marine, coastal and associated freshwater environments, including assessment of pollutant input for comparison with monitoring results. CEARAC also develops tools for environmental planning and management, based on the results of assessments, including monitoring of biological effects of pollutants and special monitoring programs using remote sensing techniques in areas which cannot be covered by routine *in situ* pollution monitoring.

In these activities of CEARAC, monitoring Harmful Algal Blooms (HAB) is important. As HAB frequently cause serious economic impacts in member states, each country conducts regular monitoring in coastal areas of frequent HAB occurrence with a goal of sharing information on HAB type, number and distribution. The selected areas of routine monitoring are: the coastal areas of Qingdao and Dalian in China; the northwest sea area of the Kyushu region and Ariake Sea in Japan; the south coast of Korea; and Amurskii Bay, Vostok Bay and Aniva Bay in Russia (Fig. 2). To understand and assess the HAB situation in the NOWPAP region, CEARAC has summarized the information on HAB in member states and published regional reports in 2005 and 2011 (NOWPAP CEARAC 2005, 2011). This article is based on the information from these reports with some additional current information for the NOWPAP region. In this report, information on HAB is presented as red tides and toxin-producing plankton, respectively.

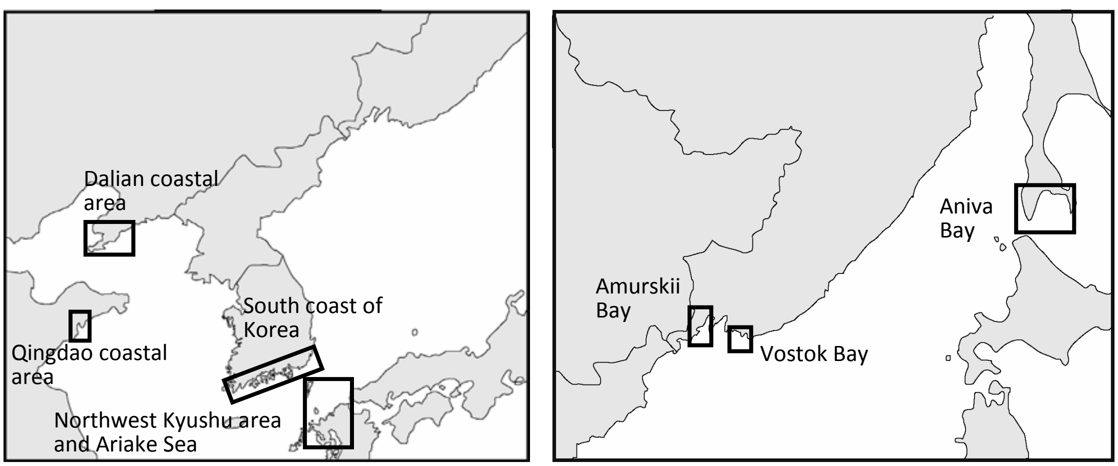

Fig. 2 Selected sea areas where HAB information was collected by NOWPAP member states.

Red tide occurrences in the NOWPAP region

Figure 3 shows the number of red tide events in the selected sea areas of member states from 1995 to 2008. Red tide events have been continuously recorded along the coastal areas, with some annual and spatial variations. Intensive fishery and aquaculture areas tend to have numerous red tide occurrences.

To date, about 100 red tide producing plankton species have been recorded in the NOWPAP region. Two flagellate species, *Heterosigma akashiwo* and *Noctiluca scintillans*, and one diatom species, *Skeletonema costatum*, have been recorded in the coastal waters of all NOWPAP member states, and these flagellate species have caused extensive damage to local fisheries. Other common and economically damaging species include *Karenia mikimotoi*, *Akashiwo sanguinea* and *Prorocentrum micans*, all flagellates. In addition, *Cochlodinium polykrikoides* is a flagellate species which has caused serious damage to fisheries in Japan and Korea.

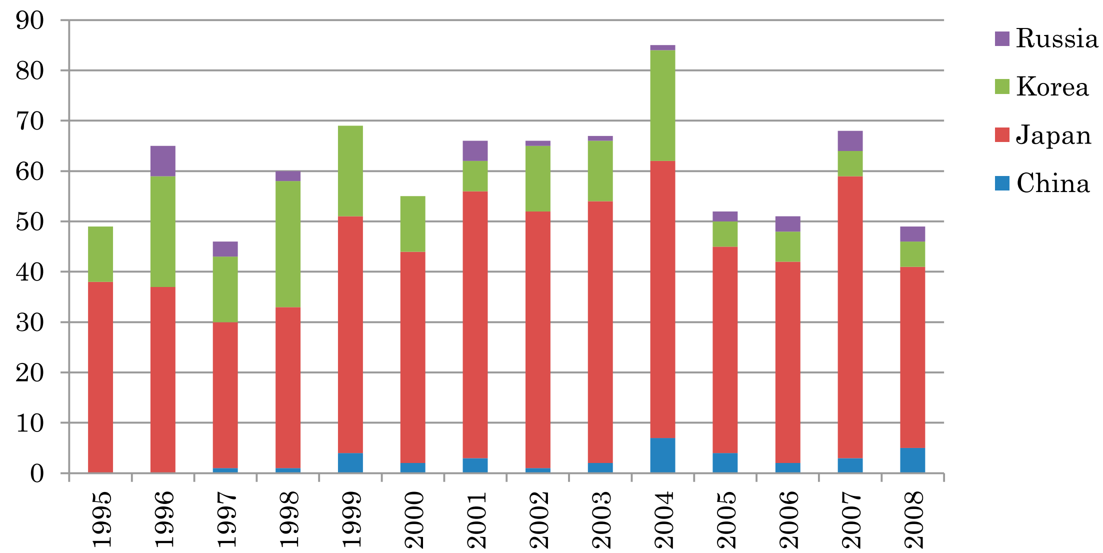

Fig. 3 Number of red tide events in the NOWPAP member states.

