# Preface

As part of the Regional Seas Programme of the United Nations Environment Programme (UNEP), the Northwest Pacific Action Plan (NOWPAP) was adopted in September 1994 by the People's Republic of China, Japan, the Republic of Korea and the Russian Federation. There are four Regional Activity Centres (RACs) responsible for carrying out individual NOWPAP activities and projects approved by the Intergovernmental Meeting.

In 1999, the Special Monitoring and Coastal Environmental Assessment Regional Activity Centre (CEARAC) was established as a RAC. It is hosted by the Northwest Pacific Region Environmental Cooperation Center (NPEC), which was established in 1998 in Toyama, Japan, under the auspices of the Ministry of Environment in Japan. CEARAC is responsible for coordinating the regional assessment of the marine, coastal and associated freshwater environments and for developing tools for environmental planning and management based on these assessments. CEARAC has two working groups. Working Group 3 (WG3) is responsible for the monitoring and assessment of harmful algal blooms (HABs), and Working Group 4 (WG4) is responsible for the development of new monitoring tools using remote sensing techniques. In recent years, WG3 and WG4 have worked on a joint assessment of the eutrophication status of the NOWPAP region.

The 'Integrated Report on Harmful Algal Blooms for the NOWPAP Region' was first published in 2005 to provide information on the status of HABs in the region and to address issues identified by WG3.

Based on the suggestions in the Integrated Report, CEARAC developed the '*Cochlodinium* Home Page' (http://www.cearac-project.org/wg3/cochlo-entrance/), the 'HAB Reference Database' (http://www.cearac-project.org/HAB_Integrated_Website/database/index.html) and published the Booklet of 'Countermeasures against Harmful Algal Blooms'. In order to share information not only among the NOWPAP member states, but with other international organizations, CEARAC developed the common sheet through the 'HAB Case Study'. This common sheet was implemented over 2008 to 2009, in order to establish an effective and efficient method of sharing information.

Over the past five years, the HAB situation in the NOWPAP region has changed. Up to 5 years ago, blooms of *C. polykrikoides* occurred frequently and were a major issue in the region, particularly as they caused significant damage to fisheries. In the last few years, however, the number of *C. Polykrikoides* bloom has decreased, and other species, such as *Chattonella antiqua,* have caused greater damage. Macroalgal blooms have also become an issue in recent years.

Sharing the latest information on HABs in the region is useful for preventing and mitigating HAB damage. As such, CEARAC has begun to summarize its findings and updated the 'Integrated Report on Harmful Algal Blooms for the NOWPAP Region' based on the approval at the 8th NOWPAP CEARAC Focal Points Meeting (Toyama, Japan, 13-15 September 2010).

CEARAC expects this latest report to assist environmental managers and decision-makers to understand the current status of HABs in the region.

The CEARAC Secretariat would like to thank all of the CEARAC Focal Points and HAB Case Study Experts for their great contributions to this publication.

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## Preface

## Executive Summary

# Executive Summary

The NOWPAP region has faced serious problems due to the frequent occurrence of HABs. This is due to increased nutrient inputs from land associated with economic development, and an increase in agricultural production in surrounding countries. Even though the number of HABs has decreased in recent years, due to the establishment of sewage plants and appropriate treatment of discharged water, HABs occur every year in the region. HABs cause damage to aquaculture and fisheries that are highly active in the region and increasing in demand.

CEARAC conducted a case study in 2008 to collect information on monitoring structures and HAB occurrence in the NOWPAP member states. CEARAC also developed a common format for sharing information. The latest report shared amongst the NOWPAP member states was the ‘HAB Case Study Report’.

## Marine environment in the NOWPAP region (Chapter 1)

The NOWPAP sea area is semi-enclosed and surrounded by China, Japan, Korea and Russia. The area covers 121-143˚E longitude and 33-52˚N latitude, a total area of about 1,700,000 km$^2$. Within this area there are four major ocean currents: the Tsushima Warm Current; the East Korean Warm Current; the Yellow Sea Warm Current; and the Liman Cold Current. The southern part of the region belongs to the subtropical zone, whereas the northern part is in the subarctic zone and freezes over winter.

In 2010, the total population of the coastal areas within the NOWPAP member states grew to 580 million, making it one of most highly-populated areas in the world. Such growth has resulted in an increased load of various land-based pollutants in the marine environment via large and small rivers, and caused environmental deterioration in various coastal areas. As certain types of aquaculture, such as commercial fisheries, shellfisheries and seaweed farming, operate in coastal areas, large amounts of such pollutants have resulted in eutrophication and environmental deterioration on the sea floor in some areas.

## HAB monitoring in the NOWPAP member states (Chapter 2)

All of the NOWPAP member states have strengthened their systems of HAB surveillance, and all conduct regular red tide and shellfish toxin monitoring. The NOWPAP member states monitor red tides and toxin-producing plankton, as these species cause significant damage to fisheries. Each member state has introduced its own warning and action standards, requiring fisherman to be warned and to take certain action after the cell density of causative species reaches a specified level. These standards are based on empirical data, and aim to reduce the damage to fisheries and aquaculture.

The regular monitoring process involves the checking of certain marine environment indicators, such as the water temperature, salinity and nutrient concentrations. In addition to the regular monitoring process, post-red tide monitoring is conducted in China, Japan and Korea, with additional monitoring of *C. polykrikoides* in Korea. Local fishery agencies and other involved organizations are responsible for analysing and monitoring the data and identifying the relationship between red-tide occurrences and environmental conditions.

## HAB Occurrences in the NOWPAP region (Chapter 3)

Between 2006 and 2008, there were 10 red-tide events in China, 208 in Japan, 21 in Korea and 31 in Russia. It is difficult to compare these figures, due to the size difference in target areas, and the monitoring frequency of each member state. Japan, however, had the largest number of red-tide events, which have caused increasing damage to fisheries in recent years.

In 2010, the loss to Japanese fisheries reached 5 billion Japanese Yen (about USD60 million) due to blooms of *Chattonella antiqua* in the Ariake Sea, the Omura Bay and the Yatsushiro Sea. On the other hand, the number of red tides in Korea has approximately halved since 2005, from an average to 5 occurrences per year. Since 2009, there have been no *Cochlodinium* bloom occurrences, and so it appears that HAB occurrences in Korea have declined in recent years.

There are 62 causative species recorded in the NOWPAP region. *Heteroshigma akashiwo* has been reported in all member states, and while the characteristics of the species have not changed its distribution in the region has. In recent years, *C. polykrikoides* has moved northward in Japan and *Chaetoceros sp.* red tides have been reported in Russia.

All member states have reported causative species of shellfish toxins [6 paralytic shellfish poisonings (PSPs), 7 diarrhetic shellfish poisonings (DSPs) and 8 amnesic shellfish poisonings (ASPs)], but only PSPs and DSPs (PSPs in Japan and DSP in China) have been reported in the NOWPAP region.

## Challenging studies to cope with HABs (Chapter 4)

There are direct and indirect measures taken to reduce HAB damage to fisheries. Direct measures include the use of physical, chemical and biological controls against causative species, while indirect methods include the control and improvement of water quality. In 2007, NOWPAP CEARAC published the ‘Booklet of Countermeasures against Harmful Algal Blooms in the NOWPAP Region’. Various countermeasure methods have been implemented in the NOWPAP region and many are under research and/or development.

In addition to introducing countermeasures, forecasting and early detection are effective tools to help cope with HABs. In the NOWPAP region, remote sensing and molecular genetics techniques are being studied to improve forecasting and early detection. Monitoring the movement of high chlorophyll patches detected by remote sensing is useful in preventing fishery damage, by allowing fish cages to be moved in the aquaculture area. Techniques for detecting phytoplankton species using satellite images are now under development and are expected to reduce HAB damage. Early in situ detection of harmful species is important for preventing damage. Several new techniques using molecular biological approaches, such as Fluorescent In Situ Hybridization (FISH), real-time Polymerase Chain Reaction (PCR), and Loop-Mediated Isothermal Amplification (LAMP), are under development for targeting various HAB species. Damage to fisheries will be mitigated if harmful species can be easily detected and managed before proliferation.

# 1 Introduction

## 1.1 Past CEARAC's activities on HABs

To understand and assess the HAB situation in the NOWPAP region, experts from each member state prepared a National Report on HABs. CEARAC summarized the information from these reports and published the 'Integrated Report on Harmful Algal Blooms for the NOWPAP Region' in 2005. The integrated report summarized the HAB situation in the region, and suggested that CEARAC undertake the following activities:

1) To facilitate the study of *Cochlodinium*
2) To seek a collaborative approach for HAB monitoring
3) To establish a common understanding of HABs through the development of a database and information network
4) To help develop a policy on the control of land-based nutrient discharges
5) To cooperate with other international organizations involved in HAB study

Based on these suggestions, CEARAC has implemented a number of activities over the past few years.

*Cochlodinium polykrikoides* blooms have caused significant damage to fisheries and aquaculture in the NOWPAP region, and occur frequently in Japan and Korea. The biology of *C. polykrikoides* has been studied extensively by experts in Japan and Korea. To assist in sharing this information, CEARAC developed the '*Cochlodinium* Home Page' (http://www.cearac-project.org /wg3/cochlo-entrance/ index.htm) in 2005 with the cooperation of experts in the NOWPAP member states. CEARAC further prepared a *Cochlodinium* pamphlet in five languages (English, Chinese, Japanese, Korean and Russian) to allow fishermen, young scientists and stakeholders to gain a quick understanding of the issues.

There are basically two approaches to preventing or minimizing red-tide damage. One is to arrest red-tide blooms before they cause significant damage. In 2007, CEARAC published the 'Booklet of Countermeasures against Harmful Algal Blooms (HABs) in the NOWPAP Region', which outlines effective countermeasures that have been implemented in member states. Further research and development into HAB countermeasures is currently being undertaken.

The second approach to minimizing HAB damage is to improve water quality. Eutrophication is common in the NOWPAP region and is a cause of red tides. CEARAC began working on marine eutrophication in 2009, which involved the development of procedures for assessing eutrophication status, including the evaluation of land-based sources of nutrients in the NOWPAP region. Each NOWPAP member state implemented an evaluation of eutrophication status using these procedures between 2010 and 2011. The assessment results on eutrophication status will be used to improve the marine environment and countermeasures against HABs.

CEARAC established the 'HAB Integrated Website' (http://www.cearac-project.org/HAB_ Integrated_Website/) in 2009 to provide information on HABs to stakeholders and policy-makers. The website is available to both NOWPAP member states as well as other countries. On the website, past publications are downloadable, and various databases, such as reference papers and HAB occurrences, in the NOWPAP region are available.

To improve information sharing among NOWPAP member states, CEARAC implemented the 'HAB Case Study' in the 2008-2009 biennium in order to establish the most effective and laborsaving way to share information. Each member state selected target sea areas in which HABs occur frequently, and conducted regular monitoring (Table 1.1; Figure 1.1). Information on monitoring organization, monitoring parameters and HAB occurrences in these selected sea areas was collected and summarized in a national report. Based on this information, the common sheet for sharing information was developed. The latest information on the NOWPAP region is shared using the common sheet, which helps stakeholders gain an understanding of the HAB situation in the region.

HABs are a common environmental issue not only in the NOWPAP region, but also in the north Pacific and southeastern Pacific. In these regions, there are other international organizations that are involved in HAB issues, such as the Intergovernmental Oceanographic Commission (IOC)/IOC Sub-Commission for the Western Pacific (WESTPAC) and the North Pacific Marine Science Organization (PICES). Cooperating with valuable information is important for the conservation of the marine environment in the Pacific region. CEARAC's Secretariat has participated in meetings with other international organizations and attended the PICES HAB Section as an ex-officio member. CEARAC has attempted to strengthen its cooperation with other international organizations.

CEARAC has subsequently implemented most of the suggestions made in the HAB Integrated Report (2005) from 2006. It is important to continue to regularly share the latest information on HABs throughout member states. Five years have passed since the publication of the HAB Integrated Report, and recent information on HAB occurrence has been collected through the HAB Case Study. As such, CEARAC plans to update the HAB Integrated Report by adding the latest information, data and techniques for preventing damage caused by HABs.

The aims of this Integrated Report are to share the current HAB problems in the NOWPAP Region not only among NOWPAP member states, but also among other countries and international organizations. This report was updated by adding information collected through HAB Case Studies in each member state from 2008 to 2010.

**Table 1.1** Selected sea areas in each member state for the HAB Case Study

| | Selected Areas in the HAB Case Study |
|---|---|
| China | Coastal area of Qingdao region and Dalian region |
| Japan | Northwest sea area of Kyushu region and Ariake Sea |
| Korea | South coast of Korea |
| Russia | Amurskii Bay, Vostok Bay and Aniva Bay |

In Figure 1, the NOWPAP region is the area within the dashed lines, and the Case Study selected areas are shown in ovals. This integrated report shows the current HAB situation in the selected areas, which are significant areas of HABs for the NOWPAP member states.

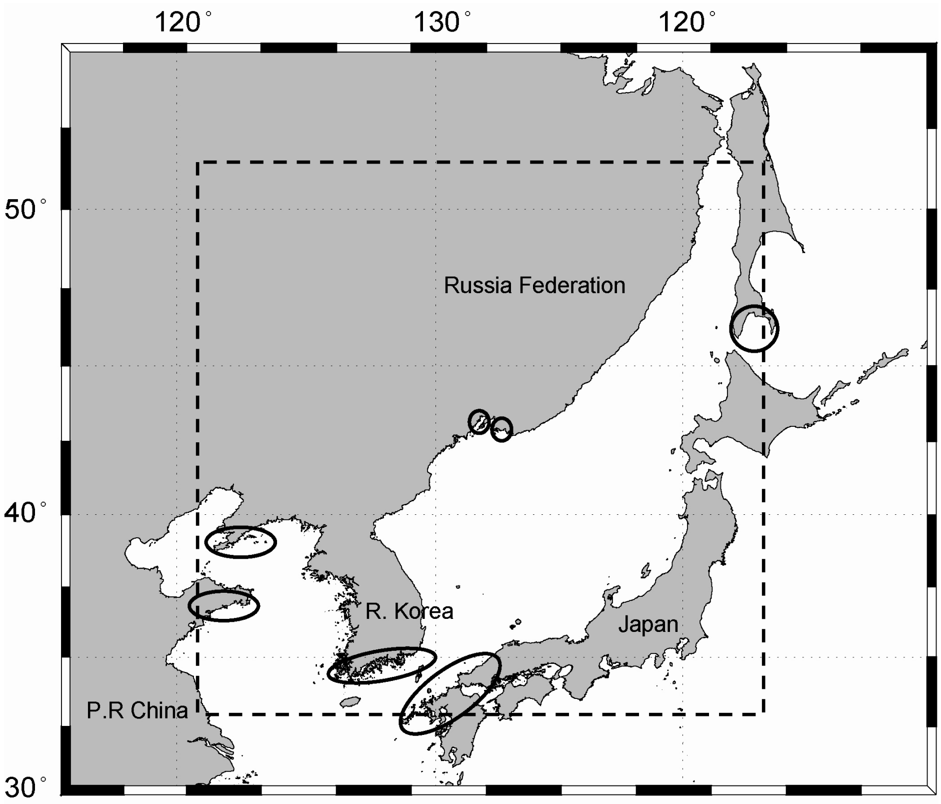


**Figure 1.1** Area of the NOWPAP region

The dashed line indicates the NOWPAP region, which covers approximately 121-143°E longitude and 33-52°N latitude without prejudice to the sovereignty of any state. Ovals indicate the HAB Case Study Area of each member state.

## 1.2 Definitions

Since each NOWPAP member has their own definition of a HAB, specific definitions were agreed upon in the first WG3 Meeting in Busan, Korea, in October 2003. The group agreed to use the scientific names of phytoplankton (referred to as plankton after the definitions below) species as used in National Reports.

HAB: A proliferation of unicellular phytoplankton that can cause massive fish or shellfish kills, contaminate seafood with toxins and alter aquatic ecosystems in ways that humans perceive as being harmful. There are two phenomena, the so called Red Tide and Toxin-producing Plankton.

Red Tide: Water discoloration by vastly increased numbers of unicellular phytoplankton that induce deterioration of aquatic ecosystems and occasionally fishery damage.

Toxin-producing Plankton: Phytoplankton species that produce toxins intracellularly and contaminate fish and shellfish throughout the food chain.

Scientific name of phytoplankton: In this report, the scientific names of phytoplankton are based on the HAB Case Study Report of each member state. However, if the name is different among NOWPAP member states, the latest scientific name will be used in this report. In addition, the scientific names of the following species have been changed. Previous names are in parenthesis:

*Karenia mikimotoi* (*Gymnodinium mikimotoi*)

*Akashiwo sanguinea* (*Gymnodinium sanguineum*)

*Mirionecta rubra* (*Mesodinium rubrum*)

## 1.3 Natural environment of the NOWPAP region

This section provides a brief overview on the natural environment in the NOWPAP region, focusing on the three major sea areas, major rivers and ocean currents. Figure 1.2 shows the geographic characteristics of the NOWPAP region.

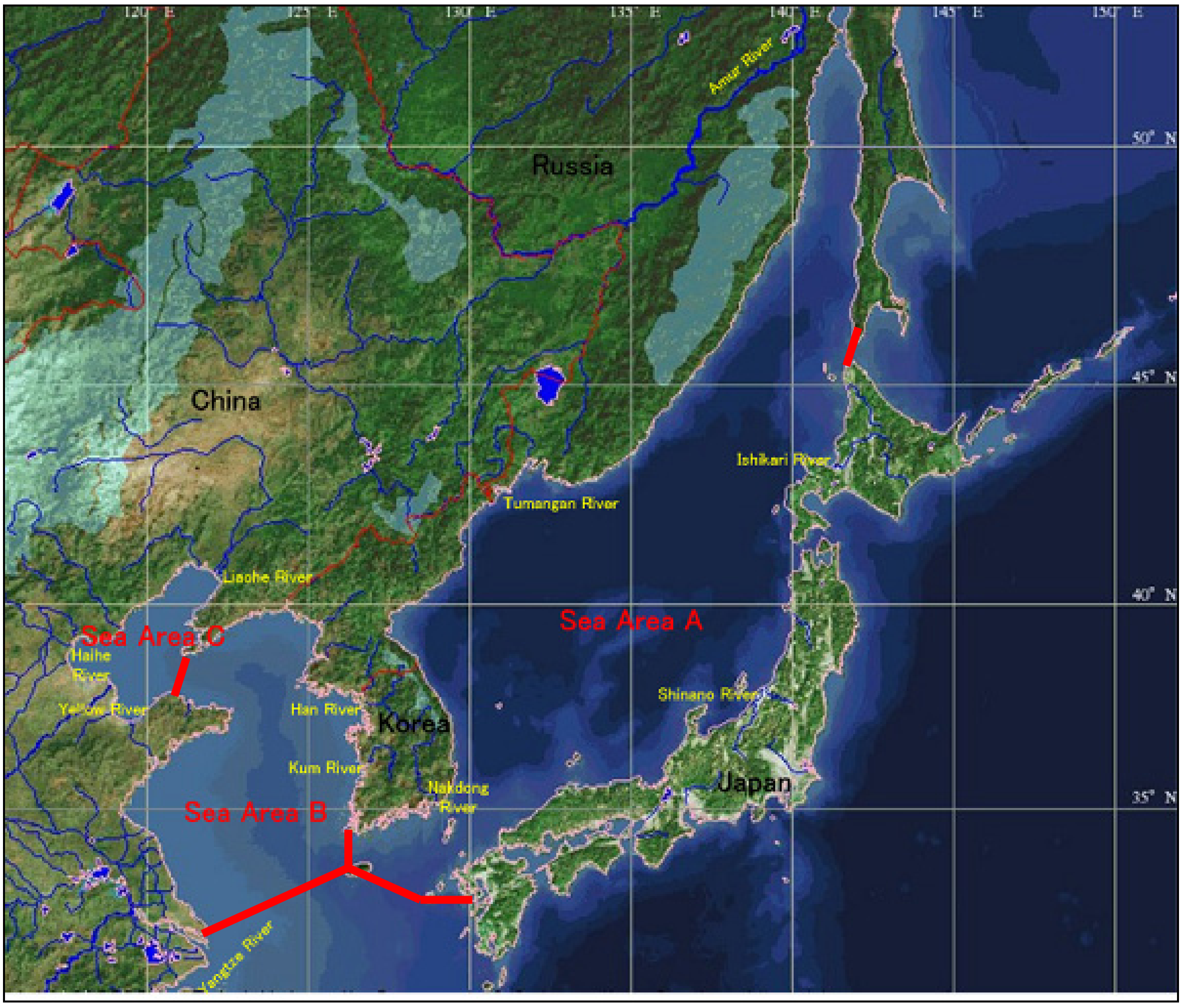


**Figure 1.2** Geographic characteristics of the NOWPAP region

### 1.3.1 Sea areas

As shown in Figure 1.2, sea areas A, B and C constitute the major part of the NOWPAP region's sea area. Table 1.2 provides basic information on each sea area.