Fishery damage by red tide and its causative species

In China, 50 red tide events were reported from 1990 to 2009, of which 2 events led to economic damage to scallop aquaculture in the Dalian coastal area. Economic damage was estimated at 20 million Chinese Yuan (3 million USD) and 120 million Chinese Yuan (20 million USD) in 1990 and 2000, respectively. In Japan, 1,407 red tide events were recorded from 1979 to 2008, of which 122 events caused fisheries damage off northern Kyushu Island and Ariake Sea. In Korea, 873 red tide events were recorded from 1995 to 2009, of which 209 events led to fish kills along the whole Korean coast. In Russia, 41 red tide events were recorded from 1991 to 2010; however, all events were recorded as harmless and caused no apparent damage.

In Japan and Korea, serious economic impacts on fisheries were reported. In 1999, approximately 7 million US dollars (USD) of fisheries damage was recorded in Imari Bay, Kyushu, Japan. Even greater economic losses were recorded in Korea in 1995 and 2003, worth approximately 95 million USD and 19 million USD, respectively. Since 2005, the number of occurrences and damage to fisheries by *C. polykrikoides* had decreased until in 2012 when *C. polykrikoides* formed blooms along the western and southern coasts of Korea for two months. The economic losses to aquacultured rockfish and parrot fish industries reached 3.3 million USD.

In Japan, *Chattonella antiqua* and *Karenia mikimotoi* cause huge economic losses to aquaculture. Since 2008, fisheries damage caused by *C. antiqua* has been severe in the Yatsushiro Sea, Kyushu, due to the impacts of these HAB on many farms of aquacultured Japanese amberjack, striped jack and yellowtail amberjack. In 2008, the amount of fisheries damage was 1.8 million USD, and increased to 29 million USD in 2009, then almost doubled to 53 million USD in 2010. In the Bungo Strait, located in the Seto Inland Sea, huge economic losses (13 million USD in terms of fishery damage) due to *K. mikimotoi* impacts on aquacultured Japanese amberjack and red seabream occurred in 2012. The Bungo Strait is outside of the NOWPAP region; however, it is connected to the NOWPAP region through the Kanmon Strait and contains many aquaculture farms.

Economic damage by massive blooms of green macroalgae *Ulva prolifera*

Green tides, which are caused by huge volumes of green macroalgae, are not directly harmful to fisheries or human health, but macroalgae often grow rapidly and huge volumes can become stranded on the coast. During green tide events, stakeholders have to remove algae in order to keep the coast clean and safe. In recent years, such macroalgae blooms have become one of the marine environmental concerns throughout the world.

In 2008, massive green macroalgae blooms occurred in the Yellow Sea and the East China Sea, including the coastal area of Qingdao. One particular bloom covered an area of about 2,400 km^2 and the total volume removed reached 1 million tons (Hu and He, 2008). The removal and treatment of such a large volume of macroalgae cost more than 100 million USD. Such massive blooms have occurred every year in Chinese coastal areas since 2007 (Zhao *et al*., 2013), becoming a serious environmental issue in the NOWPAP region.

Toxin-producing plankton and shipment stoppage in the NOWPAP region

All NOWPAP member states regularly monitor the status of shellfish toxins produced by phytoplankton species and causing syndromes in humans called paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP). In the NOWPAP region, six species, including *Alexandrium* spp. and *Gymnodinium catenatum* are PSP-inducing species. The most commonly recorded PSP species in the member states is *A. tamarense*. While no shellfish poisoning was recorded in China, Korea and Russia from 2006 to 2012, 21 PSP-poisoning cases were recorded in Japan. In 12 of these cases, an export shipment stoppage was enacted once the toxin levels exceeded the safety limit.

Nine of the 10 DSP species recorded in the NOWPAP region belong to the genus *Dinophysis*. The other is *Exuviaella marina*, which was recorded only in China (NOWPAP CEARAC, 2005). *Dinophysis fortii* and *D. acuminata* were recorded in all four NOWPAP member states; however, no damage to fishery or human health by this poisoning was reported in the region.

ASP-inducing *Pseudo-nitzschia* species were recorded mainly in Russia. In Korea, the only *Pseudo-nitzschia* species observed was *Pseudo-nitzschia pungens*. In the NOWPAP region, damage caused by ASP has not yet been reported.

Countermeasures related to economic impacts caused by red tide and toxin-producing plankton blooms

All NOWPAP member states have regular red tide and toxin-producing plankton monitoring programs to detect the presence of HAB species. Regular monitoring and early detection is one of the basic countermeasures for minimizing fishery damages. In China, after starting regular monitoring in 2002, the number of early detections of HAB increased and fishery damage and associated economic losses decreased accordingly. The positive economic effect from monitoring, resulting in reduction of fishery damage, was 90 million Chinese Yuan (about 14.7 million USD) in 2002 (Ministry of Environmental Protection, China, 2002).

Furthermore, each member state has set warning and advisory standards in order to prevent specific fisheries damage caused by various HAB species. Target species and threshold numbers of cells that result in advisories or warnings vary among countries and regions (Table 1). When the *in situ* observed cell number of target species exceeds the advisory limit, monitoring organizations alert fishermen. Then, when target species abundance increases above the warning standard level, monitoring organizations encourage fishermen to take countermeasures, such as feed withdrawal or relocation of fish cages.

Japan and Russia monitor toxin-producing plankton species to mitigate the effects of shellfish toxins and damage to human health. All NOWPAP member states set warning and advisory standards for cell density of toxin-producing plankton, *Alexandrium* spp., *Gymnodinium catenatum*, *Dinophysis* spp. and *Pseudo-nitzschia* spp.

Table 1 Warning and advisory standards for each causative species.

Country	Species name	Warning/action standards (cell/ml)	
		Advisory standard	Warning standard
China	*Mirionecta rubra*	500	–
	Noctiluca scintillans	50	–
	Skeletonema costatum	5,000	–
	Heterosigma akashiwo	50,000	–
	Eucampa. zodianus	100	–
	Chattonella marina	100	–
	Alexandrium tamarense	1,000	–
Japan	*Chattonella antiqua*	1	10
	C. marina	1	10
	Karenia mikimotoi	100	500
	Cochlodinium polykrikoides	50	500
	Heterosigma akashiwo	1,000	10,000
	Heterocapsa circularisquama	10	50
Korea	*Chattonella* spp.	2,500	5,000
	Cochlodinium polykrikoides	300	1,000
	Gyrodinium sp.	500	2,000
	Karenia mikimotoi	1,000	3,000
	Other dinoflagellates	30,000	50,000
	Diatoms	50,000	100,000
	Mixed blooms	40,000	80,000
Russia	*Pseudo-nitzschia callianth*	500	–
	P. delicatissima	500	–
	P. fraudulenta	500	–
	P. multistriata	500	–
	P. multiseries	500	–
	Alexandrium tamarense	0.5	–
	Dinophysis acuminate	0.5	–
	D. acuta	0.5	–
	D. fortii	0.5	–
	D. norvegica	0.5	–
	D. rotundata	0.5	–
	Protoceratium reticulatum	500	–

In order to reduce fisheries damage, detecting HAB at an early stage and conducting timely countermeasures is important. Early detection can lead to early warning and give fishermen sufficient time to implement countermeasures.

There are some methods for detecting HAB at an early stage, including using remote sensing techniques and molecular genetic techniques as well as information sharing and communication technology:

Remote sensing techniques

Satellites are useful tools for red tide monitoring and offer the ability to obtain information from large areas. Although there are some challenges, such as size differences between the actual red tide and the resolution of the satellite image, interference from clouds, and the inability of satellites to distinguish phytoplankton species, remote sensing techniques are applied to assist with monitoring red tides in the NOWPAP region (Tang *et al*., 2003; Ahn *et al*., 2006; Ishizaka *et al*., 2006). In addition, satellite images are used not only for monitoring but also for forecasting the movement of red tides and thereby reducing red tide damage. For example, fisheries damage was reduced by forecasting red tide movement using satellite images in Oita Prefecture, Japan (Fig. 4). This forecasting system can be applied in aquaculture areas to help fishermen take appropriate countermeasures, such as moving fish cages and feed withdrawal to minimize fisheries damage (Oita Pref. Agriculture, Forestry and Fishery Research Center, 2012).

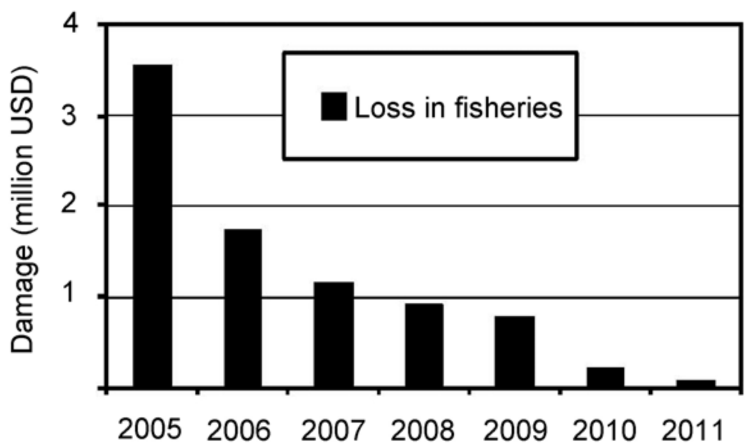

Fig. 4 Reduced fishery damage estimated using satellite imagery in Oita Prefecture (Oita Prefecture Agri. Forest. Fish. Res. Center, 2012).

Molecular genetic techniques

The more quickly that species can be identified and abundance can be calculated at a HAB site, the more likely that HAB damage can be rapidly mitigated. At present, a molecular biological approach is applied using unique DNA markers for each species. The Fluorescent In Situ Hybridization (FISH) method, real-time Polymerase Chain Reaction (PCR) and Loop-Mediated Isothermal Amplification (LAMP) methods are useful approaches for rapid species detection.