**Table 1.2** Basic Information on the three sea areas in the NOWPAP region

| | Sea Area A | Sea Area B | Sea Area C |
|---|---|---|---|
| Surface area (km$^2$) | 1,300,000 | 400,000 | 7,284 |
| Volume (km$^3$) | 1,750,000 | 17,600 | 131 |
| Average depth (m) | 1,350 | 44 | 18 |
| Maximum depth (m) | 3,796 | 100 | 85 |

Source: EMECS (2003), Environmental Guidebook on the Enclosed Coastal Seas of the World.

Sea Area A is a semi-enclosed sea surrounded by Japan, the Korean Peninsula and Russia. It is connected to the open ocean through several straits. Sea Area A is the largest and deepest of the three sea areas.

Sea Area B is a semi-enclosed sea bounded by the Chinese mainland on the west, the Korean Peninsula on the east and the East China Sea on the south. The waters of Sea Area B are yellowish due to the large amount of yellow silt that discharges from the large Chinese rivers. The depth of Sea Area B is significantly shallower than that of Sea Area A, having an average depth of 44 m.

Sea Area C is the smallest and most enclosed. It is located to the northwest of Sea Area B, and these two sea areas are connected via a relatively wide strait. Sea Area C is shallower than Sea Area B, with an average depth of 18 m. Sea Area C functions as an offshore gateway to Beijing.

### 1.3.2 Rivers

Numerous large and small rivers flow into the three sea areas. Table 1.3 shows some of these major rivers.

**Table 1.3** Major rivers that flow into the three sea areas

| Sea Area | River | Country | Catchment area (km$^2$) | Flow rate (m$^3$/s) |
|---|---|---|---|---|
| A | Tumen | China, Russia | 33,800 | 287 |
| | Razdolnaya | Russia | 16,800 | 78 |
| | Nakdong | Korea | 23,817 | 794 |
| | Tumnin | Russia | 22,400 | 252 |
| | Ishikari | Japan | 14,330 | 400 |
| | Shinano | Japan | 11,900 | 518 |
| B | Yangtze | China | 1,807,199 | 29,000 |
| | Han | Korea | 26,018 | 1,171 |
| | Nakdong | Korea | 23,817 | 365 |
| | Kum | Korea | 9,810 | 841 |
| C | Yellow | China | 752,443 | 1,820 |
| | Haihe | China | 264.617 | 717 |
| | Liaohe | China | 164,104 | 302 |

Sources: Northwest Pacific Region Environmental Cooperation Center: NPEC (2003), The State of the Environment of the Northwest Pacific Region.
River Bureau, Ministry of Land, Infrastructure and Transport (2002), River Discharges Year Book of Japan.
Ministry of Construction and Transportation (1998), Discharge Annual Report in Korea.
Pollution Monitoring Regional Activity Centre: POMRAC (2009), Regional Overview on River and Direct Inputs of Contaminants into the Marine and Coastal Environment in NOWPAP Region with Special Focus on the Land Based Sources of Pollution.

Some rivers reach enormous lengths and widths due mainly to their large catchment areas. These rivers have a significant influence on the NOWPAP region's sea areas. Despite their relatively small surface area, sea areas B and C receive large amounts of inflow from some of the largest rivers in China, such as the Yangtze and Yellow rivers. In comparison to the sea areas above, the rivers in Sea Area A are not as large as those of the other sea areas, due to their relatively small catchment areas.

### 1.3.3 Major oceanographic currents in the NOWPAP region

Two strong currents exist in Sea Area A, the Tsushima Warm Current and the Liman Cold Current. The Tsushima Warm Current, a branch of the Kuroshio Current, enters Sea Area A from the strait between Japan and Korea and flows northeastward. The Liman Cold Current runs along the Eurasian Continent from north to south.

The Tsushima Warm Current diverges into three smaller branches upon entering Sea Area A. The first branch runs along the coastline of the Japanese archipelago, and the second runs along the Korean Peninsula and then turns and meanders eastward. The third cuts across the center of Sea Area A. Eventually, the major bodies of these currents flow into the Pacific Ocean or the Sea of Okhotsk through the straits between Hokkaido and Honshu, and Hokkaido and Sakhalin respectively. According to past records, the Tsushima Warm Current enters Sea Area A and exits into the Pacific Ocean approximately 2 months later. Some of the remaining current continues to travel northward, slowly cooling during its travel. Due to the shallowness of the strait between the Sakhalin and Russian mainland, part of this current turns around and heads south along the Eurasian Continent, becoming the Liman Current.

The Kuroshio Current also diverges into sea areas B and C as the Yellow Sea Warm Current. Figure 1.3 is a schematic of the oceanographic currents in the NOWPAP region.

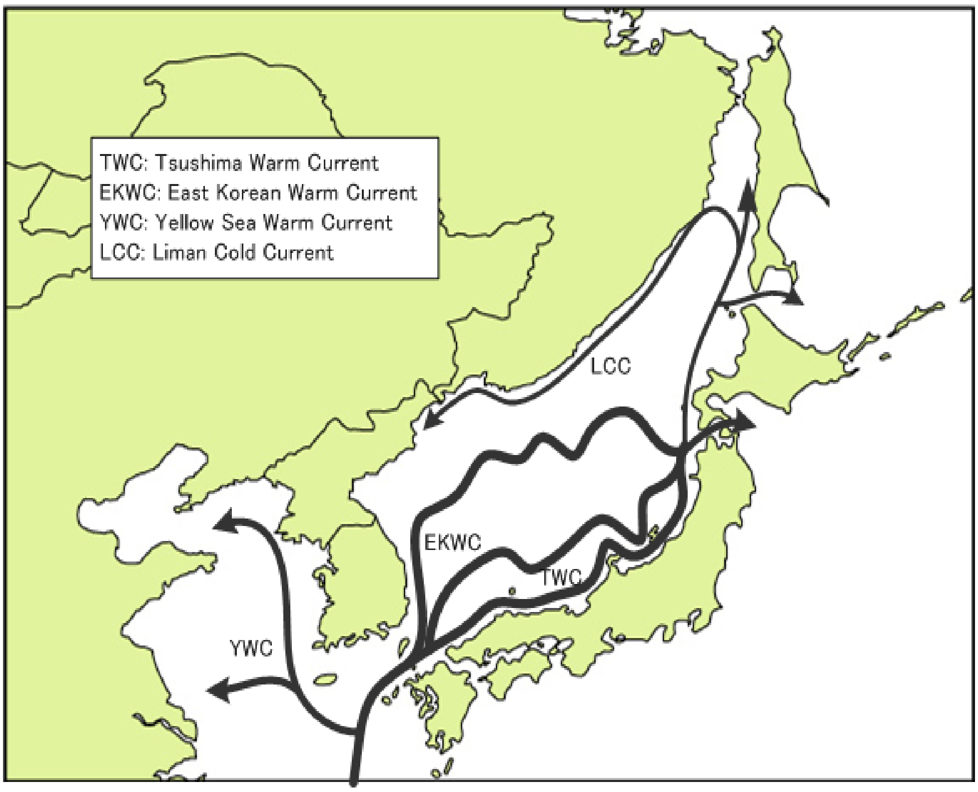


**Figure 1.3** Major oceanographic currents in the NOWPAP region

Source: Based on Yoon J.H. (1997), Bull. Jpn. Soc. Fish. Oceanogr., 61 (3): 300–303.

## 1.4 Impacts on the marine environment in the NOWPAP region

### 1.4.1 Population

The total population in the NOWPAP region's catchment areas was approximately 580 million in 2010. This is an increase of 20 million since 2003. About 85% of the population is in the Chinese region, with approximately 33 and 50 million people inhabiting the Japanese and Korean regions, respectively. Only 3.8 million people inhabit the Russian catchment area. The population density is highest in Korea, followed by China and Japan. The population density in Russia is about one and a half to two orders of magnitude less than that of other NOWPAP member states. Figure 1.4 shows the population size and density in the NOWPAP region's catchment areas.

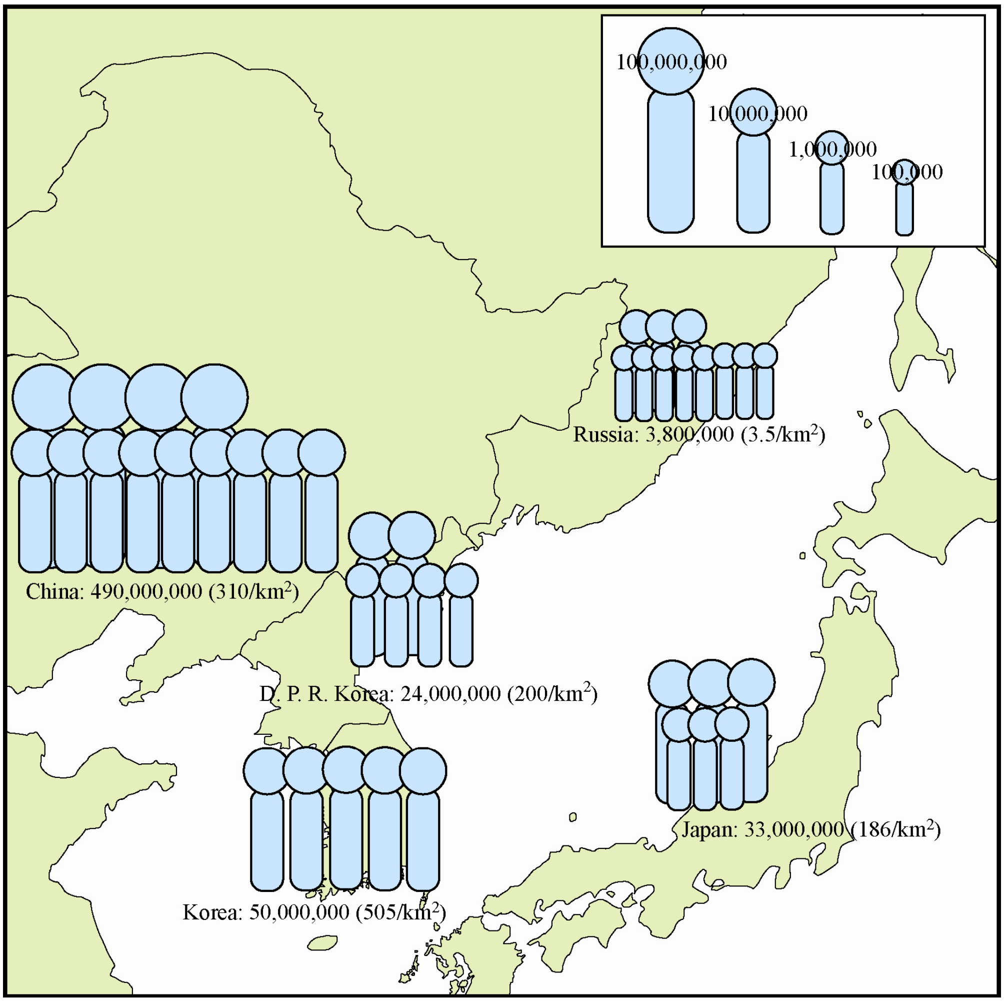


**Figure 1.4** Population size and density in the NOWPAP region's catchment areas

Source: China Population and Housing Census (2010), 2010 Population Census of Japan, 2010 Population Census, Statistics Korea (2010), Russian Census (2010)

The population of China is the sum of in those in Heilongjiang Province, Jilin Province, Liaoning Province, Hebei Province, Henan Province, Shandong Province, Shanxi Province, Jiangsu Province, Anhui Province, Beijing, Tianjin Province and Shanghai

The population of Japan is the sum of those in Hokkaido, Aomori Prefecture, Akita Prefecture, Yamagata Prefecture, Niigata Prefecture, Toyama Prefecture, Ishikawa Prefecture, Fukui Prefecture, Kyoto Prefecture, Hyogo Prefecture, Tottori Prefecture, Shimane Prefecture, Yamaguchi Prefecture, Fukuoka Prefecture and Saga Prefecture

The population of D.P.R. Korea and South Korea is the national population.

The population of Russia is the sum of those in Primorskii Krai, Khabarovsk Krai and Sakhalin Oblast

### 1.4.2 Nutrients inputs from land

Eutrophication caused by excessive inputs of nitrogen and phosphorus is primarily related to red-tide occurrences. In the NOWPAP region, rapid economic growth caused a eutrophic trend in some areas. The NOWPAP Pollution Monitoring Regional Activity Centre (POMRAC) published the ‘Regional Overview on River and Direct Inputs of Contaminants into the Marine and Coastal Environment in NOWPAP Region with Special Focus on the Land Based Sources of Pollution’ in 2009. This report showed that huge amounts of nutrients flow into the NOWPAP region. In some countries, discharge control is well managed, reducing nutrient inputs into the ocean. However, annual inputs from some rivers have increased the eutrophication situation in the NOWPAP region, which has not yet been remedied. Table 1.4 and Figure 1.5 show the annual discharge of nutrients into the NOWPAP member states in 2005.

**Table 1.4** Annual discharge of nutrients (tons/year) from major rivers in the NOWPAP member states in 2005

| | $NH_4$-N | T-N | T-P | $NH_4$ | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|
| China | 1,008,713 | - | - | - | - | - |
| Japan | - | 88,107 | 4,912 | - | - | - |
| Korea | - | 161,023 | 6,954 | - | - | - |
| Russia | - | - | - | 4,533 | 4,489 | 553 |

Source: POMRAC (2009), Regional Overview on River and Direct Inputs of Contaminants into the Marine and Coastal Environment in NOWPAP Region with Special Focus on the Land Based Sources of Pollution

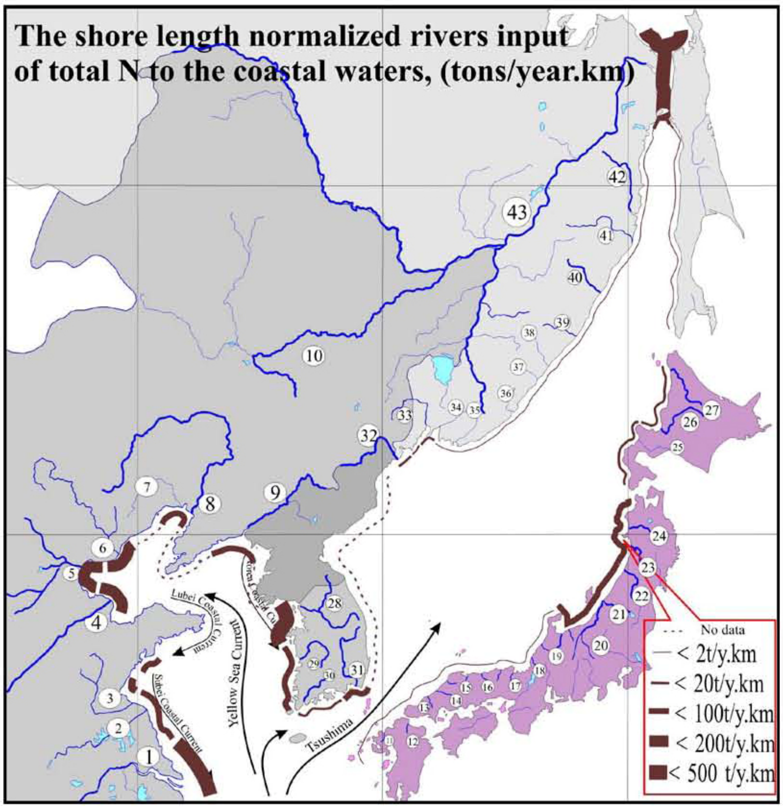


**Figure 1.5** The length of coastline normalized the river’s total nitrogen input (t/year/km)

Source: POMRAC (2009), Regional Overview on River and Direct Inputs of Contaminants into the Marine and Coastal Environment in NOWPAP Region with Special Focus on the Land Based Sources of Pollution

### 1.4.3 Aquaculture

Various types of aquaculture operate in the NOWPAP region, including cultivating fish, shellfish and seaweeds. Figure 1.6 shows the major aquaculture operating areas in the region. Aquaculture operates widely along the coasts of China, Japan and Korea. In Russia, aquaculture is limited to certain areas, but is expanding. Table 1.5 shows the types of aquaculture conducted in the NOWPAP region.

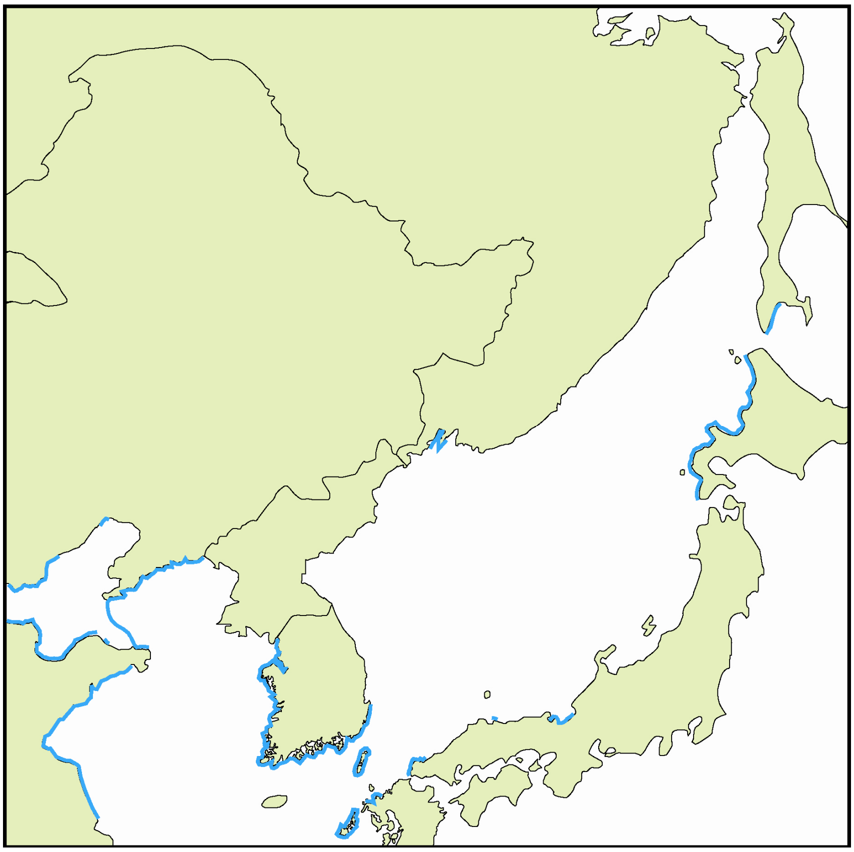


**Figure 1.6** Major aquaculture areas in the NOWPAP region

Sources: Yoon Y. H. (2001), Bull. Plankton Soc. Japan, 48 (2): 113–120.
Matsuoka K. (2004), Bull. Plankton Soc. Japan, 51 (1): 38–45.
Geological Institute, China Scientific Academy (1999); Chinese national atlas of natural resources.