Information and communication technology

Information and communication technology is essential for sharing and disseminating information among relevant organizations and persons. In Ehime Prefecture, Japan, a website describing the coastal environment was developed by Ehime University supported by the Ministry of Internal Affairs and Communications, Japan. Various environmental data, such as water temperature, salinity, dissolved oxygen, and red tide occurrence are disseminated among concerned parties. Such rapid information sharing also helps with early detection of red tides and can reduce economic fisheries losses. The cost for development and operation of such a system is high (47,000 USD and 4,500 USD, respectively, per year); however, it is estimated that the cost-effectiveness of this system is 35,000 USD per year (Ministry of Internal Affairs and Communications, 2012).

More detailed information is introduced in CEARAC reports which can be downloaded from the CEARAC website at http://cearac.nowpap.org/publications /index.html.

References

Ahn, Y.-H., Shanmugam, P., Ryu, J.-H. and Jeong, J.-C. 2006. Satellite detection of harmful algal bloom occurrences in Korean water. *Harmful Algae* **5**: 213–231.

Hu C. and He, M.-X. 2008. Origin and offshore extent of floating algae in Olympic sailing area. *Eos Trans*. **89**: 302–303.

Ishizaka J., Kitaura, Y., Touke, Y., Sasaki, H., Tanaka, A., Murakami, H., Suzuki, T., Matsuda, K. and Nakata, H. 2006. Satellite detection of Red Tide in Ariake Sound, 1998–2001. *J. Oceanogr*. **62**: 37–45.

Ministry of Environmental Protection, the People's Republic of China. 2002. Report on the State of the Environment in China.

Ministry of Internal Affairs and Communications. 2012. Case studies on information and communication technology (in Japanese). http://www.soumu.go.jp/main_sosiki/joho_tsusin/top/local_support/ict/data/jireishu/h24/q093806_jirei_h24.pdf.

NOWPAP CEARAC. 2005. Integrated Report on Harmful Algal Blooms for the NOWPAP Region, 64 pp., ISBN: 4-9902809-1-1.

NOWPAP CEARAC. 2011. Integrated Report on Harmful Algal Blooms for the NOWPAP Region, 97 pp., ISBN: 978-4-9902809-3-2.

Oita Prefecture Agriculture, Forestry and Fisheries Research Center. 2012. (in Japanese).

Tang D., Kester, D.R., Ni, I., Qi, Y. and Kawamura, H. 2003. In situ and satellite observation of a harmful algal bloom and water condition at the Pearl River estuary in the last autumn 1998. *Harmful Algae* **2**: 89–99.

Zhao J., Jiang, P., Liu, Z.Y., Wei, W., Lin, H.-Z., Li, F.-C., Wang, J.-F. and Qin, S. 2013. The Yellow Sea green tides were dominated by one species, *Ulva* (*Enteromorpha*) *prolifera*, from 2007 to 2011. *Chinese Sci. Bull*. **58**: 2298–2302.

Appendix 1

Workshop summary from PICES-2013

MEQ Workshop (W6)
Economic impacts of harmful algal blooms on fisheries and aquaculture

Co-Convenors: Chang Hoon Kim (Korea) and Vera Trainer (USA)

Invited speaker: Daniel Huppert (University of Washington, USA)

Background

Harmful algal blooms (HABs) have adverse economic and social impacts on the aquaculture industry, human health, coastal economies, and wild fisheries. HABs have prompted routine closures of both commercial and recreational shellfish harvesting as well as contributing to the death of aquaculture finfish resulting in financial losses in coastal communities. But the economic impacts generated by these events extend far beyond the industry itself. Obtaining more realistic estimates of HAB economic impacts, and the costs of preventing and managing them, calls for an integrated assessment approach that comprises the following: the economic impact of HABs on the aquaculture industry, the secondary integrated industries, and consumers, on both local and regional scales; some valuation of the costs and benefits of taking any recognized steps to lessen the HAB problem (*e.g.*, reducing coastal pollution and other human-related activities); and weighing the costs and benefits of enhanced monitoring and surveillance that potentially reduces the magnitude of the impacts (*e.g.*, by limiting shellfish harvesting closure windows or alteration in the timing of finfish harvesting).

This workshop comprised two parts, with the first being a presentation of what is known about the economic and social impacts of HABs in the eastern and western Pacific, by both HAB researchers and invited speakers who could inform on cutting edge approaches and methodologies for assessment of HAB and other marine economic impacts (*e.g.*, oil spills). In the second part, participants identified specific steps for developing improved and more comprehensive economic impact assessments of HABs on fisheries and aquaculture in the North Pacific.

Summary

The primary goal of the workshop was to provide PICES scientists with a better understanding of the economic and social impacts of both toxin-producing and high-biomass blooms in PICES member countries It was proposed, due to the quality of presentations and the novel information they contained, that they be consolidated into a PICES Scientific Report entitled "*Economic impacts of HABs on fisheries and aquaculture in PICES member nations*".

The ½-day workshop consisted of six oral presentations and one poster, representing authorship from five PICES member countries: Canada, Japan, Korea, Russia, and the United States. There were three last minute cancellations primarily due to the U.S. government partial shutdown. Attendance at the meeting was good, with approximately 20 participants. The workshop entailed lively discussions and questions among participants.

Invited speaker, Dr. Dan Huppert (University of Washington, USA), talked about the regional economic impacts of razor clam beach closures on Washington State's Pacific beaches. Closures occur when the risk of amnesic shellfish poisoning (ASP) and paralytic shellfish poisoning (PSP) is high. Washington has short razor clamming seasons on the weekends. Dr. Huppert's work assessed the impacts of HABs from fall 2007 to fall 2008. Research questions were: 1. How much do clammers spend in the coastal region? 2. How does spending change when razor clam beaches are closed? 3. How does change in spending impact local income and employment? A total of 450 surveys were distributed by the Washington Department of Fish and Wildlife and 240 were returned by mail. Total expenditures were added, including hotel, camping, restaurant, groceries, gas, ferry, and other items. The average expenditure per clammer day was $100. Almost $25 million in total estimated expenditures was estimated for the 2007–2008 clamming season. Reaction to closures included: Only 14% would have stayed at the beach and 67% would go home if there was a closure. If more closures occur in the future, 52% would go to the same beach less frequently. The total expenditure for a 1-day opening at all 4 coastal beaches was ~$4,500. An Input-Output (I-O) model was used to estimate income and employment impacts with calculation of direct and indirect impacts. An example of a direct impact is: A clammer spends money and changes local income. An example of an indirect impact is: Local community members spend less because they have less income. The local economic impact of a 1-year beach closure (all beaches) is $11.36 million. Reduced employment is ~364 jobs. The net benefit of the clam fishery to the coastal community would be calculated differently.

The group discussed how to assess the cultural and social impacts of fisheries closed due to HABs and how to assess the true benefit of monitoring. Dr. Takafumi Yoshida (NOWPAP) reviewed HABs in the NOWPAP region. An integrated report on HABs for the NOWPAP region was published in 2011. It provides information on HAB monitoring and HAB occurrences. The negative impacts of HABs are on fisheries/aquaculture, human health, and tourism. Total economic loss in fisheries from 2006–2012 was $94 million USD for Korea, Japan, and China. In the Yatsushiro Sea in 2009 and 2010, there were huge economic losses incurred by blooms of *Chattonella antiqua*. The losses were $3.3 billion USD in 2009 and $4 billion in 2010. In 2013 in South Gyeongsang Province, Korea, $28 million USD was lost by October 2013. The green tide in China has cost $30 million USD for cleanup and $100 million USD in fisheries losses. To mitigate HAB damage, China is conducting regular monitoring to detect red tides in the early stage. This program has reduced economic loss by $14.7 million USD in 2002 (J.People.com). In Japan, the fisheries cooperatives, universities, and local fishery agencies contribute to a portal website. The result is a reduction in economic loss of $35,000 USD per year to no dollars lost, and the number of early red tide detections has increased from 71 to 181. The operational cost of this website is $4,500 per year.

Dr. Nicky Haigh (Vancouver Island University, Canada) reviewed the economic losses to the British Columbia salmon aquaculture industry due to HABs 2009–2012. Salmon is the largest agricultural export in British Columbia, at $800 million CAD. There are 130 farm leases with 75–80 usually in operation. Fish killing HAB species include raphidophytes (*Heterosigma akashiwo*, *Chatonella* cf. *marina*), dictochophytes (*Dictyocha speculum, Dictyocha fibula, Pseudochattonella* cf. *verruculosa*), diatoms (*Chaetoceros*), dinoflagellates (*Cochlodinium fulvescens, Alexandrium catenella*), and haptophytes (*Chrysochromulina* spp.). The relative economic loss is characterized in the following categories:
- Low: 10s of fish killed,
- Moderate: 100s of fish killed,
- High: >1000 fish killed.

High losses are usually due to *Heterosigma* or *Chattonella*.
- Losses due to HABs: $4.6 million CAD (2009), $1.9 million (2010), $3.1 million (2011), $6.4 million (2012),
- Total direct losses: ~ $16 million CAD (primarily *Heterosigma, Chaetoceros, Chattonella marina*).

Other losses are due to mitigation including:
- Lost production: withholding feed during blooms which results in less growth,
- Mitigation: barrier curtains and upwelling or bubbling equipment, compressors, fuel (Costs $1-2 million CAD annually per company).

Future needs are to:
- clearly identify HAB species,
- elucidate toxins and toxicity. What makes them toxic?
- understand the effects of environmental factors on HAB species prevalence,
- understand the effects of climate change (warming, acidification) on different HAB species
- use better monitoring methods – especially for small species like *Chrysochromulina*. Some species are harmful at low levels, *i.e.*, *Chattonella* cf. *marina*.