**Table 1.5** Types of aquaculture conducted in the NOWPAP Region

| | Location | Type of aquaculture |
|---|---|---|
| China | Coast of Bohai Sea, Shandong Peninsula, Liaodong Peninsula | Tiger prawns, Scallop, Seaweeds, etc. |
| Japan | North coast of Kyushu | Amberjack, Red seabream, Yellowtail |
| | Wakasa Bay | Tiger puffer, Red seabream, Yellowtail, |
| | West coast of Hokkaido | Scallop |
| Korea | West and south coast | Bastard halibut, Amberjack, Rockfish |
| Russia | South coast of Sakhalin, Peter the Great Bay | Scallop, Seaweeds, Mussel, Cucumaria |

# 2 Information on HAB monitoring

## 2.1 Monitoring framework in the NOWPAP region

HAB monitoring in the NOWPAP member states is primarily conducted by fisheries research organizations and environmental monitoring centers, but various national institutes also provide valuable information. Korea has a particularly well established cooperative structure between national institutes and local government, where local government focuses on monitoring inshore while national institutes monitor inshore and offshore areas.

Table 2.1 summarizes HAB monitoring organizations in each member state. The location of monitoring sites in the target sea areas of HAB Case Studies are shown in Figure 1.1.

**Table 2.1** HAB monitoring organization in the NOWPAP member states

| | Monitoring Organization | Monitored sea area |
|---|---|---|
| China | North China Sea Environmental Monitoring Centre | Qingdao coastal area |
| | National Marine Environmental Monitoring Centre | Zhangzi Island off Dalian |
| Japan | Yamaguchi Prefectural Fisheries Research Center | Coastal area of Yamaguchi Pref. |
| | Fukuoka Fisheries and Marine Technology Research Center | Northern Kyushu<br>Fukuoka Bay, Karatsu Bay, Genkai Sea, Hibiki Sea, Ariake Sea |
| | Saga Prefectural Genkai Fisheries Promotion Center | Northern Kyushu<br>Karatsu Bay, Nagoyaura, Kariya Bay, Imari Bay |
| | Saga Prefectural Ariake Fisheries Promotion Center | Ariake Sea |
| | Nagasaki Prefectural Institute of Fisheries | Northern Kyushu<br>Imari Bay, Hirado<br>Western Kyushu<br>Ohmura Bay, Tachibana Bay, Coasts of Kitamatsu, Kujyukushima, Coast of Seihei, Ariake Sea |
| | Shimane Prefectural Fisheries Technology Center | Coastal area of Shimane Pref. |
| | Tottori Prefectural Fisheries Experimental Station | Coastal area of Tottori Pref. |
| | Hyogo Fisheries Technology Institute | Coastal area of Hyogo Pref. |
| | Kyoto Prefectural Agriculture, Forestry and Fisheries Technology Center, Fisheries Technology Department | Coastal area of Kyoto Pref. |
| | Fukui Prefectural Fisheries Experimental Station | Coastal area of Fukui Pref. |
| | Ishikawa Prefecture Fisheries Research Center | Coastal area of Ishikawa Pref. |
| | Toyama Prefectural Fisheries Research Institute | Coastal area of Toyama Pref. |
| | Niigata Prefectural Fisheries and Marine Research Institute | Coastal area of Niigata Pref. |

**Table 2.1** Continued

| Country | Monitoring organization | Monitored sea area |
|---|---|---|
| Korea | National Fisheries Research and Development Institute | South coast covering inshore and offshore |
| | - Southeast Sea Fisheries Research Institute | Southeastern area |
| | - Southwest Sea Fisheries Research Institute | Southwestern area |
| | Local government | South coast targeted on potential HAB areas in inshore |
| | - Fisheries station under Gyeongnam province:<br>Tonyeong (TFS), Sacheon (SFS), Goseong (GFS), Geoje (GEF), Namhae (NFS) | Southeastern area |
| | - Fisheries station under Jeonam province:<br>Wando (WFS), Yeosoo (YFS), Goheung (GFS), Jangheung (JFS), Kangjin (KFS) | Southwestern area |
| Russia | A.V. Zhirmunskii Institute of Marine Biology, FEB RAS (1991-2006)<br>Center of Monitoring of HABs & Biotoxins A.V. Zhimunskii Institute of Marine Biology, FEB RAS (2007-) | Amurskii Bay and Vostok Bay |
| | Sakhalin Research Institute of Fisheries & Oceanography | Aniva Bay |

### 2.1.1 Monitoring of HAB and monitoring parameters in the NOWPAP member states

All NOWPAP members have a regular red tide and toxin-producing plankton monitoring program to check for the presence of HAB species. Member states target and strengthen the monitoring of red-tide species which cause major damage to fisheries (Table 2.2). Furthermore, each member state has set warning and action standards in order to prevent damage by various species (Table 2.3). This standard varies from country to country and from region to region. However, if the cell number of target species in situ is observed over the warning level, monitoring organizations alert fishermen. Moreover, if target species make a bloom over the action standard level, monitoring organizations encourage countermeasures, such as feed withdrawal and the movement of fish cages.

Japan and Russia target toxin-producing plankton species to prevent shellfish toxin and damage to human health. All NOWPAP member states set warning and action standards for cell density of toxin-producing plankton, *Alexandrium* spp., *Gymnodinium catenatum*, *Dinophysis* spp. and *Pseudo-nitzschia* spp.

Due to such monitoring, damage to human health by shellfish poisoning has not been reported in recent years.

In addition to the above mentioned monitoring, China, Japan and Korea conduct post red-tide monitoring, and Korea conducts additional monitoring focusing on *Cochlodinium polykrikoides* blooms.

Information on regular red-tide monitoring, post red-tide monitoring and the monitoring of shellfish toxin is summarized as Tables 2.4, 2.5 and 2.6 respectively.

**Table 2.2** Target red-tide species and toxin-producing plankton species in monitoring programs

| | Target red-tide species | Target toxin-producing plankton species |
|---|---|---|
| China | *Mirionecta rubra*<br>*Noctiluca scintillans*<br>*Skeletonema costatum*<br>*Heterosigma akashiwo*<br>*Eucampia zodianus*<br>*Chaetoceros affinis*<br>*Chattonella marina* | |
| Japan | *Karenia mikimotoi*<br>*Cochlodinium polykrikoides*<br>*Heterocapsa circularisquama*<br>*Chattonella antiqua*<br>*Chattonella marina*<br>*H. akashiwo* | *Dinophysis fortii*<br>*Dinophysis acuminata*<br>*Dinophysis caudata*<br>*Gymnodinium catenatum*<br>*Alexandrium catenella*<br>*Alexandrium tamarense* |
| Korea | *Akashiwo sanguinea*<br>*C. polykrikoides*<br>*Prorocentrum dentatum*<br>*Prorocentrum minimum*<br>*Ceratium furca*<br>*H. akashiwo*<br>*Noctiluca scintillans* | |
| Russia | *Pseudo-nitzschia delicatissima*<br>*Pseudo-nitzschia multiseries*<br>*S. costatum*<br>*K. mikimotoi*<br>*N. scintillans*<br>*Dynobryon balticum*<br>*Chattonella* sp.<br>*H. akashiwo* | *Pseudo-nitzschia delicatissima*<br>*Pseudo-nitzschia fraudulenta*<br>*Pseudo-nitzschia multistriata*<br>*Pseudo-nitzschia muitiseries*<br>*Pseudo-nitzschia seriata/pungens*<br>*A. tamarense*<br>*D. acuminate*<br>*Dinophysis acuta*<br>*D. fortii*<br>*Dinophysis norvegica*<br>*Dinophysis rotundata*<br>*K. mikimotoi*<br>*Protoceratium reticulatum* |

**Table 2.3** Warning and action standards for each causative species

| Region | | Species name | Warning/action standards (cell/ml) | | Affected fish/shellfish |
|---|---|---|---|---|---|
| | | | Warning standard | Action standard | |
| China[*1] | | *M. rubra* | 500 | | |
| | | *N. scintillans* | 50 | | |
| | | *S. costatum* | 5,000 | | |
| | | *H. akashiwo* | 50,000 | | |
| | | *E. zodianus* | 100 | | |
| | | *C. marina* | 100 | | |
| | | *A. tamarense* | 1,000 | | |
| Japan | Yamaguchi Pref.[*2] | *K. mikimotoi* | 500 | 5,000 | |
| | | *H. akashiwo* | 5,000 | 50,000 | |
| | Fukuoka Pref. [*3] | *H. akashiwo* | - | 10,000 | |
| | Nagasaki Pref. [*4] | *C. antiqua* | 1 | 10 | Yellowtail, cockles etc. |
| | | *C. marina* | 1 | 10 | Yellowtail etc. |
| | | *K. mikimotoi* | 100 | 500 | Fish, Shellfish, crustaceans etc. |
| | | *C. polykrikoides* | 50 | 500 | Yellowtail, rea seabream, pufferfish, striped jack etc. |
| | | *H. akashiwo* | 1,000 | 10,000 | Yellowtail, grouper etc. |
| | | *H. circularisquama* | 10 | 50 | Shellfish (bivalves) |
| Korea[*5] | | *Chattonella* spp. | 2,500 | 5,000 | |
| | | *C. polykrikoides* | 300 | 1,000 | |
| | | *Gyrodinium* sp. | 500 | 2,000 | |
| | | *K. mikimotoi* | 1,000 | 3,000 | |
| | | Other dinoflagellates | 30,000 | 50,000 | |
| | | Diatoms | 50,000 | 100,000 | |
| | | Mixed blooms | 40,000 | 80,000 | |
| Russia[*6] | | *Pseudo-nitzschia calliantha* | 500 | | Shellfish |
| | | *Pseudo-nitzschia delicatissima* | 500 | | Shellfish |
| | | *Pseudo-nitzschia fraudulenta* | 500 | | Shellfish |
| | | *Pseudo-nitzschia multistriata* | 500 | | Shellfish |
| | | *Pseudo-nitzschia multiseries* | 500 | | Shellfish |
| | | *Pseudo-nitzschia seriata/pungens* | 500 | | Shellfish |
| | | *A. tamarense* | 0.5 | | Shellfish |
| | | *D. acuminata* | 0.5 | | Shellfish |
| | | *D. acuta* | 0.5 | | Shellfish |
| | | *D. fortii* | 0.5 | | Shellfish |
| | | *D. norvegica* | 0.5 | | Shellfish |
| | | *D. rotundata* | 0.5 | | Shellfish |
| | | *P. reticulatum* | 500 | | Shellfish |

Sources:[*1] Ocean and Fishery Administration of Shandong Province (2006), Annual Report of Marine Environment of Shandong Province
Ocean and Fishery Administration of Liaoning Province (2005-2009), Annual Report of Marine Environment of Liaoning Province
[*2] Yamaguchi Prefecture (http://www.pref.yamaguchi.lg.jp/cms/a16500/uminari-top.html)
[*3] Fukuoka Fisheries and Marine Technology Research Center (http://www.sea-net.pref.fukuoka.jp/)
[*4] Nagasaki Prefectural Institute of Fisheries (http://www.marinelabo.nagasaki.jp/news/gyorendayori/H13/1307no75akasio-tyui.pdf)
[*5] National Fisheries Research and Development Institute (http://portal.nfrdi.re.kr/redtide/index.jsp)
[*6] The Federal Legislative At SanPIN 2.3.2.2401-08

### 2.1.2 Monitoring of shellfish toxin

Monitoring of shellfish toxin is conducted in all of the NOWPAP member states in order to prevent the shipment and harvesting of contaminated shellfish by fishery research organizations.

All of the NOWPAP member states have quarantine limits for harvested shellfish. When the toxin level exceeds this limit, the shipping and harvesting of shellfish is stopped until the toxin level returns to an acceptable level. The standard value for preventing the shipment of shellfish is 80 µg (STX eq.)/100g of meat for PSP and 0.05 MU/g for DSP in China; 4 MU/g wet weight of meat for PSP and 0.05 MU/g wet weight of meat for DSP in Japan; 80 µg /100g of meat for PSP in Korea; 80 µg/100 g of saxitoxin (mollusks) for PSP and 0.16 mg/kg of okadaic acid (mollusks) for DSP and 20 mg/kg of domoic acid (mollusks) and 30 mg/kg of domoic acid (crab's internal) for ASP in Russia respectively. Some researchers have reported that 1 MU/g is equivalent to approximately 20 µg (STX eq.)/100g.

## 2.2 Common issues with monitoring activities in the NOWPAP region

Although HAB monitoring is conducted by all NOWPAP Members, there is some variation amongst members in monitoring methods and frequency. Such variation has resulted from differing HAB problems, and limited personnel, technology and finance in certain areas.

Local variations in monitoring schemes further confound HAB data comparisons within and between regions. This is particularly apparent in China and Japan. In Japan, for example, the method of HAB monitoring varies with each prefectural fishery laboratory. This variation occurs because fishery laboratories conduct HAB monitoring in accordance with indigenous species and their monitoring budget. As a result, a consistent nationwide methodology for HAB monitoring has not been established. Furthermore, monitoring could be stopped if prefectural fishery laboratories are unable to obtain finance for HAB monitoring.

**Table 2.4** Parameters and frequency of regular red-tide monitoring in the NOWPAP member states

| | | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Monitoring parameters | Bloom and its causative organisms | - Name of red-tide species | - Name of red-tide species<br>- Cell density<br>- Water color | - Name of red-tide species<br>- Cell density<br>- Water color | - Name of red-tide species<br>- Cell density<br>- Water color |
| | Water quality | - Transparency<br>- Nutrients<br>- Index on pH[*1], DO[*2], Nutrient quality[*3], HAB risk[*4],<br>(in Dalian coastal area) | - Water temperature<br>- Salinity<br>- DO<br>- pH<br>- COD<br>- Transparency<br>- Nutrients<br>- Chlorophyll *a* | - Water temperature<br>- Salinity<br>- DO<br>- Transparency<br>- Nutrients<br>- Chlorophyll *a* | - Water temperature<br>- Salinity<br>- Heavy metals |
| | Meteorology | - Weather<br>- Wind direction/speed | - Weather<br>- Coverage by cloud<br>- Wind direction/speed<br>- Precipitation<br>- Daylight time | No monitoring | - Weather<br>- Ice cover |
| | Others | No monitoring | Sediment quality | No monitoring | No monitoring |
| Monitoring frequency | | No information | Fukuoka Pref.: 1/month<br>Saga Pref.: 1/month (May-October)<br>Nagasaki Pref.: 1/month (June-October) | 9/year<br>(March-November) | 1991-1993<br>May-Dec (1-2/month)<br>1996-1998<br>Jan.-May (4/month)<br>1999-2000<br>May-Apr (2/month)<br>2004-2008<br>Oct-Dec (2/month) |

*1: pH index ($D_{pH}$): the pH value is classified as one of indices, 1, 3 or 5, which refer to a pH range from 7.5 to more than 9.5. The higher the pH value, the higher the grade.

*2: DO index ($D_{DO}$): the DO value is classified as one of indices, 1, 3 or 5, which refer to a DO range from 105 % to more than 110%. The higher the DO saturation, the higher the grade.

*3: Nutrient quality index ($D_U$): $D_U$ is determined by the dissolved inorganic nitrogen, dissolved inorganic phosphorus and COD concentrations. $D_U$ is classified as one of three indices, 1, 3 and 5. The higher the $D_{,}$, the higher grade.

*4: HAB risk index ($D_R$): $D_R$ is determined from the Chl-*a* concentration and biomass of the dominant species. Dominant species are classified into 5 types by length. Chl-a is classified into coincident grades as biomass. $D_R$ is drawn by putting Chl-a and biomass of dominant species together and classified according to grades. $D_R$ is classified into three grades initially, representing index value 1, 2-20 and 25, being low HAB risk, potential HAB risk and HAB occurrence respectively.

**Table 2.5** Parameters and frequency of post-red tide monitoring in the NOWPAP member states

| | | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Monitoring parameters | Bloom and its causative species | - Name of red-tide species<br>- Cell density<br>- Bloom area size | - Name of red-tide species<br>- Cell density<br>- Bloom area size<br>- Water color | - Name of red-tide species<br>- Cell density<br>- Bloom area size<br>- Water color | No monitoring |
| | Water quality | - Water temperature<br>- Salinity<br>- DO | - Water temperature<br>- Salinity<br>- DO | - Water temperature<br>- Salinity | No monitoring |
| | Meteorology | No monitoring | No monitoring | Weather<br>Coverage by cloud<br>Wind direction/speed | No monitoring |
| | Others | No monitoring | No monitoring | No monitoring | No monitoring |
| Monitoring frequency | | Immediately after water discoloration | Immediately after water discoloration | Immediately after water discoloration | No monitoring |

**Table 2.6** Parameters and frequency of regular monitoring of shellfish toxin in the NOWPAP member states

| | | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Monitoring parameters | Bloom and its causative species | - Name of toxin-producing plankton species | - Name of toxin-producing plankton species<br>- Cell density<br>- Water color | - Name of toxin-producing plankton species<br>- Cell density<br>- Water color | - Name of toxin-producing plankton species<br>- Cell density |
| | Water quality | No monitoring | - Water temperature<br>- Salinity<br>- DO<br>- pH<br>- Transparency<br>- Nutrients<br>- Chlorophyll *a* | - Water temperature<br>- Salinity<br>- DO | - Water temperature<br>- Salinity |
| | Meteorology | No monitoring | No monitoring | No monitoring | No monitoring |
| | Others | No monitoring | - Toxin levels in shellfish (MU/g) | - Toxin levels in shellfish | - Toxin levels in shellfish |
| Monitoring frequency | | No information | Toxin-producing plankton monitoring: 12-16/year<br>Toxin level monitoring: weekly during the period toxin levels exceed standard. Otherwise, biweekly and/or less in non-blooming season | 1/month<br>Every week, once toxin is detected (usually 30/year) | Since September 2008 3/year |

## 2.3 Monitoring framework in target sea areas of the HAB Case Study

In the ‘HAB Case Study’, each member state selected target sea areas where HABs frequently occur and where monitoring is regularly conducted. In these areas, organizations such as local fishery institutes conduct regular monitoring to better understand HAB occurrences, and to measure the situation of the marine environment.

The monitoring sites in the target sea areas of each member state are shown in Figures 2.1-2.5.

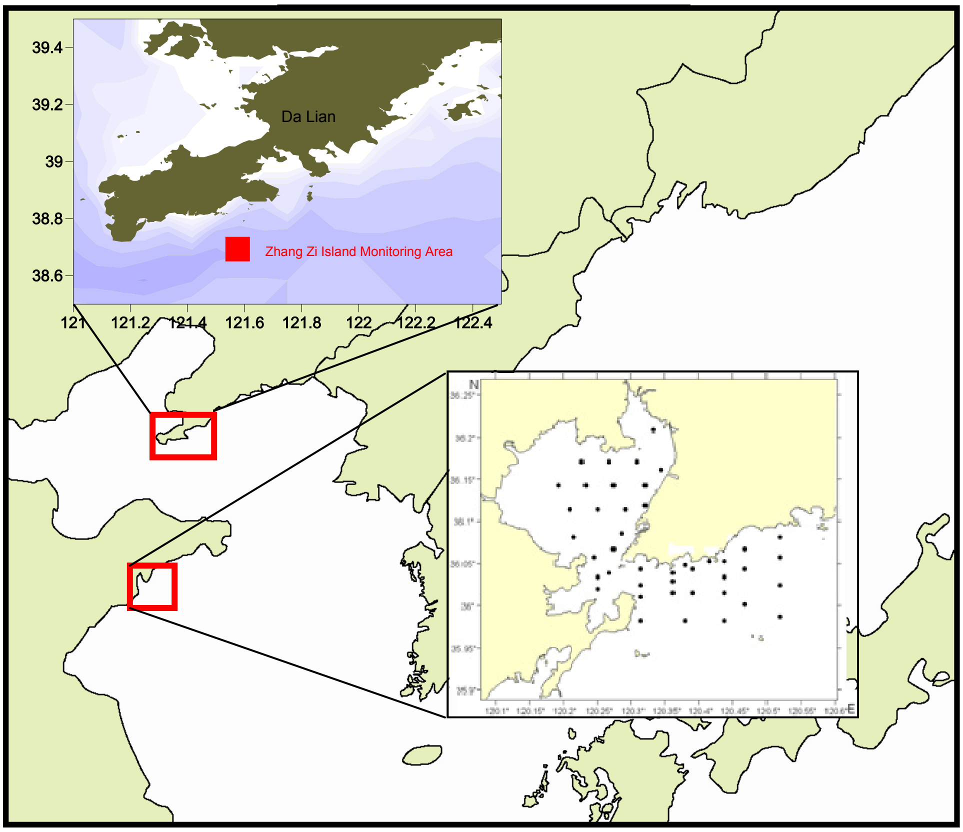


**Figure 2.1** Location of monitoring sites in China

The target sea areas of China are the coastal areas of Qingdao and Dalian. The Qingdao coastal area faces the North Yellow Sea and includes Jiaozhou Bay. With an average water depth of 7 m and a maximum depth of 64 m, most parts of Jiaozhou Bay are less than 5 m deep. The major rivers which discharge directly into Qingdao area are the Haipo, Moshui, Licun and Dagu. Dalian coastal area is located on the opposite side of the Shandong Peninsula and faces the North Yellow Sea and Bohai Sea. The average depth in this area is 18 m. The Biliu, Fuzhou, Zhuanghae, Yingna, Dasha, Shizui, Liauancun and Dengsha rivers flow into this area. In the Qingdao coastal area, the North China Sea Environmental Monitoring Centre conducts HAB monitoring at 43 monitoring sites. In the Dalian coastal area, the National Marine Environmental Monitoring Centre has conducted HAB monitoring around Zhangzi Island since 2003.

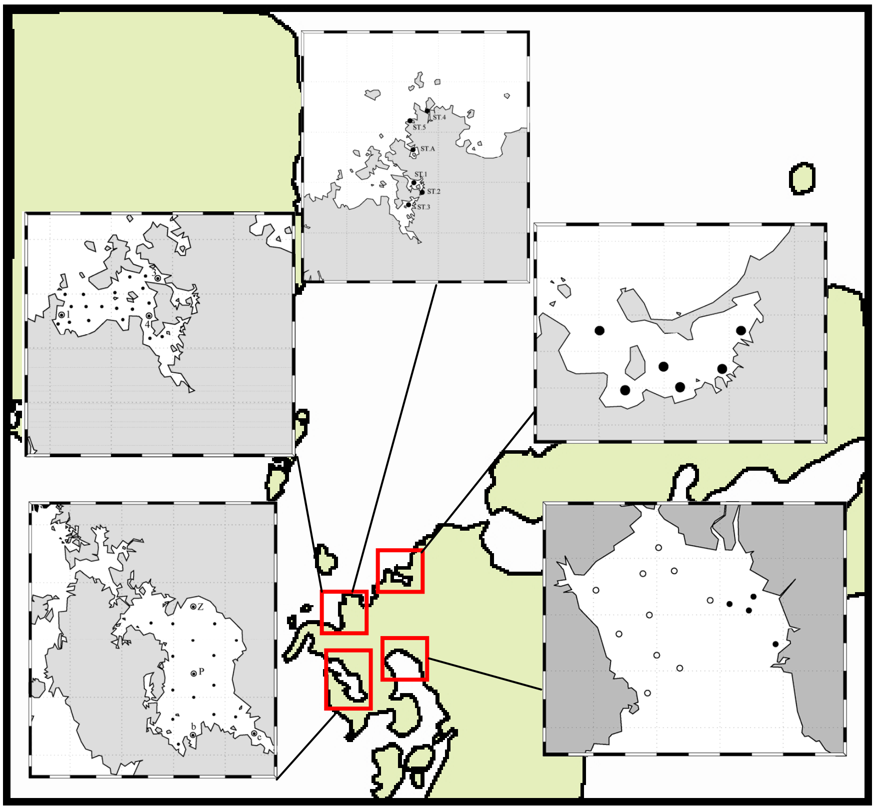


**Figure 2.2** Location of red-tide monitoring sites in Japan

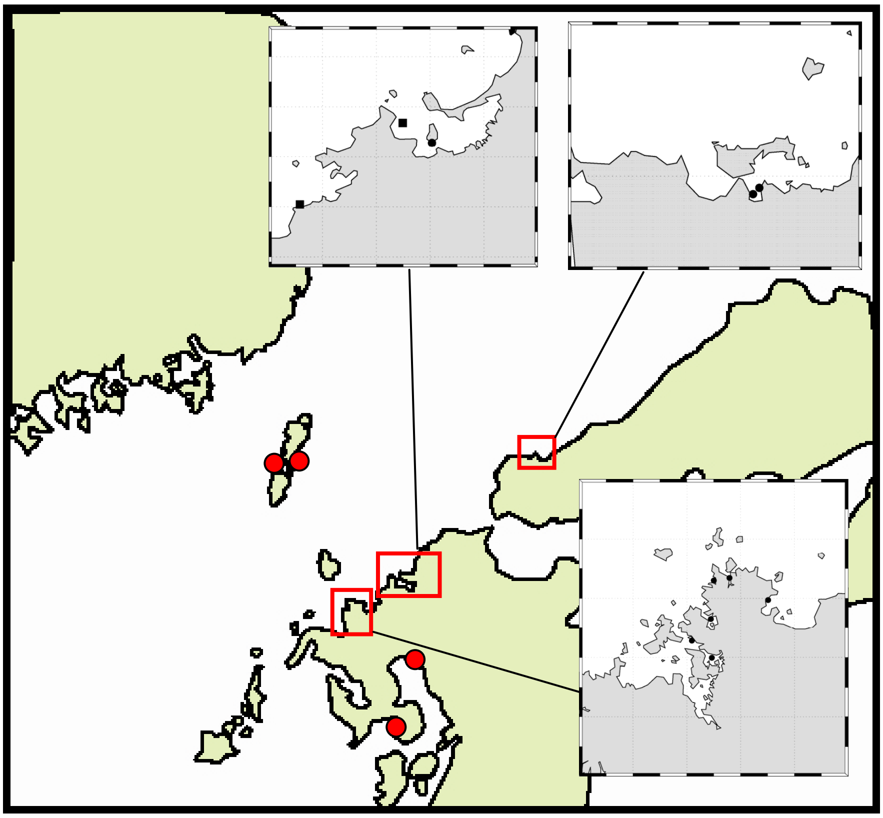


**Figure 2.3** Location of shellfish poisoning and toxin-producing plankton monitoring sites in Japan

The target sea areas of Japan are strongly influenced by the Tsushima Warm Current. The topography of the coastline is complex. In some areas, such as in the west Kyushu area, numerous small islands are scattered along the coast. There are also many remote islands, such as the Goto Islands, Tsushima and Iki. In this target sea area, four local fishery agencies conduct HAB monitoring. These are the Yamaguchi Prefectural Fisheries Research Center, the Fukuoka Fisheries and Marine Technology Research Center, the Saga Prefectural Genkai Fisheries Promotion Center and the Nagasaki Prefectural Institute of Fisheries. Fishery is a major industry in the coastal areas of this region, and many aquaculture farms operate along the calm inlets.

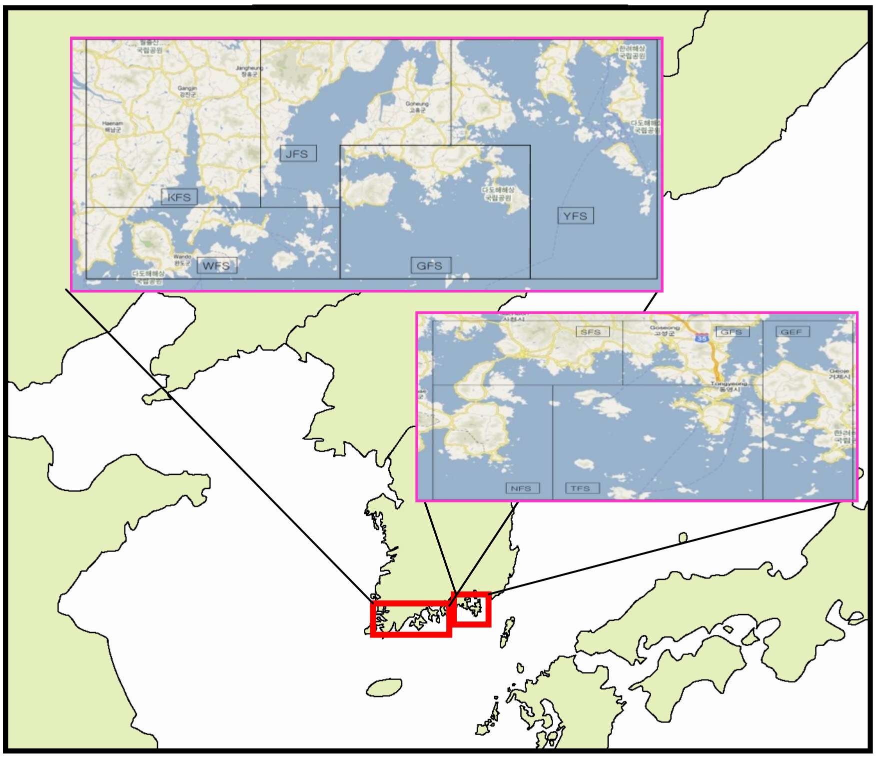


**Figure 2.4** Location of monitoring sites in Korea

The target sea areas of Korea are located in the eastern part of the South Sea, which face the East China Sea. Its southern part, facing offshore, is directly affected by the Tsushima Warm Current, and has a long irregular coast line resulting in relatively low waves during typhoons. Fisheries, including fish farming, are therefore well developed in this area. The target sea area neighboring Goseong-jaran Bay and Jinju Bay is an important culture ground for finfish, cage culture and shellfish bottom culture.

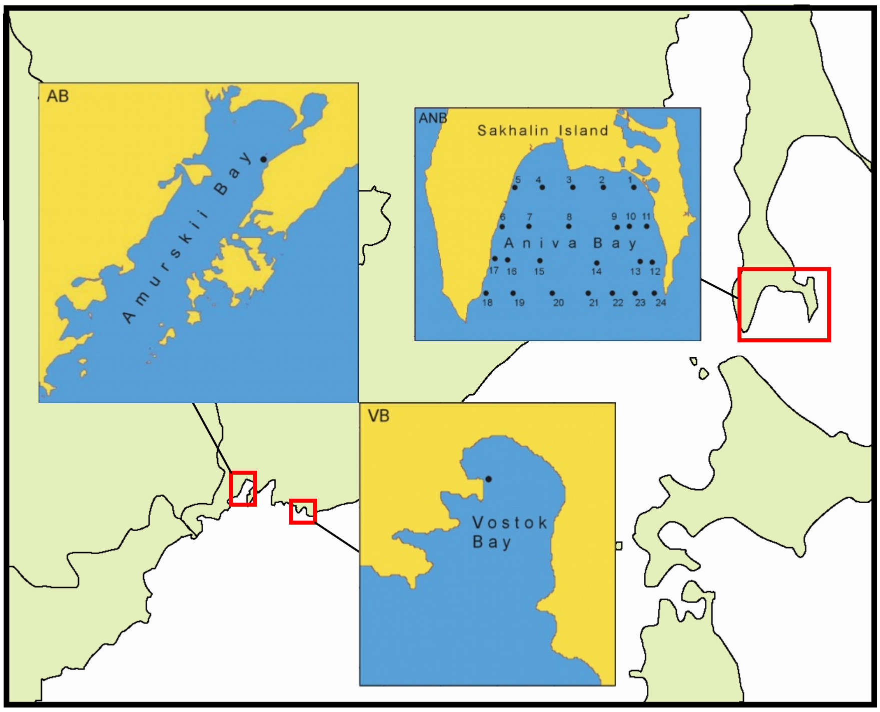


**Figure 2.5** Location of monitoring sites in Russia

The target sea areas in Russia cover the north part of Amurskii Bay, Vostok Bay and Aniva Bay. Amurskii Bay is the largest secondary bay within Peter the Great Bay in the northwestern part of the NOWPAP region. The Amurskii Bay is the most developed area in Primorkii Krai where the large cities of Vladivostok and Ussuriysk are located. Vostok Bay is a subarea of Peter the Great Bay. It has an increasing population and is one of the largest recreational zones in the Far East. Aniva Bay is one of the largest in Sakhalin Island, located in the south.

# 3 HAB occurrence in the NOWPAP region

The data on HAB occurrence in this report is based on the 'HAB Case Study Report' made by each member state from 2008 to 2010. The period of data shown in this report varies amongst member states, and is shown in Table 3.1. These differences are due to the year in which the reports on HAB occurrence in each member state were published.

**Table 3.1** Periods of HAB occurrence in the NOWPAP member states used in this report

| | Period |
|---|---|
| China | 1990 – 2009 |
| Japan | 2006 – 2008 (Northwestern sea area of Kyushu region), 2008 (Ariake Sea) |
| Korea | 2007 – 2009 |
| Russia | 1991 – 2010 (Amurskii Bay), 2001 – 2009 (Vostok Bay), 2001 – 2002 (Aniva Bay) |

## 3.1 Red-tide occurrences in the NOWPAP region

Table 3.2 summaries recent red-tide occurrences in the NOWPAP region based on the 'HAB Case Study Report' of the NOWPAP member states. Red-tide events have been continuously recorded along the coastal areas with annual and spatial variations. Intensive fishery and aquaculture areas tend to have recorded numerous red-tide occurrences. To date, about 100 red-tide producing plankton species have been recorded in the NOWPAP Region (Table 3.3). In Table 3.3, red-tide plankton species observed in recent years are shown in parentheses.

Two flagellate species, *Heterosigma akashiwo* and *Noctiluca scintillans*, and the one diatom species, *Skeletonema costatum*, have been recorded in the coastal waters of all NOWPAP members states. Both of these flagellate species have caused extensive damage to local fisheries. Other common and damage-causing species include *Karenia mikimotoi*, *Akashiwo sanguinea* and *Prorocentrum micans,* all being flagellates. *Cochlodinium polykrikoides* is a species which has caused serious damage to fisheries in Japan and Korea.

The extent of red tides within the NOWPAP region is usually limited to less than 100 km$^2$ in the Japanese, Korean and Russian waters. Blooms in the Chinese waters however, often extend over 100 km$^2$ (Table 3.2). A possible reason for the difference in records between China and other NOWPAP members could be their different data sources. In China, bloom size was largely identified through aerial survey, whereas the other NOWPAP members collected data primarily from sea vessels.

**Table 3.2** Summary of recent red-tide events in the NOWPAP region

| | China (Qingdao coastal area and Dalian coastal area) | Japan (Northwestern sea area of Kyushu region and Ariake Sea) | Korea (South coast of Korea) | Russia (Amurskii Bay, Vostok Bay and Aniva Bay) |
|---|---|---|---|---|
| Total number of events | 50 red-tide events from 1990–2009, of which 2 events led to fish-kills in the Dalian coastal area. | 278 red-tide events occurred during 2005-2008.<br>1407 red-tide events recorded from 1979-2008, in which 122 events caused fishery damage. | 194 red-tide events occurred during 1995-2009.<br>873 red-tide events recorded from 1995-2009, of which 209 events led to fish-kills over the whole Korean coast. | 41 red-tide events were recorded. All events were harmless and caused no damage. |
| Causative species | See Table 3.3 | See Table 3.3 | See Table 3.3 | See Table 3.3 |
| Cell density | *Heterosigma akashiwo* recorded the highest density at 95,400cells/ml. | The highest density is 173,000 cells/ml by multi-species red tide with *Heterocapsa rotundata* and *Amphidinium* sp. | In recent years, a low density of *Cochlodinium polykrikoides* bloom (below 5,600 cells/ml) was observed.<br>*Scrippsiella trochoidea* recorded the highest density at 15,000 cells/ml. | *Skeletonema costatum* recorded the highest density at 12,700 cells/ml in the Amurskii Bay. |
| Size of bloom | In the Qingdao coastal area, *Mirionecta rubra* formed the largest red tide at 450 km$^2$.<br>In Dalian, the largest red tide reached 827km$^2$, however the causative species is unknown. | In the Ariake Sea, *Mirionecta rubra* formed the largest red tide at 171 km$^2$.<br>The area of other red-tide events is less than 1km$^2$. | Large blooms (ca. 40-60 km$^2$) were primarily by *C. polykrikoides*. | There is no information on size of bloom. |
| Duration | Most red tides lasted less than 1 week. However, *Rhizosolenia delicatula* bloom lasted for 20 days in 2004. | A multi-species red tide consisting of *Asterionella kariana* and *Skeltonema costatum* lasted for one month. Most red-tide events ended within one week. | The duration of a *C. polykrikoides* bloom was 22-50 days. | The duration of *Prorocentrum triestinum* bloom was 76 days in the Amurskii Bay, however the duration of most of blooms were less than 1 week in Vostok Bay and Aniva Bay. |

**Table 3.3** Red-tide species recorded in the NOWPAP region

| Class | Genus and Species | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Bacillariophyceae | *Asterionella* sp. | | (✔) | | |
| | *Asterionellopsis glacialis* | | | | ✔ |
| | *Chaetoceros curvisetum* | | (✔) | | |
| | *Chaetoceros socialis* | (✔) ✔ | | | |
| | *Chaetoceros affinis* | | | | ✔ |
| | *Chaetoceros contortus* | | | | ✔ |
| | *Chaetoceros curvisetus* | | | | ✔ |
| | *Chaetoceros salsugineus* | | | | ✔ |
| | *Chaetoceros* sp. | ✔ | (✔) | (✔) | |
| | *Coscinodiscus asteromphalus* | (✔) ✔ | | | |
| | *Coscinodiscus gigas* | | | (✔) | |
| | *Coscinodiscus* sp. | | | (✔) | |
| | *Ditylum brightwellii* | | | | (✔) |
| | *Dactyliosolen fragilissimus* | | | | ✔ |
| | *Eucampia zodiacus* | (✔) ✔ | | (✔) | |
| | *Eucampia* sp. | | | (✔) | |
| | *Leptocylindrus danicus* | (✔) | (✔) ✔ | (✔) | |
| | *Leptocylindrus minimus* | | | | ✔ |
| | *Leptocylindrus* sp. | | (✔) | | |
| | *Navicula* sp. | (✔) | | (✔) | |
| | *Neodelphineis pelagica* | | (✔) | | |
| | *Nitzschia hybrid* f. *hyaline* | | | | ✔ |
| | *Nitzschia* sp. | | (✔) | | |
| | *Pseudo-nitzschia calliantha* | | | | (✔) ✔ |
| | *Pseudo-nitzschia multiseries* | | | | (✔) ✔ |
| | *Pseudo-nitzschia pseudodelicatissima* | | | | (✔) ✔ |
| | *Pseudo-nitzschia pungens*$^{*1}$ | | | (✔) ✔ | (✔) ✔ |
| | *Pseudo-nitzschia delicatissima* | | | | ✔ |
| | *Pseudo-nitzschia fraudulenta* | | | | ✔ |
| | *Pseudo-nitzschia multistriata* | | | | ✔ |
| | *Pseudo-nitzschia seriata* | | | | ✔ |
| | *Pseudo-nitzschia* sp. | | (✔) | | |
| | *Rhizosolenia delicatula* | ✔ | (✔) | | |
| | *Rhizosolenia fragilissima* | | | (✔) | |
| | *Rhizosolenia setigera* | | | (✔) | |
| | *Rhizosolenia* sp. | (✔) | (✔) ✔ | (✔) | |
| | *Skeletonema costatum* | (✔) ✔ | (✔) ✔ | (✔) ✔ | (✔) ✔ |
| | *Skeletonema* sp. | | ✔ | (✔) | |
| | *Thalassiosira decipiens* | | | (✔) | |
| | *Thalassiosira rotula* | | | (✔) | |
| | *Thalassiosira mala* | | | | ✔ |
| | *Thalassiosira nordenskioeldii* | | | | ✔ |
| | *Thalassiosira* sp. | ✔ | (✔) ✔ | (✔) | |
| | *Thalassionema nitzschioides* | | | | ✔ |
| Cyanophyceae | *Microcystis virdis* | | | (✔) | |