Dr. Meg Chadsey (University of Washington, USA) presented on cooperation of science and management for HABs. The Washington State razor clam fishery has 250,000 digger trips to the coast every year. The tribal clam harvest is estimated at $7 million per year. The conceptual framework for environmental management includes community, scientists, and managers who, through institutional arrangements, seek to mitigate environmental problems. The standard method of management was to collect and analyze shellfish. This method resulted in emergency closures. The Quileute tribe contacted the University of Washington in 1995 to ask for assistance with the HAB problem. This resulted in convening of a stakeholder meeting in 2000 that resulted in the establishment of the Olympic Region Harmful Algal Bloom (ORHAB) partnership. ORHAB objectives were to study bloom dynamics, build credibility for funding, and assess economic impacts of HABs on the State's coastal economies. The overall goal was to develop local capacity and affordable tools for DA monitoring. ORHAB brought agencies together and helped to coordinate information regarding seafood safety. In 2003, a tax to shellfish license fees allowed the project to be transitioned to State funding. The funding request was $150 thousand which now is not enough to support all ORHAB costs. "Use inspired basic research" resulted in scientific papers responsive to management needs.

Dr. Hao Guo (Dalian Maritime University, China) examined the economic cost of HABs in China from 2008–2012. China's coastline is 32,000 km long of which the continental coastline is 18,000 km. China has 144 monitoring agencies. A national HAB monitoring system was established in 2002, and monitoring zones are focused in aquaculture areas as well as in ecologically protected areas. Financial losses due to the frequency and scale of red tides reached a high level during 2003–2006. Over the past 20 years, the occurrence of red tides and affected areas is basically stable. Approximately 57% of HABs are in the East China Sea, and large-scale HABs occur near the Yangtze River. The majority of HABs occur in May and June. The total economic loss from HABs in China during the years 2008–2012 was $364 million USD. The East China Sea has suffered the largest direct economic effect (91%) in the last 5 years. *Noctiluca scintillans* has caused disasters through high levels of ammonia, resulting in mass mortalities of cultivated shellfish. *Prorocentrum donghaiense*, common in the East China Sea, has led to problems with reproduction, survival and hatching rates in fish and scallops. Recurrent blooms of *Karenia mikimotoi* have been associated with massive deaths of fish and shellfish. In 2012, these blooms caused massive damage to abalone, with a direct economic loss of more than $330 million USD. In 2010, *Mesodinium rubrum* spread to a 20 km^2 area, resulting in a great economic loss. *Cochlodinium geminatum* produced ichthyotoxins causing major losses in fisheries and shellfisheries. Approximately $500,000 million USD was lost in August 2011 due to this organism. From 2009–2012, the *Aureococcus anophagefferens* brown tide caused damage to scallop culture in Hebei Province by causing loss of feeding. A total of $364 million USD was lost due to HAB occurrences encompassing a total area of 53,000 km^2 from 2008–2012. The worst hit species were cultivated abalone and fish.

Shigeru Itakura explored the economic impacts of HABs on fisheries and aquaculture in western Japan. The Ministry of Agriculture, Forestry and Fisheries (MAFF) collects economic impact data in Japan for both toxic blooms and red tides. Extensive damage has been caused by HABs in Japan. From 1972 to the present, there have been many HABs, including *Chattonella, Karenia, Heterocapsa, Cochlodinium*, and diatoms which affect yellowtail, red sea bream, pearl oyster, oyster, and porphyra. *Chattonella* is the most harmful algae in Japan, and was responsible for causing the most damage to fisheries in the Seto Inland Sea from 1980–2008. *Heterocapsa* and *Cochlodinium* became problem HABs starting in 1995, and diatoms became a problem after 1990. The amount of fisheries damage on the Kyushu coast increased up to 1999, then appeared to decrease. *Cochlodinium* damage appears to be decreasing in recent years. The economic loss due to toxic red tides is difficult to quantify but includes such factors as: unrecognized financial losses, halts in hiring, damage of wild aquatic resources, reluctance to buy fisheries products due to rumors, and the cost of countermeasures and mitigation.

List of papers

Oral presentations

Karen Dyson and Daniel D. Huppert (Invited)
Regional economic impacts of razor clam beach closures due to Harmful Algal Blooms (HABs) on the Pacific coast of Washington

Takafumi Yoshida and Hiroshi Ono
Economic impacts of Harmful Algal Blooms in the NOWPAP region

Nicola Haigh and Svetlana Esenkulova
Economic losses to the British Columbia salmon aquaculture industry due to Harmful Algal Blooms 2009–2012

Hao Guo, Dewen Ding and Chunjiang Guan
The economic cost of Harmful Algal Blooms in China from 2008-2012

Meg Chadsey, Vera L. Trainer and Thomas Leschine
Cooperation of science and management for Harmful Algal Blooms: Domoic acid and the Washington Coast razor clam fishery

Shigeru Itakura and Ichiro Imai
Economic impacts of Harmful Algal Blooms on fisheries and aquaculture in the western Japan – An overview of interannual variability and interspecies comparison

Poster presentation

Ji A Park, HyeongKyu Kwon, HanSoeb Yang and Seok Jin Oh
Utilization of different nitrogen sources by the toxic dinoflagellates, *Alexandrium tamarense* and *Alexandrium catenella*, isolated from Masan Bay, Korea

Appendix 2

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Continued from inside back cover

Jamieson, G. and Zhang, C.-I. (Eds.) 2005. Report of the Study Group on Ecosystem-Based Management Science and its Application to the North Pacific. **PICES Sci. Rep. No. 29**, 77 pp.

Brodeur, R. and Yamamura, O. (Eds.) 2005. Micronekton of the North Pacific. **PICES Sci. Rep. No. 30**, 115 pp.