**Table 3.3** Continued

| Class | Genus and Species | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Dinophyceae | *Akashiwo sanguinea* | | | ✔ | |
| | *Alexandrium catenella* | (✔) ✔ | (✔) | | |
| | *Alexandrium fraterculus* | | (✔) | ✔ | |
| | *Alexandrium* sp. | | | (✔) | |
| | *Ceratium furca* | (✔) | (✔) ✔ | ✔ | |
| | *Ceratium fusus* | | (✔) | (✔) ✔ | |
| | *Ceratium* sp. | | | (✔) | |
| | *Cochlodinium polykrikoides* | | (✔) ✔ | (✔) ✔ | |
| | *Cochlodinium* sp. | | (✔) | | |
| | *Dinophysis ovata* | (✔) | | | |
| | *Exuviaella marina* | (✔) | | | |
| | *Gonyaulax spinifera* | (✔) ✔ | | | |
| | *Gonyaulax polygramma* | | | ✔ | |
| | *Gymnodinium instriatum* | | ✔ | | |
| | *Gymnodinium* sp. | | | (✔) | |
| | *Gyrodinium* sp. | (✔) | (✔) | | |
| | *Heterocapsa circularisquama* | | (✔) ✔ | | |
| | *Heterocapsa* sp. | ✔ | | (✔) | |
| | *Heterocapsa triquetra* | | | (✔) ✔ | |
| | *Heterocapsa rotundata* | | | | ✔ |
| | *Karenia mikimotoi* | (✔) | (✔) ✔ | (✔) | |
| | *Noctiluca scintillans*[*2] | (✔) ✔ | (✔) ✔ | (✔) ✔ | (✔) ✔ |
| | *Noctiluca* sp. | | ✔ | | |
| | *Oxyrrhis marina* | | | | (✔) |
| | *Prorocentrum balticum* | | (✔) | | |
| | *Prorocentrum dentatum* | | (✔) ✔ | (✔) ✔ | |
| | *Prorocentrum micans* | (✔) | (✔) | (✔) | |
| | *Prorocentrum minimum* | (✔) | (✔) ✔ | (✔) ✔ | (✔) ✔ |
| | *Prorocentrum sigmoides* | | (✔) ✔ | | |
| | *Prorocentrum triestinum* | | (✔) ✔ | (✔) ✔ | ✔ |
| | *Prorocentrum* sp. | | ✔ | (✔) ✔ | |
| | *Protoceratium reticulatum* | | | | ✔ |
| | *Scrippsiella trochoidea* | | | (✔) | |
| | *Scrippsiella* sp. | | ✔ | | |
| Raphidophyceae | *Chattonella antiqua* | (✔) ✔ | (✔) ✔ | | |
| | *Chattonella globosa* | | | | (✔) ✔ |
| | *Chattonella marina* | (✔) ✔ | (✔) | | |
| | *Chattonella* sp. | | | | ✔ |
| | *Fibrocapsa japonica* | | (✔) | | |
| | *Heterosigma akashiwo*[*3] | (✔) ✔ | (✔) ✔ | (✔) ✔ | (✔) ✔ |
| Chrysophyceae | *Dictyocha fibula* | | ✔ | (✔) | |
| | *Dinobryon balticum* | | | | ✔ |

**Table 3.3** Continued

| Class | Genus and species | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| Eugrenophyceae | *Eutreptia lanowii* | | | | (✔) |
| | *Eutreptiella gymnastica* | | (✔) | (✔) | (✔) |
| | *Eutreptiella* sp. | | | (✔) | |
| | *Euglena pascheri* | | | | ✔ |
| Haptophyceae | *Phaeocystis* sp. | (✔) | | | |
| Cryptophyceae | *Chroomonas marina* | | | (✔) | |
| | *Chroomonas salina* | | | (✔) | |
| | *Cryptomonas acuta* | | | (✔) | |
| | *Cryptomonas* sp. | | | (✔) | |
| | *Plagioselmis* sp. | | | | ✔ |
| Prasinophyceae | *Pyramimonas* sp. | | (✔) | | |
| Prumnesiophycidae | *Gephyrocapsa oceanica* | | ✔ | | |
| Ciliate | *Mirionecta rubra* | (✔) ✔ | (✔) ✔ | (✔) ✔ | |
| | *Tontonia* sp. | | (✔) | | |

The parentheses indicate the species reported in the last HAB Integrated Report.

*1: *Nitzschia pungens* is the synonym of *Pseudo-nitzschia pungens*. In this Report, *N. pungens* is referred to as *P. pungens.*

*2: *Noctiluca scintillans* is the sole species of the genus. Therefore, *Noctiluca* sp. is included in *N. scintillans*.

*3: Since 2000, the species considered to be part of *Gymnodinium* have been divided into several genera, based on the nature of the apical groove and biochemistry.

### 3.1.1 Red tides in China

In the North Yellow Sea, 50 red-tide events have been observed since 1990, with 42 of them in target sea areas. Fishery damage only resulted from two of these events.

Between 1990 and 2008, 29 red-tide events were recorded in the Qingdao coastal area (Table 3.4). The most frequently observed species were *Mirionecta rubra* and *Skeletonema costatum*.

In recent years, the area of red-tide occurrences has expanded. Jiaozhou Bay was a major area during the 1990's, while Fushan Bay has become a main area since the early 21st century. In the last 5-6 years, occurrences have spread from the western (Lingshan Bay) to the eastern (Shazikou Bay) parts of the Qingdao coastal area.

**Table 3.4** Recent red-tide events in the Qingdao coastal area

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 26 Jun, 1990 | Jiaozhou Bay | *M. rubra* | 2 $km^2$ |
| Apr, 1992 | Jiaozhou Bay | - | - |
| 12 May, 1992 | East Qingdao area | - | - |
| Aug, 1992 | Jiaozhou Bay | - | - |
| Aug, 1997 | Center of Jiaozhou Bay | *S. costatum* | - (small) |
| 3-8 Jul, 1998 | Northeast part of Jiaozhou Bay | *S. costatum* | 10 $km^2$ |
| 8-15 Jun, 1999 | Northeast part of Jiaozhou Bay | *Eucampia zodicacus* | - (small) |
| 23-24 Jul, 1999 | Jiaozhou Bay | *S. costatum* | 26 $km^2$ |
| 26 Jul, 1999 | Fushan Bay | *M. rubra* | 60 $km^2$ |
| 20-23 Jul, 2000 | Center of Jiaozhou Bay | *Noctiluca scintillans* | 92 $km^2$ |
| 4 Apr, 2001 | Fushan Bay | *N. scintillans* | - (small) |
| 11-12 Jun, 2001 | Jiaozhou Bay | *N. scintillans* | 5 $km^2$ |
| 7-13 Jul, 2001 | Mouth of Jiaozhou Bay | *M. rubra* | 9.8 $km^2$ |
| 28 Jun-2 Jul, 2002 | Fushan Bay | *M. rubra* | 60 $km^2$ |
| Jul, 2003 | Jiaozhou Bay | *Coscinodiscus asteromphalus* | 200 $km^2$ |
| 4-10 Jul, 2003 | Tuandao Bay, Huiquan Bay | *M. rubra* | 450 $km^2$ |
| Feb, 2004 | Northeast part of Jiaozhou Bay | *Guinaradia delicatula* | - (small) |
| 9-28 Feb, 2004 | East part of Jiaozhou Bay | *Rhizosolenia delicatula* | 70 $km^2$ |
| 22-25 Mar, 2004 | Northeast part of Jiaozhou Bay | *Thalassiosira nordenskoeldii* | 70 $km^2$ |
| Jul, 2004 | North part of Jiaozhou Bay | *C. asteromphalus* | - (small) |
| 10 Aug, 2004 | Fushan Bay | *M. rubra* | 50 $km^2$ |
| 12-17 Jun, 2005 | Lingshan Bay | *Heterosigma akashiwo* | 80 $km^2$ |
| Aug, 2006 | Fushan Bay | *M. rubra* | 5 $km^2$ |
| 7- 10 Jun, 2007 | Shazikou Bay | *H. akashiwo* | 70$km^2$ |
| 20-23 Aug, 2007 | Eastern coastal area | *S. costatum* | 15 $km^2$ |
| 25 -28 Sep, 2007 | Shazikou Bay | *Gonyaulax spinifera* | 8 $km^2$ |
| 28-29 Jun, 2008 | Jiaozhou Bay | *Heterocapsa* sp. | 5 $km^2$ |
| 7-8 Aug, 2008 | Southern coastal area | *Chattonella antiqua* | 86 $km^2$ |
| 26 Aug, 2008 | Fushan Bay | *N. scintillans* | 10 $km^2$ |

There have been 13 red-tide events in the Dalian coastal area since 1990 (Table 3.5). The dominant species in this area is *N. scintillans*. In Dalian, two bloom events were caused by toxin-producing plankton, *Exuviaella marina* and *Alexandrium catenella*.

Dalian Bay and surrounding areas was a main red tide affected area prior to 2000, and the

Zhuanghe area has become a heavily affected in recent years.

**Table 3.5** Recent red-tide events in Dalian coastal area

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 1990 | Changhai area | - | - |
| 11 Aug, 1993 | Dalian Bay | - | 40 km$^2$ |
| Jul, 1999 | Dalian Bay | *E. marina* | |
| 17-21 Jul, 1999 | Dalian Bay | *N. scintillans* | 100 km$^2$ |
| 2 Aug, 2000 | Zhuanghe area | - | 827 km$^2$ |
| 6 Sep, 2004 | Jinshatan | *Chattonella marina* | - |
| 25 Sep, 2004 | Jinshatan | *A. catenella* | - |
| 25 Jun, 2005 | Caotun area | *N. scintillans* | - |
| 26 Aug-3 Sep, 2005 | Zhuanghe area | *Chaetoceros affinis* | 16 km$^2$ |
| 29 Aug-2 Sep, 2005 | Zhuanghe area | *C. affinis* | 16 km$^2$ |
| 8 May, 2006 | Zhuanghe area | *N. scintillans* | 20 km$^2$ |
| 27 Feb, 2008 | Dalian Bay | *T. nordenskioeldii,*<br>*S. costatum* | 108 km$^2$ |
| Aug, 2008 | Xianghai Bay | *C. marina* | 5 km$^2$ |

The number of red-tide events has increased significantly in target sea areas over recent years. Figure 3.1 shows the yearly trend in red-tide events in these areas from 1990 to 2008. Since 1999, the number of red-tide events has increased dramatically. Eighty percent of red-tide events occurred between June and August in the Qingdao region and 75% occurred between July and September in Dalian. The locations of red-tide events in recent years are shown in Figures 3.2a and b.

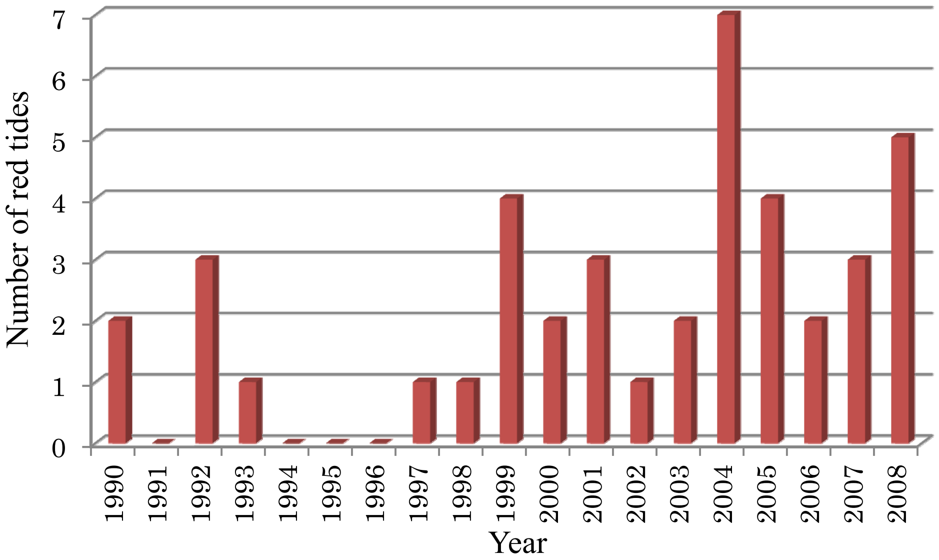
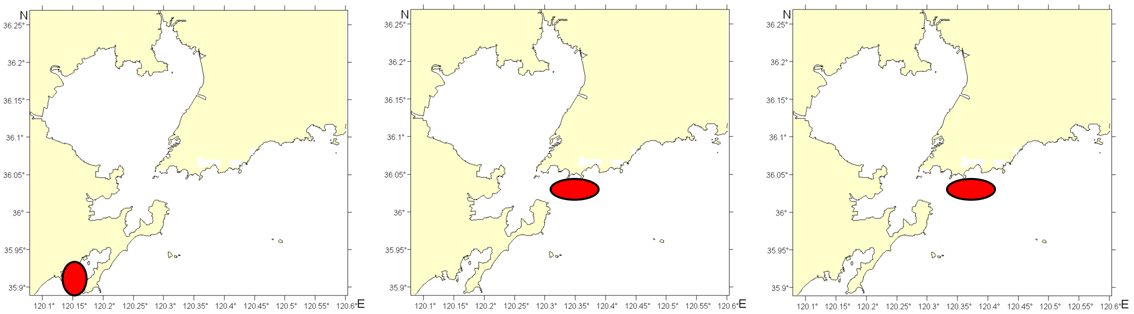
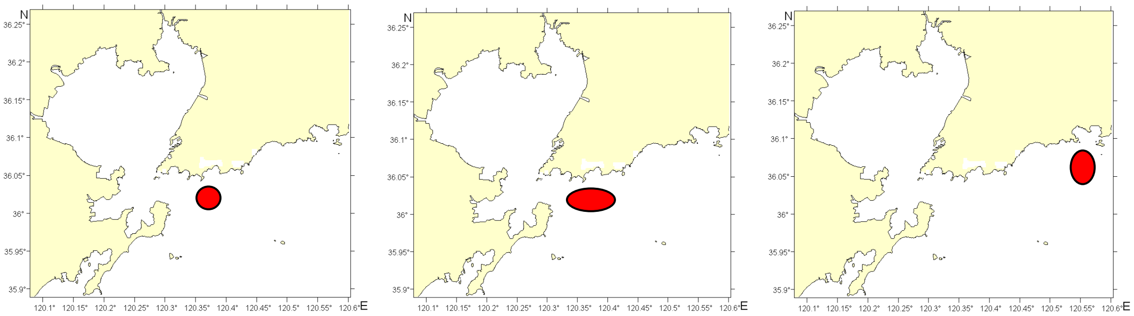


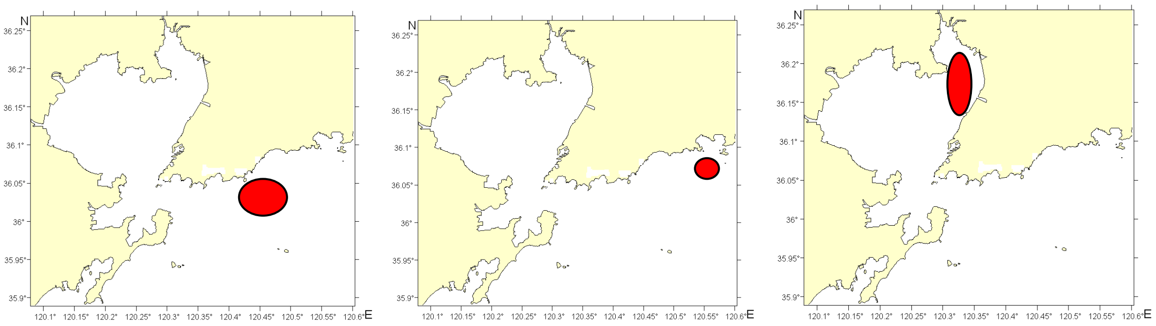
**Figure 3.1** Number of red-tide events in target sea areas in China



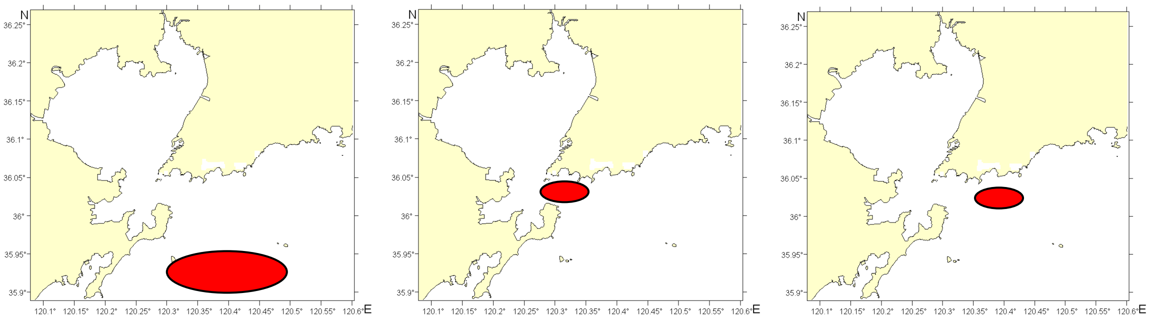
June, 2005 June, 2005 July, 2006



August, 2006 August, 2006 July, 2007

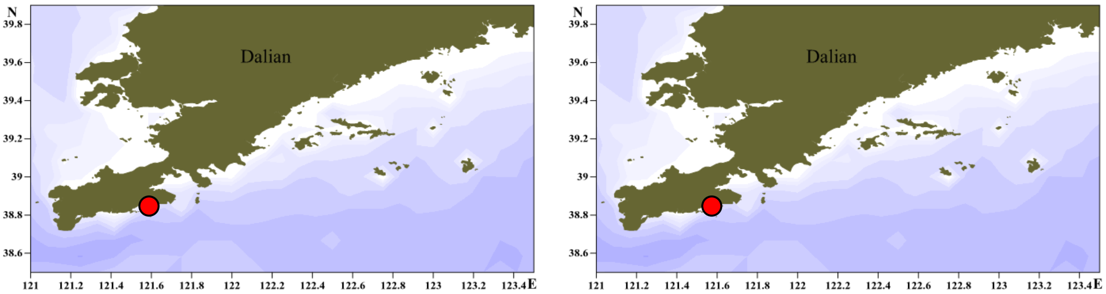


August, 2007 September, 2007 June, 2008

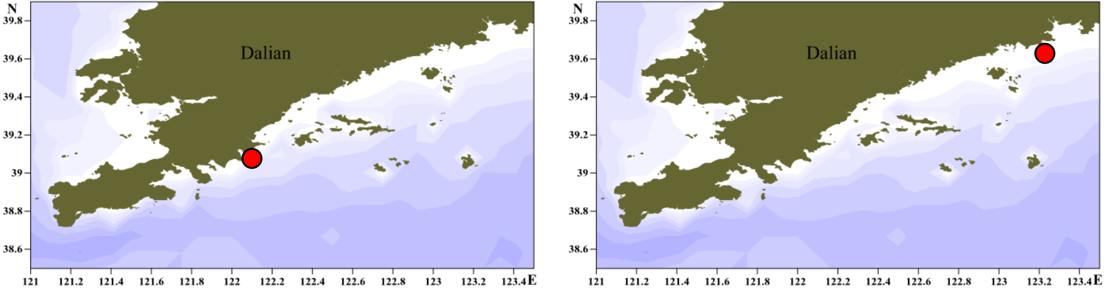


August, 2008 August, 2008 August, 2008

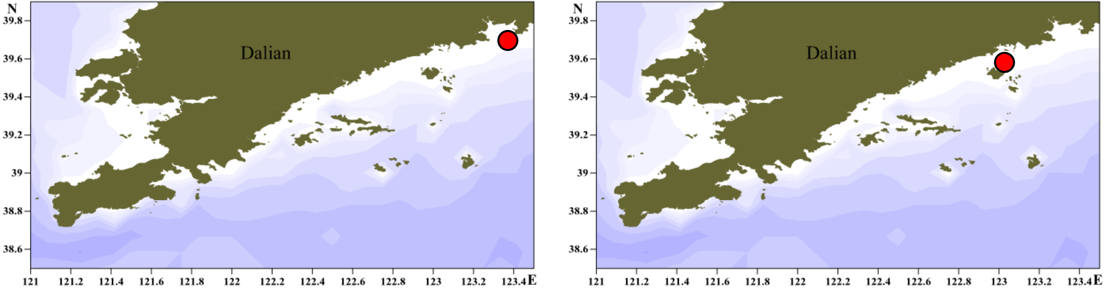
**Figure 3.2a** Locations of red-tide events in the Qingdao coastal area



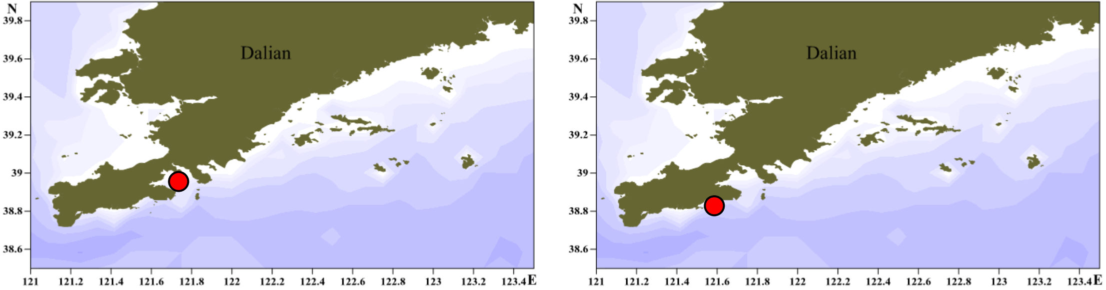
September, 2004 September, 2004



June, 2005 August, 2005



September, 2005 May, 2006



February, 2008 August, 2008

**Figure 3.2b** Locations of red-tide events in the Dalian coastal area

### 3.1.2 Red tides in Japan

There have been 1,407 red-tide events observed in the northwestern sea area of the Kyushu region since 1979. Of these events, 122 caused fishery damage. Figure 3.3 shows the number of red-tide events by year. The annual number of red-tide events has fluctuated between 29 and 92, and highest in 1980. From 2005 to 2008, 278 red-tide events occurred in Japanese target areas (Table 3.6), with 45% of these occurring in the Ariake Sea. Figure 3.4 shows the location of red-tide events in the northwestern sea area of Kyushu and in the Ariake Sea from 2006 to 2008, and Figures 3.5a-c show the location of red-tide events by month in 2006, 2007 and 2008, respectively.

In regards to species that are known to cause fishery damage, *Cochlodinium polykrikoides* was recorded 42 times, its frequency increasing over recent years. *Karenia mikimotoi* was recorded 157 times and has been recorded continuously from 1979 to 2008. *Heterocapsa circularisquama* was recorded 17 times, all after 1996. *Chattonella antiqua* was recorded 12 times, all after 1990. In 2008, fishery damage was small and economic loss was less than one million Japanese yen. In 2006 and 2007 however, fishery damage totaled over 15 million Japanese yen. In recent years, *K. mikimotoi* is a red-tide species that has caused extensive fishery damage.

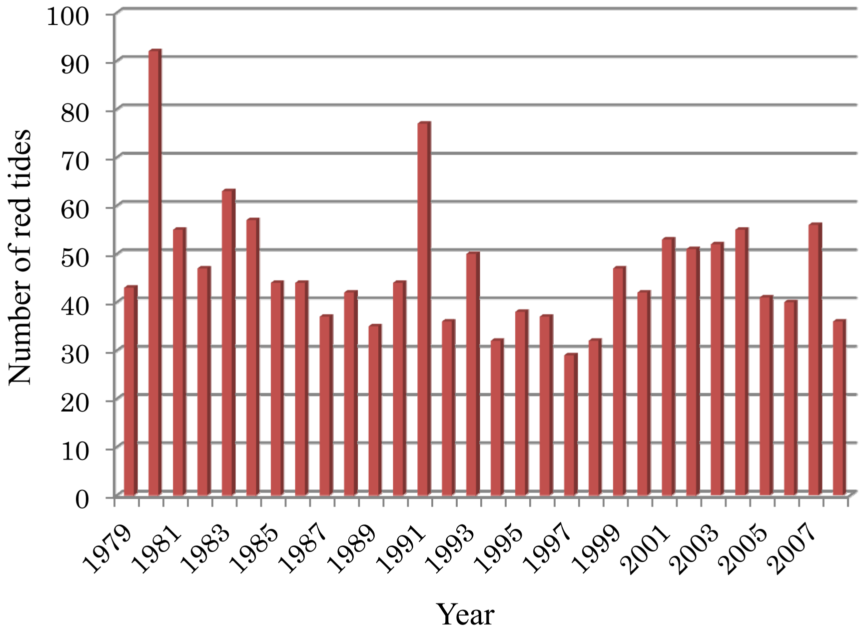


**Figure 3.3** Number of red-tide events in target sea areas in Japan

**Table 3.6** Recent red-tide events in the target sea area in Japan

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 20-27 Feb, 2006 | Coastal area of Yamaguchi | *Noctiluca scintillans* | |
| 24 Feb-15 Mar, 2006 | West Kyushu | *Cryptophyceae* | |
| 25-28 Feb, 2006 | Coastal area of Yamaguchi | *N. scintillans* | |
| 1-2 May, 2006 | West Kyushu | *Strombidium* sp. | 0.00005 km$^2$ |
| 27-29 Mar, 2006 | Coastal area of Yamaguchi | *N. scintillans* | 0.3 km$^2$ |
| 15-26 May, 2006 | Goto Islands | *Heterosigma akashiwo* | 0.005 km$^2$ |
| 16 May-29 Jun, 2006 | West Kyushu | *H. akashiwo* | |
| 1-3 Jun, 2006 | West Kyushu | *Prorocentrum* sp. | 0.0001 km$^2$ |
| 5-12 Jun, 2006 | North Kyushu | *N. scintillans* | |
| 21-27 Jun, 2006 | North Kyushu | *Prorocentrum triestinum* | |
| 29 Jun, 2006 | North Kyushu | *Skeltonema* sp.,<br>*Leptocylindrus* sp.,<br>*Chaetoceros* sp.,<br>*P. triestinum* | |
| 3-14 Jul, 2006 | West Kyushu | *K. mikimotoi* | |
| 4-12 Jul, 2006 | West Kyushu | *Ceratium furca* | 0.44 km$^2$ |
| 8-31 Jul, 2006 | West Kyushu | *K. mikimotoi* | |
| 9-11 Jul, 2006 | West Kyushu | *Mirionecta rubra* | |
| 11-31 Jul, 2006 | North Kyushu | *Skeletonema* sp.,<br>*Chaetoceros* sp. | |
| 13 Jul-4 Aug, 2006 | Coastal area of Yamaguchi | *K. mikimotoi* | 50 km$^2$ |
| 14-18 Jul, 2006 | West Kyushu | *Prorocentrum* spp. | 0.5 km$^2$ |
| 18-26 Jul, 2006 | North Kyushu | *K. mikimotoi* | |
| 20-22 Jul, 2006 | North Kyushu | *C. furca* | |
| 20-23 Jul, 2006 | North Kyushu | *M. rubra* | |
| 20-25 Jul, 2006 | West Kyushu | *K. mikimotoi* | |
| 20-25 Jul, 2006 | Tsushima Island | *C. polykrikoides* | |
| 21-23 Jul, 2006 | North Kyushu | *C. furca* | |
| 25 Jul-11 Aug, 2006 | North Kyushu | *K. mikimotoi* | |
| 26-30 Jul, 2006 | North Kyushu | *Nizchia* sp.<br>*Thalassiosira* sp. | |
| 27-30 Jul, 2006 | North Kyushu | *Skeletonema costatum* | |
| 2-11 Aug, 2006 | Coastal area of Yamaguchi | *K. mikimotoi* | |
| 21-25 Aug, 2006 | North Kyushu | *Thalassiosira* sp.<br>*S. costatum* | |
| 21-25 Aug, 2006 | West Kyushu | *Prorocentrum minimum* | |
| 22-23 Aug, 2006 | North Kyushu | *Thalassiosira* sp. | |
| 6-21 Sep, 2006 | West Kyushu | *H. akashiwo* | |
| 22-26 Sep, 2006 | North Kyushu | Diatoms | |
| 11-13 Oct, 2006 | North Kyushu | *C. polykrikoides* | 0.25 km$^2$ |
| 16-19 Oct, 2006 | Coastal area of Yamaguchi | *M. rubra* | 0.0001 km$^2$ |
| 26 Oct-6 Nov, 2006 | West Kyushu | *Prorocentrum sigmoides* | 5.3 km$^2$ |
| 30 Oct-7 Dec, 2006 | North Kyushu | *P. sigmoides* | 2.1 km$^2$ |
| 1-3 Nov, 2006 | Tsushima Island | *M. rubra* | |

**Table 3.6** Continued

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 20-22 Nov, 2006 | North Kyushu | *P. triestinum* | |
| 27-28 Nov, 2006 | North Kyushu | *P. triestinum* | |
| 16-18 Jan, 2007 | Tsushima Island | *Scrippsiella* sp. | |
| 6-9 Feb, 2007 | Coastal area of Yamaguchi | *N. scintillans* | |
| 9-19 Feb, 2007 | Coastal area of Yamaguchi | *N. scintillans* | |
| 8 Mar-9 May, 2007 | North Kyushu | *Gephyrocapsa oceanic* | |
| 23-30 Mar, 2007 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 23 Mar-2 Apr, 2007 | Goto Islands | *N. scintillans* | 0.0005 $km^2$ |
| 26-30 Mar, 2007 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 9-12 Apr, 2007 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 19-24 Apr, 2007 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 23-30 May, 2007 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 25-29 May, 2007 | Tsushima Island | *H. akashiwo* | |
| 5-6 Jun, 2007 | Tsushima Island | *N. scintillans* | |
| 7-12 Jun, 2007 | North Kyushu | *H. akashiwo* | |
| 14-16 Jun, 2007 | Tsushima Island | *C. furca* | |
| 14 Jun-5 Jul, 2007 | West Kyushu | *K. mikimotoi* | |
| 19 Jun-9 Jul, 2007 | West Kyushu | *K. mikimotoi* | |
| 22-27 Jun, 2007 | North Kyushu | *S. costatum* | |
| 24-29 Jun, 2007 | Goto Islands | *C. furca* | 0.005 $km^2$ |
| 24 Jun-7 Jul, 2007 | Goto Islands | *C. furca* | 0.02 $km^2$ |
| 25-27 Jun, 2007 | Goto Islands | *C. furca* | 0.01 $km^2$ |
| 27-29 Jun, 2007 | Goto Islands | *P. triestinum* | 0.25 $km^2$ |
| 2-5 Jul, 2007 | West Kyushu | *K. mikimotoi* | |
| 6-9 Jul, 2007 | North Kyushu | *H. akashiwo* | |
| 7-9 Jul, 2007 | Tsushima Island | *C. furca* | |
| 9-16 Jul, 2007 | North Kyushu | *S. costatum*<br>*P. triestinum*<br>*H. akashiwo* | |
| 11-23 Jul, 2007 | North Kyushu | *K. mikimotoi*<br>*C. polykrikoides* | |
| 27-29 Jul, 2007 | North Kyushu | *N. scintillans* | |
| 1-2 Aug, 2007 | North Kyushu | *N. scintillans* | |
| 6-16 Aug, 2007 | North Kyushu | *Chaetoceros* sp.<br>*P. triestinum* | |
| 22-27 Aug, 2007 | West Kyushu | *Skeletonema* sp. | |
| 23-24 Aug, 2007 | North Kyushu | *M. rubra* | |
| 23-28 Aug, 2007 | North Kyushu | *Chaetoceros* sp.<br>*K. mikimotoi* | |
| 24-25 Aug, 2007 | West Kyushu | *P. triestinum* | |
| 28 Aug-3 Sep, 2007 | West Kyushu | *K. mikimotoi* | |
| 6-12 Sep, 2007 | West Kyushu | *K. mikimotoi* | |
| 6-11 Sep, 2007 | Tsushima Island | *Dictyocha fibula* | |
| 11-13 Sep, 2007 | West Kyushu | *Gyrodinium instriatum* | |

**Table 3.6** Continued

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 12-18 Sep, 2007 | North Kyushu | *Leptocykindrus* sp.<br>*Chaetoceros* sp.<br>*Skeletonema* sp. | |
| 16-28 Sep, 2007 | West Kyushu | *P. sigmoides* | |
| 20-25 Sep, 2007 | North Kyushu | *Skeletonema* sp.<br>*Thalassiosira* sp.<br>*Chaetoceros* sp. | |
| 3-5 Oct, 2007 | West Kyushu | *P. sigmoides* | |
| 15-16 Nov, 2007 | North Kyushu | *C. polykrikoides* | |
| 19-29 Nov, 2007 | Goto Islands | *M. rubra* | |
| 21 Nov, 2007 | Tsushima Island | *M. rubra* | |
| 26-27 Nov, 2007 | Goto Islands | *M. rubra* | |
| 29-30 Nov, 2007 | Goto Islands | *M. rubra* | |
| 29 Nov-6 Dec, 2007 | Coastal area of Yamaguchi | *M. rubra* | 0.0001 km$^2$ |
| 1-5 Dec, 2007 | Goto Islands | *M. rubra* | |
| 5-23 Dec, 2007 | North Kyushu | *M. rubra* | |
| 7-19 Dec, 2007 | Coastal area of Yamaguchi | *M. rubra* | 0.04 km$^2$ |
| 10-11 Dec, 2007 | Goto Islands | *M. rubra* | |
| 11-12 Dec, 2007 | West Kyushu | *M. rubra* | |
| 12-13 Dec, 2007 | West Kyushu | *M. rubra* | |
| 12-14 Dec, 2007 | Coastal area of Yamaguchi | *M. rubra* | 0.02 km$^2$ |
| 12-19 Dec, 2007 | Goto Islands | *M. rubra* | |
| 21-24 Dec, 2007 | North Kyushu | *Akashiwo sanguinea* | |
| 29 Feb, 2008 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 6 Mar, 2008 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 11 Mar, 2008 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 12-17 Mar, 2008 | North Kyushu | *N. scintillans* | |
| 17-18 Mar, 2008 | North Kyushu | *N. scintillans* | |
| 21-22 Mar, 2008 | West Kyushu | *N. scintillans* | |
| 14-30 Apr, 2008 | North Kyushu | *Gephyrocapsa oceanica* | |
| 15 Apr, 2008 | Coastal area of Yamaguchi | *Noctiluca* sp. | |
| 30 Apr-2 May, 2008 | North Kyushu | *N. scintillans* | |
| 8-12 May, 2008 | West Kyushu | *H. akashiwo* | |
| 8-14 May, 2008 | North Kyushu | *N. scintillans* | |
| 15-29 May, 2008 | North Kyushu | *P. minimum*<br>*P. dentatum* | |
| 15-20 May, 2008 | North Kyushu | *Leptocylindrus danicus* | |
| 28-30 May, 2008 | North Kyushu | *H. akashiwo* | |
| 30-31 May, 2008 | West Kyushu | *H. akashiwo* | |
| 4-13 Jun, 2008 | North Kyushu | *H. akashiwo* | |
| 13-14 Jun, 2008 | West Kyushu | *Skeletonema* sp. | |
| 20-23 Jun, 2008 | West Kyushu | *M. rubra* | |
| 23-30 Jun, 2008 | North Kyushu | *S. costatum* | |
| 23 Jun-2 Jul, 2008 | North Kyushu | *C. antiqua* | |

**Table 3.6** Continued

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 24-28 Jun, 2008 | West Kyushu | *Ceratium fusus* | |
| 24 Jun-1 Jul, 2008 | West Kyushu | *H. akashiwo* | |
| 24-25 Jun, 2008 | North Kyushu | *Chaetoceros* | |
| 25-27 Jun, 2008 | Iki Island | *H. akashiwo* | 0.1 $km^2$ |
| 25 Jun-1 Jul, 2008 | North Kyushu | *Prorocentrum triestinum* | |
| 1-2 Jul, 2008 | West Kyushu | *Prorocentrum* sp. | |
| 2-24 Jul, 2008 | West Kyushu | *K. mikimotoi* | |
| 3-4 Jul, 2008 | North Kyushu | *P. dentatum* | |
| 17-18 Jul, 2008 | West Kyushu | *H. akashiwo* | |
| 23 Jul, 2008 | Coastal area of Yamaguchi | *K. mikimotoi* | |
| 25-26 Jul, 2008 | West Kyushu | *Rhizosolenia* sp. | |
| 26 Jul-21 Aug, 2008 | West Kyushu | *Chattonella antiqua*<br>*Chattonella marina*<br>*C. fusus* | |
| 30 Jul, 2008 | Coastal area of Yamaguchi | *K. mikimotoi* | |
| 1-7 Sep, 2008 | West Kyushu | *M. rubra* | 171 $km^2$ |
| 4-5 Sep, 2008 | Goto Islands | *M. rubra* | 0.03 $km^2$ |
| 10-21 Sep, 2008 | West Kyushu | *Akashio sanguinea*<br>*C. fusus* | |
| 22-30 Sep, 2008 | North Kyushu | *C. polykrikoides* | |
| 24-28 Sep, 2008 | West Kyushu | *M. rubra* | |
| 30 Sep-1 Oct, 2008 | West Kyushu | *Heterocapsa circularisquama* | |
| 3-15 Oct, 2008 | North Kyushu | *Skeletonema* | |
| 3-9 Oct, 2008 | North Kyushu | *C. antiqua* | |
| 9-10 Oct, 2008 | West Kyushu | *Skeletonema* | |
| 7-27 Nov, 2008 | North Kyushu | *M. rubra*<br>*C. polykrikoides*<br>*A. catenella*<br>*G. catenatum* | |
| 25-26 Nov, 2008 | Goto Islands | *M. rubra* | |
| 26-27 Nov, 2008 | Tsushima Island | *M. rubra* | |
| 3-22 Dec, 2008 | Goto Islands | *M. rubra* | |