Takeda, S. and Wong, C.S. (Eds.) 2006. Report of the 2004 Workshop on *In Situ* Iron Enrichment Experiments in the Eastern and Western Subarctic Pacific. **PICES Sci. Rep. No. 31**, 187 pp.

Miller, C.B. and Ikeda, T. (Eds.) 2006. Report of the 2005 Workshop on Ocean Ecodynamics Comparison in the Subarctic Pacific. **PICES Sci. Rep. No. 32**, 103 pp.

Kruse, G.H., Livingston, P., Overland, J.E., Jamieson, G.S., McKinnell, S. and Perry, R.I. (Eds.) 2006. Report of the PICES/NPRB Workshop on Integration of Ecological Indicators of the North Pacific with Emphasis on the Bering Sea. **PICES Sci. Rep. No. 33**, 109 pp.

Hollowed, A.B., Beamish, R.J., Okey, T.A. and Schirripa, M.J. (Eds.) 2008. Forecasting Climate Impacts on Future Production of Commercially Exploited Fish and Shellfish. **PICES Sci. Rep. No. 34**, 101 pp.

Beamish, R.J. (Ed.) 2008. Impacts of Climate and Climate Change on the Key Species in the Fisheries in the North Pacific. **PICES Sci. Rep. No. 35**, 217 pp.

Kashiwai, M. and Kantakov, G.A. (Eds.) 2009. Proceedings of the Fourth Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 36**, 305 pp.

Jamieson, G., Livingston, P. and Zhang, C.-I. (Eds.) 2010. Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. **PICES Sci. Rep. No. 37**, 166 pp.

Pakhomov, E. and Yamamura, O. (Eds.) 2010. Report of the Advisory Panel on Micronekton Sampling Intercalibration Experiment. **PICES Sci. Rep. No. 38**, 108 pp.

Makino, M. and Fluharty, D.L. (Eds.) 2011. Report of the Study Group on Human Dimensions. **PICES Sci. Rep. No. 39**, 40 pp.

Foreman, M.G. and Yamanaka, Y. (Eds.) 2011. Report of Working Group 20 on Evaluations of Climate Change Projections. **PICES Sci. Rep. No. 40**, 165 pp.

McKinnell, S.M., Curchitser, E., Groot, C., Kaeriyama, M. and Myers, K.W. 2012. PICES Advisory Report on the Decline of Fraser River Sockeye Salmon *Oncorhynchus nerka* (Steller, 1743) in Relation to Marine Ecology. **PICES Sci. Rep. No. 41**, 149 pp.

Takeda, S., Chai, F. and Nishioka, J. (Eds.) 2013. Report of Working Group 22 on Iron Supply and its Impact on Biogeochemistry and Ecosystems in the North Pacific Ocean. **PICES Sci. Rep. No. 42**, 60 pp.

Shaw, C.T., Peterson, W.T. and Sun, S. (Eds.) 2013. Report of Working Group 23 on Comparative Ecology of Krill in Coastal and Oceanic Waters around the Pacific Rim. **PICES Sci. Rep. No. 43**, 100 pp.

Abo, K., Burgetz, I. and Dumbauld, B. (Eds.) 2013. Report of Working Group 24 on Environmental Interactions of Marine Aquaculture. **PICES Sci. Rep. No. 44**, 122 pp.

Hollowed, A.B., Kim, S., Barange, M. and Loeng, H. (Eds.) 2013. Report of the PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish. **PICES Sci. Rep. No. 45**, 197 pp.

Ross, P.S. (Ed.) 2013. Report of the Study Group on Marine Pollutants. **PICES Sci. Rep. No. 46**, 49 pp.

Trainer, V.L. and Yoshida, T. (Eds.) 2014. Proceedings of the Workshop on Economic Impacts of Harmful Algal Blooms on Fisheries and Aquaculture. **PICES Sci. Rep. No. 47**, 85 pp.

PICES Scientific Reports

Hargreaves, N.B., Hunter, J.R., Sugimoto, T. and Wada, T. (Eds.) 1993. Coastal Pelagic Fishes (Report of Working Group 3); Subarctic Gyre (Report of Working Group 6). **PICES Sci. Rep. No. 1**, 130 pp.

Talley, L.D. and Nagata, Y. (Eds.) 1995. The Okhotsk Sea and Oyashio Region (Report of Working Group 1). **PICES Sci. Rep. No. 2**, 227 pp.

Anonymous. 1995. Report of the PICES-STA Workshop on Monitoring Subarctic North Pacific Variability. **PICES Sci. Rep. No. 3**, 94 pp.

Hargreaves, N.B. (Ed.) 1996. Science Plan, Implementation Plan (Report of the PICES-GLOBEC International Program on Climate Change and Carrying Capacity). **PICES Sci. Rep. No. 4**, 64 pp.

LeBlond, P.H. and Endoh, M. (Eds.) 1996. Modelling of the Subarctic North Pacific Circulation (Report of Working Group 7). **PICES Sci. Rep. No. 5**, 91 pp.

Anonymous. 1996. Proceedings of the Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 6**, 426 pp.

Beamish, R.J., Hollowed, A.B., Perry, R.I., Radchenko, V.I., Yoo, S. and Terazaki, M. (Eds.) 1997. Summary of the Workshop on Conceptual/Theoretical Studies and Model Development and the 1996 MODEL, BASS and REX Task Team Reports. **PICES Sci. Rep. No. 7**, 93 pp.