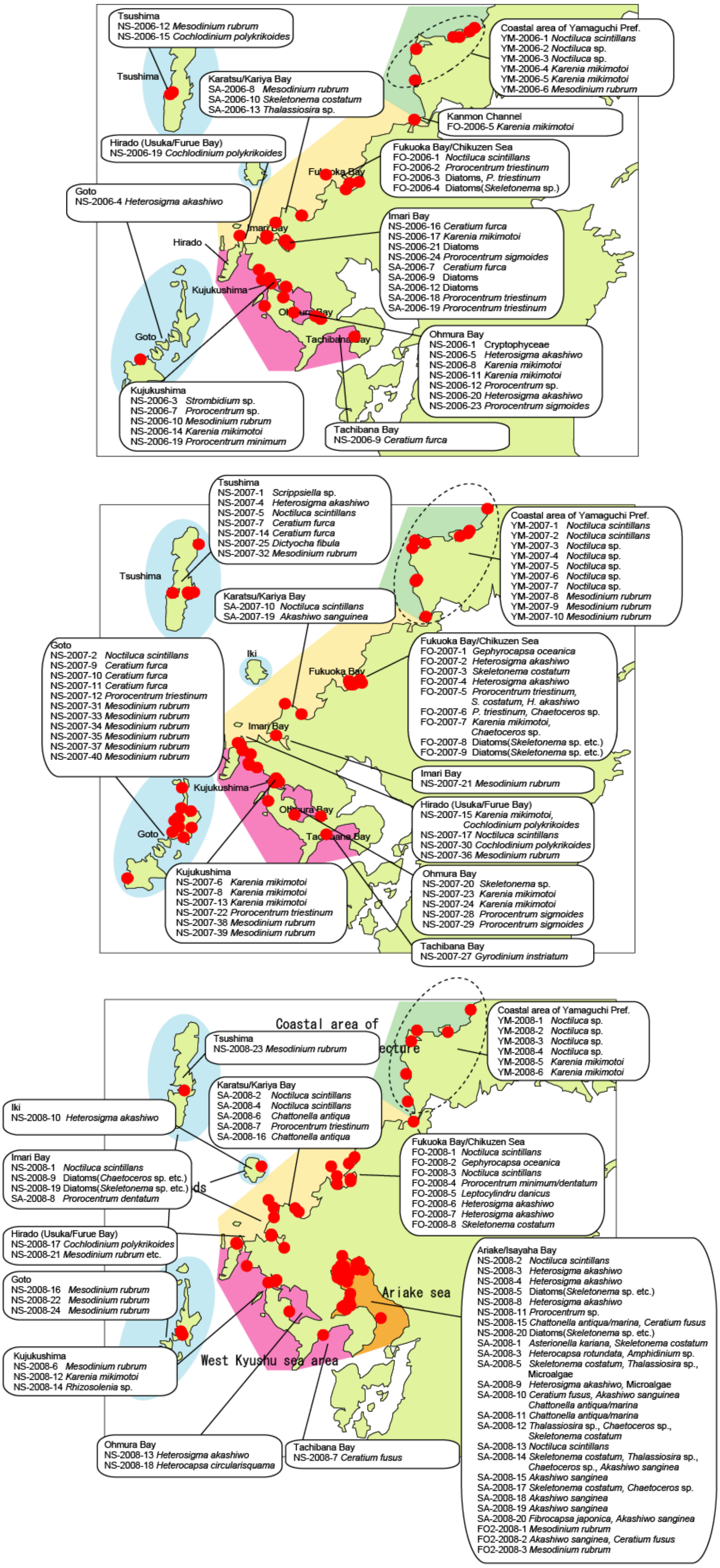
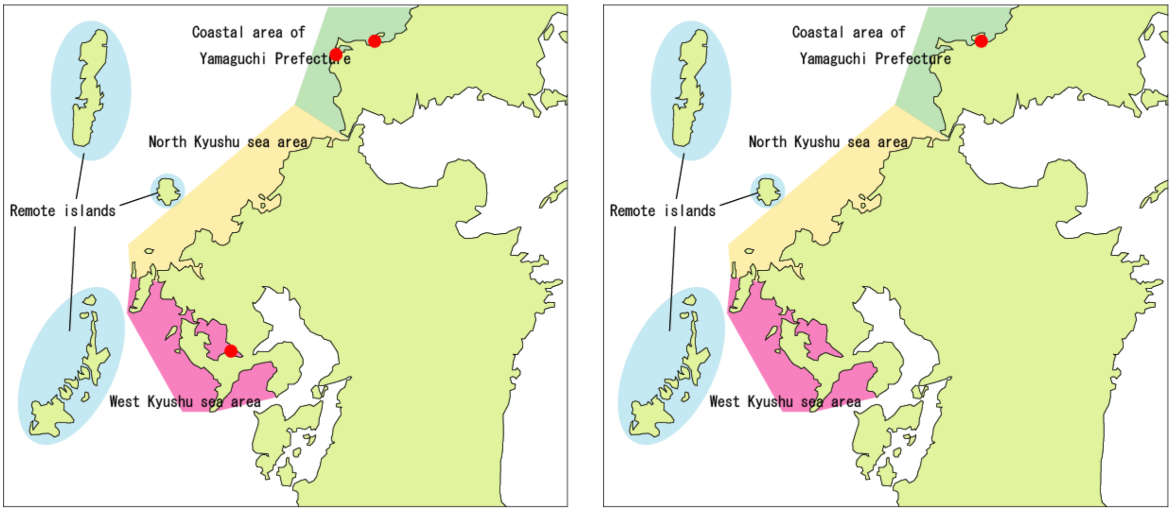
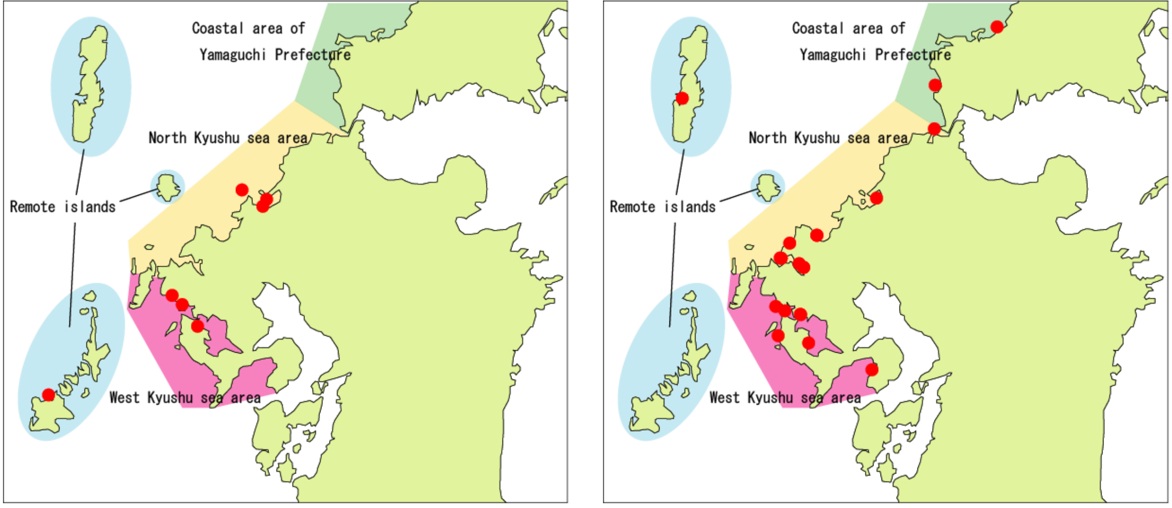


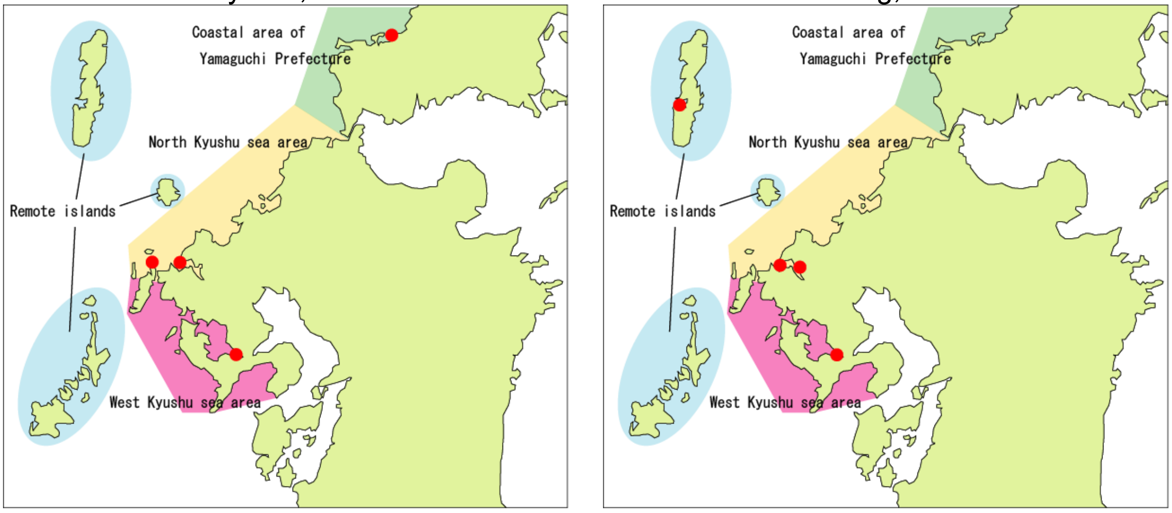
**Figure 3.4** Location of red tides from 2006 to 2008 in target sea areas



Jan-Feb, 2006 Mar-Apr, 2006

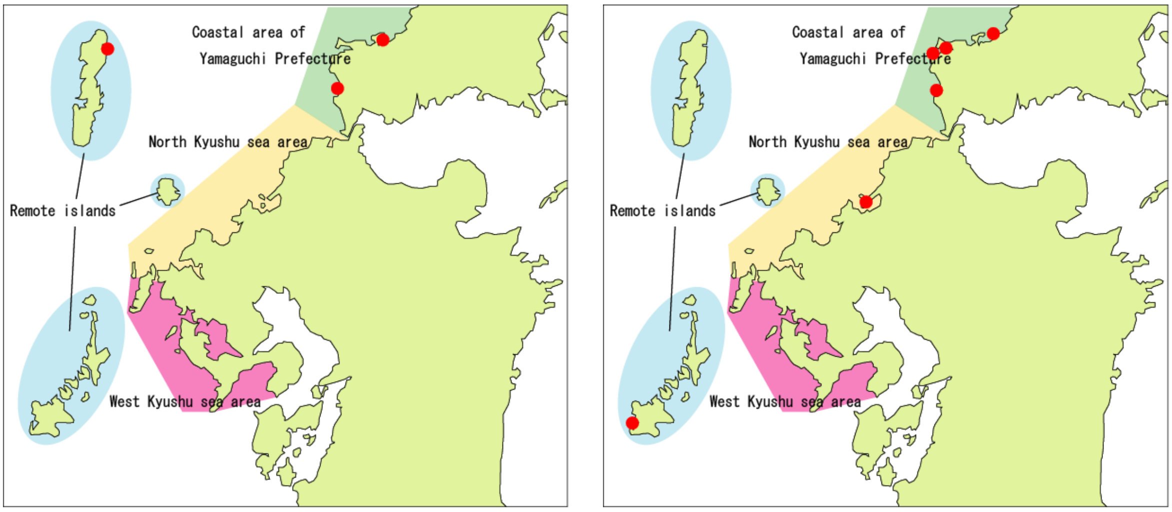


May-Jun, 2006 Jul-Aug, 2006

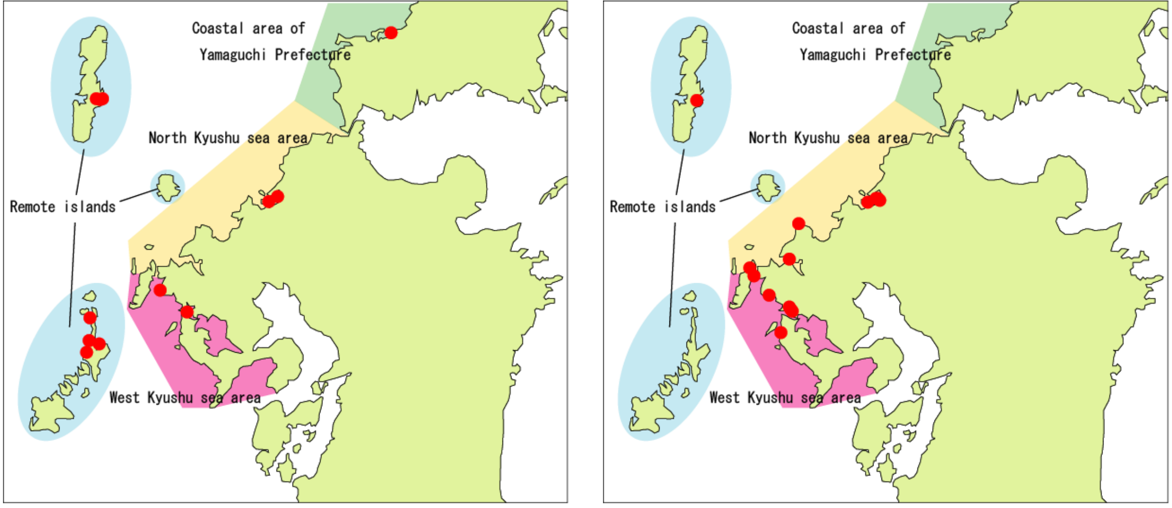


Sep-Oct, 2006 Nov-Dec, 2006

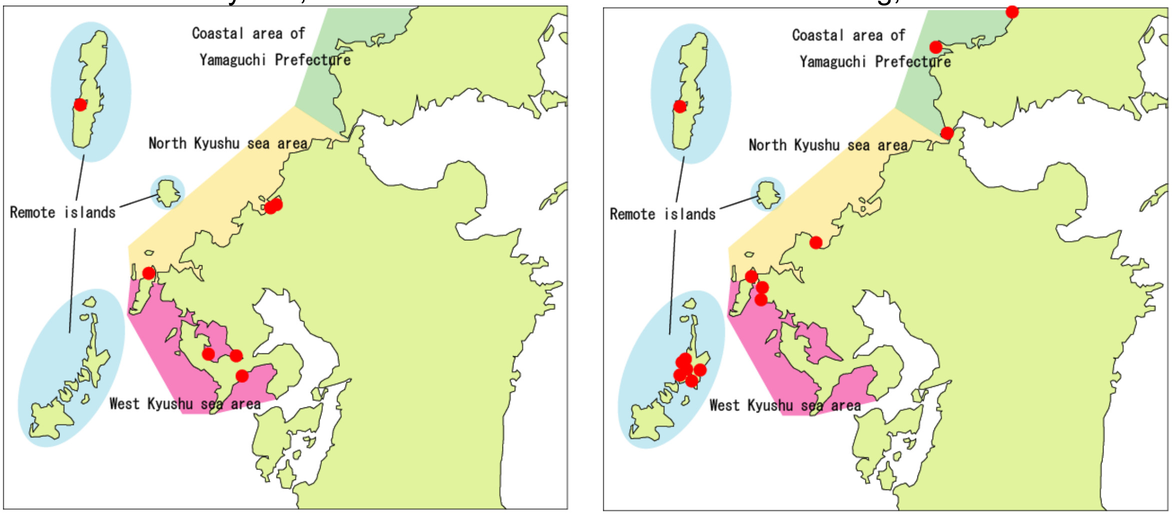
**Figure 3.5a** Location of red-tide events by months in 2006



Jan-Feb, 2007 Mar-Apr, 2007

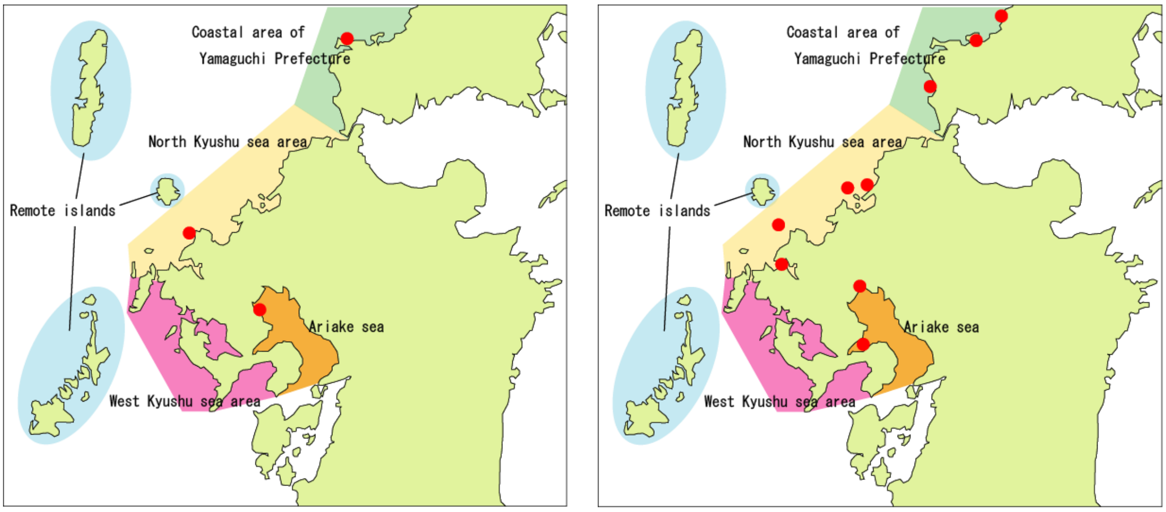


May-Jun, 2007 Jul-Aug, 2007



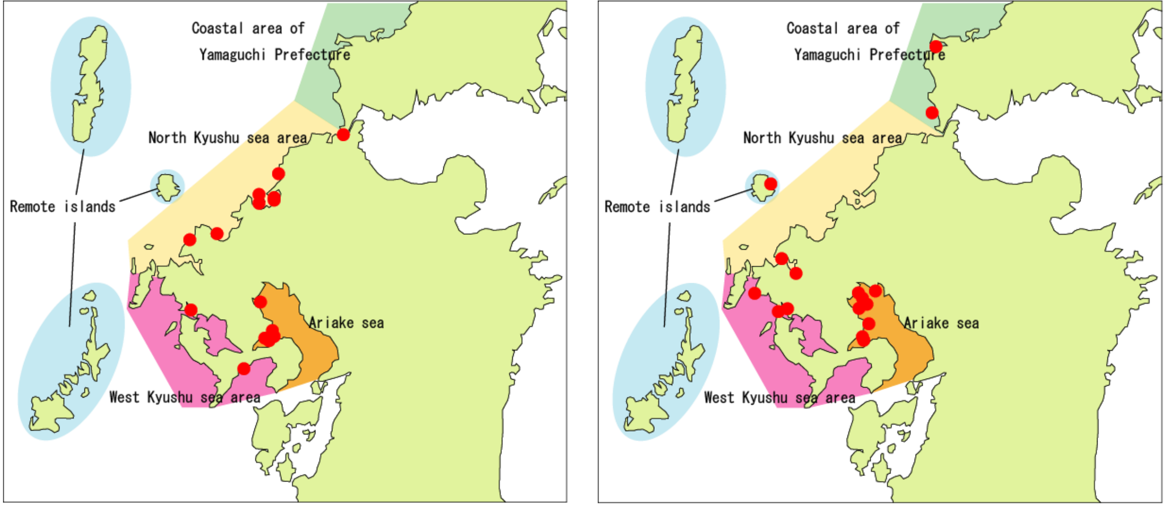
Sep-Oct, 2007 Nov-Dec, 2007

**Figure 3.5b** Location of red-tide events by months in 2007



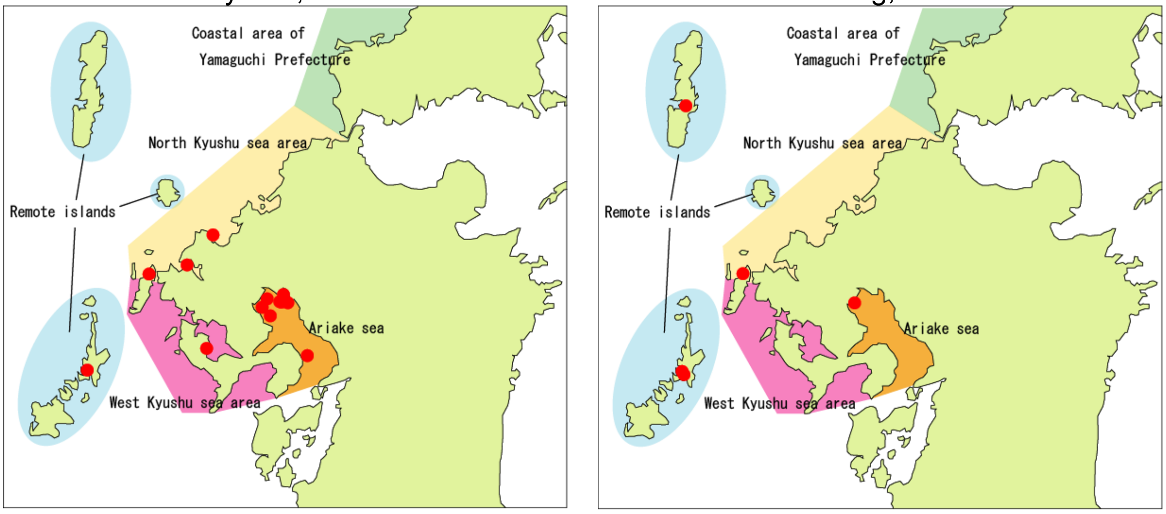
Jan-Feb, 2008

Mar-Apr, 2008



May-Jun, 2008

Jul-Aug, 2008



Sep-Oct, 2008

Nov-Dec, 2008

**Figure 3.5c** Location of red-tide events by months in 2008

### 3.1.3 Red tides in Korea

Throughout the entire Korean coast, 873 red-tide events have been observed since 1995. Of these, 179 were in Korea's target sea areas. The number of red-tide events has sharply decreased since 2005 however, with less than six events a year (Figure 3.6). After 2005, *C. polykrikoides* blooms have clearly decreased and there have not been any fish killed in the Korean target sea areas since 2008.