Nagata, Y. and Lobanov, V.B. (Eds.) 1998. Multilingual Nomenclature of Place and Oceanographic Names in the Region of the Okhotsk Sea. **PICES Sci. Rep. No. 8**, 57 pp. (Reprint from MIRC Science Report, No. 1, 1998)

Hollowed, A.B., Ikeda, T., Radchenko, V.I. and Wada, T. (Organizers) 1998. PICES Climate Change and Carrying Capacity Workshop on the Development of Cooperative Research in Coastal Regions of the North Pacific. **PICES Sci. Rep. No. 9**, 59 pp.

Freeland, H.J., Peterson, W.T. and Tyler, A. (Eds.) 1999. Proceedings of the 1998 Science Board Symposium on The Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and Its Marginal Seas. **PICES Sci. Rep. No. 10**, 110 pp.

Dugdale, R.C., Hay, D.E., McFarlane, G.A., Taft, B.A. and Yoo, S. (Eds.) 1999. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Summary of the 1998 MODEL, MONITOR and REX Workshops, and Task Team Reports. **PICES Sci. Rep. No. 11**, 88 pp.

Lobanov, V.B., Nagata, Y. and Riser, S.C. (Eds.) 1999. Proceedings of the Second PICES Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 12**, 203 pp.

Danchenkov, M.A., Aubrey, D.G. and Hong, G.H. 2000. Bibliography of the Oceanography of the Japan/East Sea. **PICES Sci. Rep. No. 13**, 99 pp.

Hunt, G.L. Jr., Kato, H. and McKinnell, S.M. (Eds.) 2000. Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean. **PICES Sci. Rep. No. 14**, 168 pp.

Megrey, B.A., Taft, B.A. and Peterson, W.T. (Eds.) 2000. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 1999 MONITOR and REX Workshops, and the 2000 MODEL Workshop on Lower Trophic Level Modelling. **PICES Sci. Rep. No. 15**, 148 pp.

Stehr, C.M. and Horiguchi, T. (Eds.) 2001. Environmental Assessment of Vancouver Harbour Data Report for the PICES MEQ Practical Workshop. **PICES Sci. Rep. No. 16**, 213 pp.

Megrey, B.A., Taft, B.A. and Peterson, W.T. (Eds.) 2001. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 2000 BASS, MODEL, MONITOR and REX Workshops, and the 2001 BASS/MODEL Workshop. **PICES Sci. Rep. No. 17**, 125 pp.

Alexander, V., Bychkov, A.S., Livingston, P. and McKinnell, S.M. (Eds.) 2001. Proceedings of the PICES/CoML/IPRC Workshop on "Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific". **PICES Sci. Rep. No. 18**, 210 pp.

Otto, R.S. and Jamieson, G.S. (Eds.) 2001. Commercially Important Crabs, Shrimps and Lobsters of the North Pacific Ocean. **PICES Sci. Rep. No. 19**, 79 pp.

Batchelder, H.P., McFarlane, G.A., Megrey, B.A., Mackas, D.L. and Peterson, W.T. (Eds.) 2002. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 2001 BASS/MODEL, MONITOR and REX Workshops, and the 2002 MODEL/REX Workshop. **PICES Sci. Rep. No. 20**, 176 pp.

Miller, C.B. (Ed.) 2002. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the PICES 2002 Volunteer Observing Ship Workshop. **PICES Sci. Rep. No. 21**, 38 pp.

Perry, R.I., Livingston, P. and Bychkov, A.S. (Eds.) 2002. PICES Science: The First Ten Years and a Look to the Future. **PICES Sci. Rep. No. 22**, 102 pp.

Taylor, F.J.R. and Trainer, V.L. (Eds.) 2002. Harmful Algal Blooms in the PICES Region of the North Pacific. **PICES Sci. Rep. No. 23**, 152 pp.

Feely, R.A. (Ed.) 2003. CO_2 in the North Pacific Ocean (Working Group 13 Final Report). **PICES Sci. Rep. No. 24**, 49 pp.

Aydin, K.Y., McFarlane, G.A., King, J.R. and Megrey, B.A. (Eds.) 2003. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: The BASS/MODEL Report on Trophic Models of the Subarctic Pacific Basin Ecosystems. **PICES Sci. Rep. No. 25**, 93 pp.

McKinnell, S.M. (Ed.) 2004. Proceedings of the Third Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 26**, 275 pp.

Kishi, M.J. (Ed.) 2004. Report of the MODEL Task Team Second Workshop to Develop a Marine Ecosystem Model of the North Pacific Ocean including Pelagic Fishes. **PICES Sci. Rep. No. 27**, 49 pp.

King, J.R. (Ed.) 2005. Report of the Study Group on the Fisheries and Ecosystem Responses to Recent Regime Shifts. **PICES Sci. Rep. No. 28**, 162 pp.

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Front cover figure

A sign posted in Puget Sound, Washington State, USA, by the Washington State Department of Health, warning of a ban on shellfish harvest due to high levels of paralytic shellfish toxins. These toxins have severe economic impacts on recreational, commercial and subsistence fisheries. Photo credit: Vera Trainer.