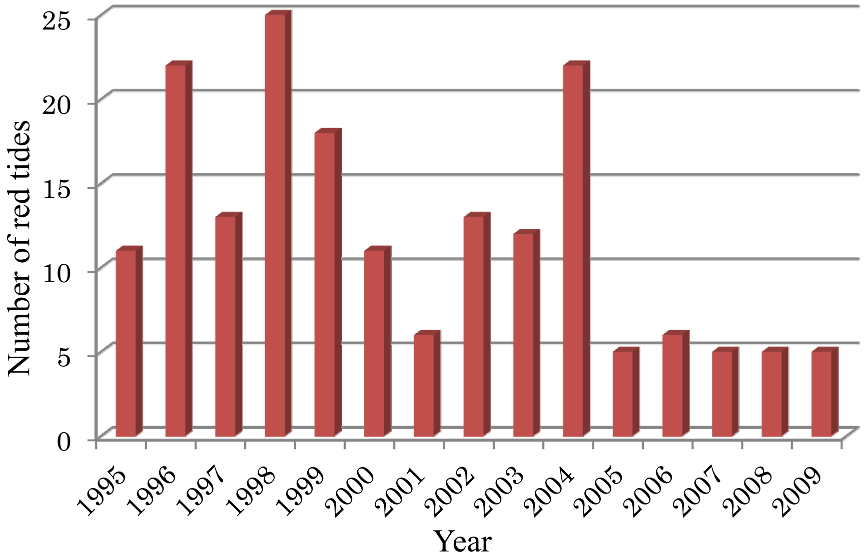


**Figure 3.6** Annual trend of red-tide events in target sea areas

From 2007 to 2009, 16 red-tide events were recorded on the south coast of Korea (Table 3.7). The most frequently observed species was *C. polykrikoides*, which caused 9 events.

**Table 3.7** Recent red-tide occurrence in south coast of Korea

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 24-30 Jul, 2007 | Tongyeong Dosan | *Akashiwo sanguinea* | - |
| 6 Aug-15 Sep, 2007 | Namhae Mizo | *C. polykrikoides* | 50 $km^2$ |
| 9 Aug-12 Sep, 2007 | Tongyeong Sarang Suyou-do | *C. polykrikoides* | 70 $km^2$ |
| 11 Aug-1 Sep, 2007 | Goseong Bay | *C. polykrikoides* | 3 $km^2$ |
| 3-9 Sep, 2007 | Jinju Bay | *C. polykrikoides* | 2 $km^2$ |
| 19-29 Oct, 2007 | Upper Sarang-do | *C. polykrikoides* | 2 $km^2$ |
| 4 Aug-23 Sep, 2008 | Tongyeong Dosan | *C. polykrikoides* | 40 $km^2$ |
| 8 Aug-22 Sep, 2008 | Namhae Mizo | *C. polykrikoides* | 60 $km^2$ |
| 16-25 Sep, 2008 | Tongyeong Sarang Suyou-do | *C. polykrikoides* | 60 $km^2$ |
| 29 Aug-5 Sep, 2008 | Goseong Bay | *C. polykrikoides* | 3 $km^2$ |
| 11-20 Sep, 2008 | Jinju Bay | *C. polykrikoides* | 2 $km^2$ |
| Aug, 2009 | Donghae-myeon | *C. furca* | 0.8 $km^2$ |
| 11-19 Aug, 2009 | Nam-myeon | *A. fraterculus* | 2 $km^2$ |
| 11-13 Aug, 2009 | Tae-do | *G. polygramma* | 3 $km^2$ |
| 24-26 Aug, 2009 | Chilcheon-do | *S. trochoidea* | 2 $km^2$ |
| 1-9 Nov, 2009 | Sandong eunjeom | *Gymnodinium.* sp. | 0.5 $km^2$ |

In Korean target sea areas, more than 60% of red-tide events occurred between July and August, with *C. polykrikoides* being the major causative species. Another fish killing species, *Chattonella* spp., also occurred between July and August along west coast. The duration of red-tide events was between 5 and 50 days, and varied significantly depending on the causative species. *C. polykrikoides* lasted between 22 and 50 days, while other dinoflagellates lasted between 5 and 11 days. The longer duration of *C. polykrikoides* events than other dinoflagellates, is thought to be related to the greater availability of nutrients offshore, which are supplied by currents. *C. polykrikoides* also spread to neighboring areas by wind or currents where nutrients were abundant.

Figure 3.7a-d shows the spatial distribution of red-tide affected areas from 2007 to 2009.

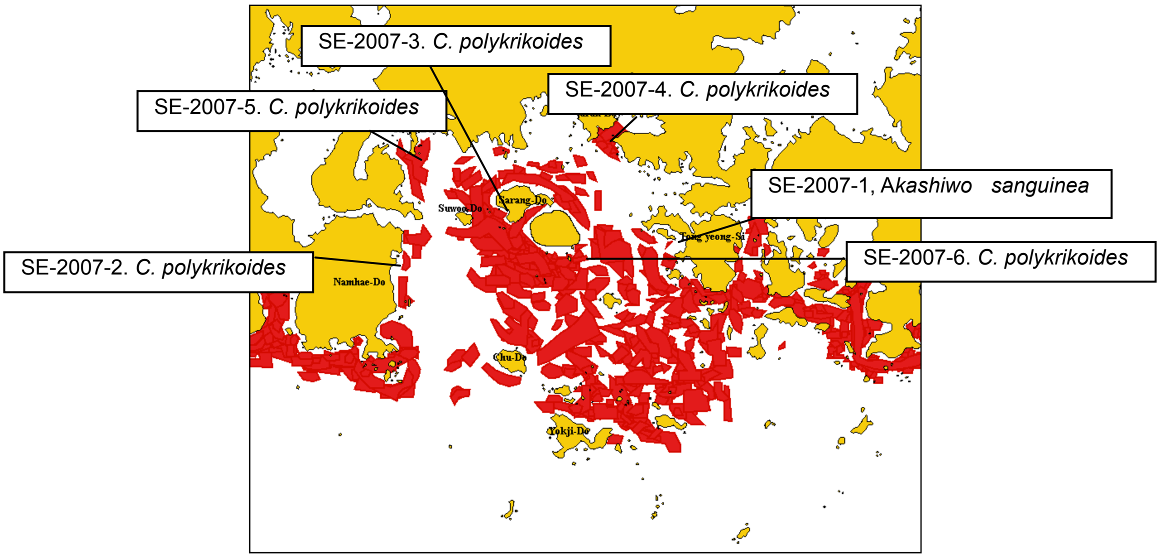


**Figure 3.7a** Spatial distribution of HABs in 2007 (red areas indicate HAB-affected dimensions).

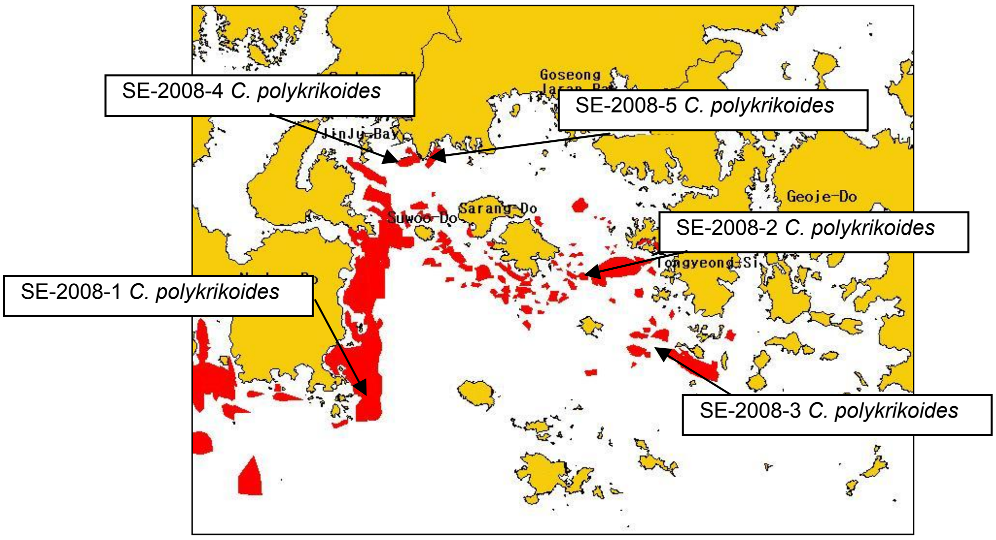
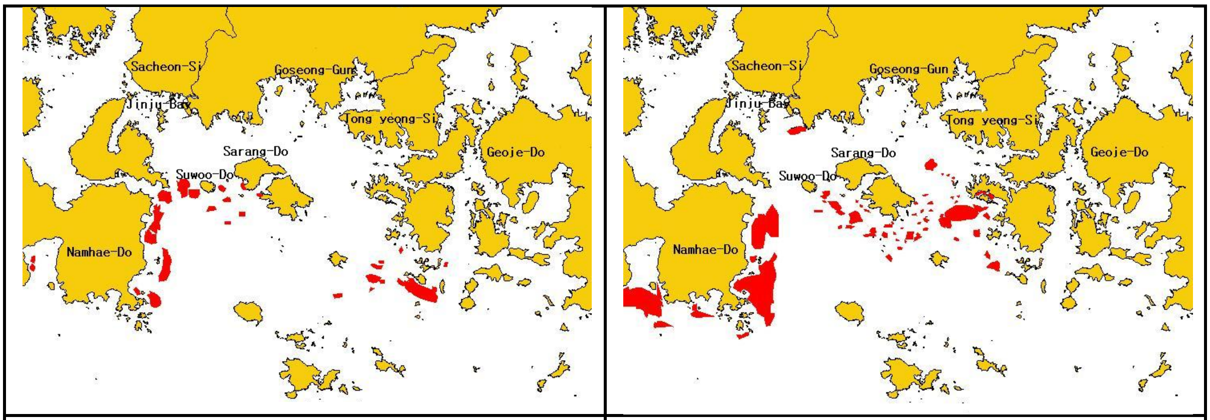
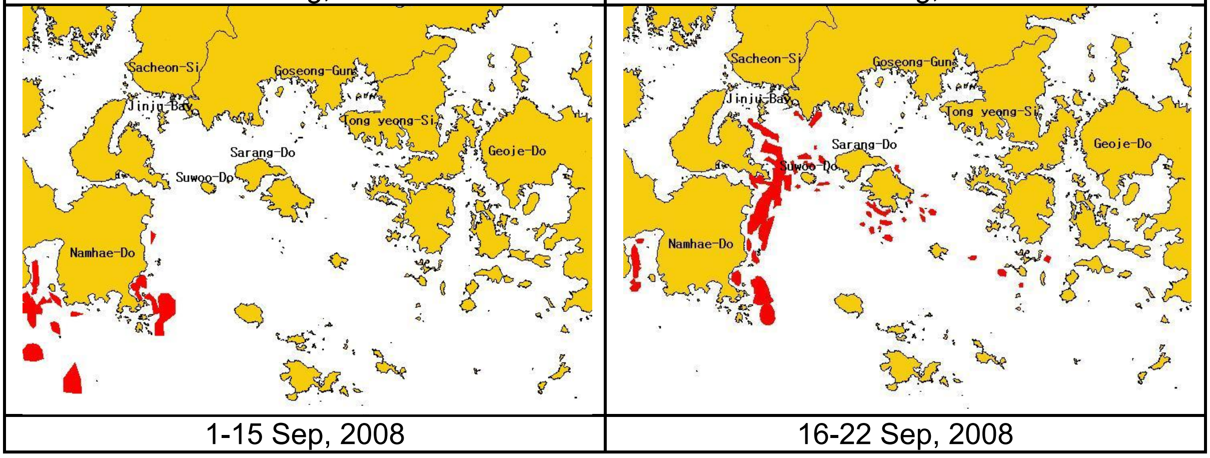


**Figure 3.7b** Cumulative spatial distribution of HABs in 2008 (red areas indicate HAB-affected dimensions).



1-15 Aug, 2008

16-31 Aug, 2008



1-15 Sep, 2008

16-22 Sep, 2008

**Figure 3.7c** Changes in HAB affected areas every half a month (red areas indicate HAB-affected dimensions).

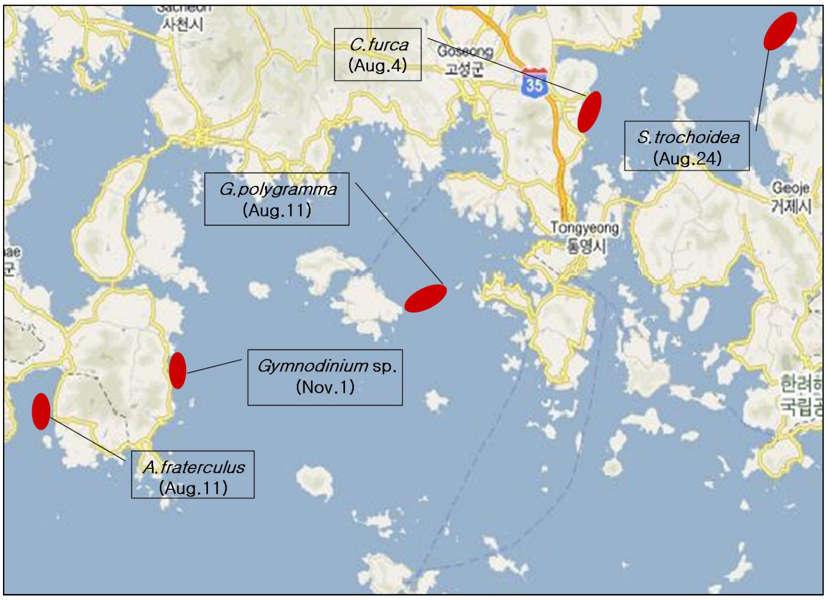


**Figure 3.7d** Spatial distribution of HABs in 2009 (red areas indicate HAB-affected dimensions)

### 3.1.4 Red tides in Russia

In Russian target sea areas, 53 red-tide events and a total of 20 red-tide species have been observed since 1991. No cases of fishery damage have been recorded. Most red-tide events occurred in Amurskii Bay and Vostok Bay. In Aniva Bay, one *Heterosigma akashiwo* red-tide event was recorded. Figure 3.8 shows the annual trend of red-tide events in target sea areas. In recent years, red-tide events have occurred consistently in the area.

Table 3.8 and Figures 3.9 a-c indicate the location and causative species of red-tide events in target sea areas.

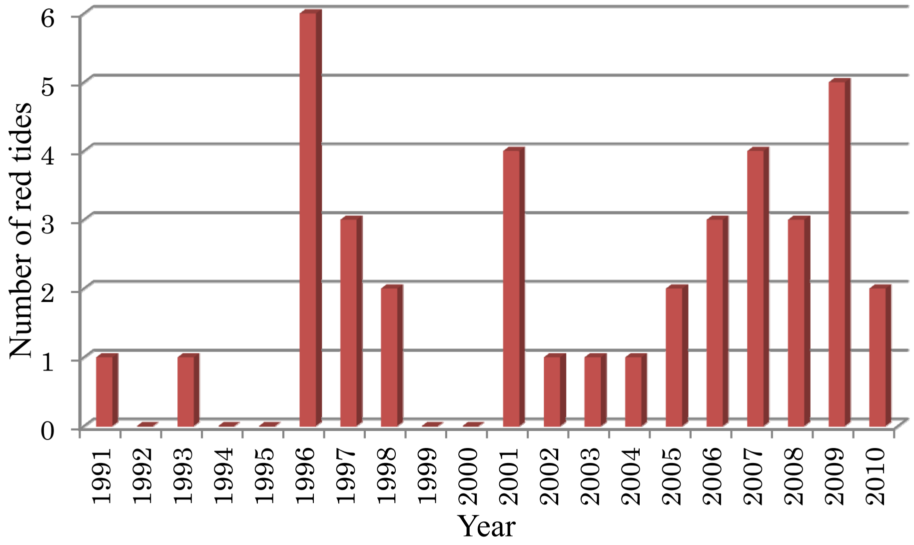


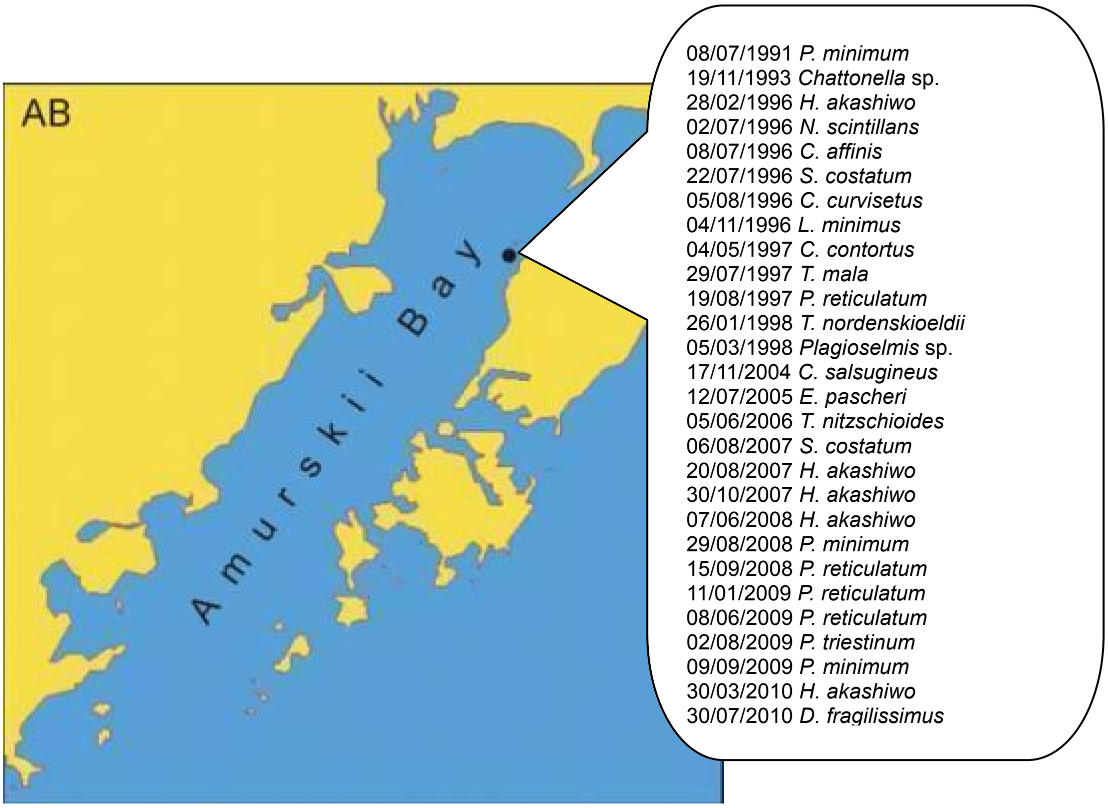
**Figure 3.8** Annual trend of red-tide events in target sea areas

**Table 3.8** Recent red-tide occurrences in Amurskii Bay, Vostok Bay and Aniva Bay

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 8 Jul-12 Aug, 1991 | Amurskii Bay | *Prorocentrum minimum* | |
| 19 Nov, 1993 | Amurskii Bay | *Chattonella* sp. | |
| 28 Feb, 1996 | Amurskii Bay | *Heterosigma akashiwo* | |
| 2-16 Jul, 1996 | Amurskii Bay | *Noctiluca scintillans* | |
| 8 Jul-30 Aug, 1996 | Amurskii Bay | *Chaetoceros affinis* | |
| 5-12 Aug, 1996 | Amurskii Bay | *Chaetoceros curvisetus* | |
| 4 Nov-16 Dec, 1996 | Amurskii Bay | *Leptocylindrus minimus* | |
| 22 Jul-30 Aug, 1996 | Amurskii Bay | *Skeletonema costatum* | |
| 4 May-4 Jun, 1997 | Amurskii Bay | *Chaetoceros contortus* | |
| 29 Jul, 1997 | Amurskii Bay | *Thalassiosira mala* | |
| 19-28 Aug, 1997 | Amurskii Bay | *Protoceratium reticulatum* | |
| 5-12 Mar, 1998 | Amurskii Bay | *Plagioselmis* sp. | |
| 26 Jan-17 Feb, 1998 | Amurskii Bay | Thalassiosira nordenskioeldii | |
| 13 Aug, 2001 | Aniva Bay | *H. akashiwo* | |
| 16 Aug, 2001 | Vostok Bay | *S. costatum* | |
| 30 Sep, 2001 | Vostok Bay | *Asterionellopsis glacialis* | |
| 14 Jul, 2002 | Vostok Bay | *Chatonella globosa* | |

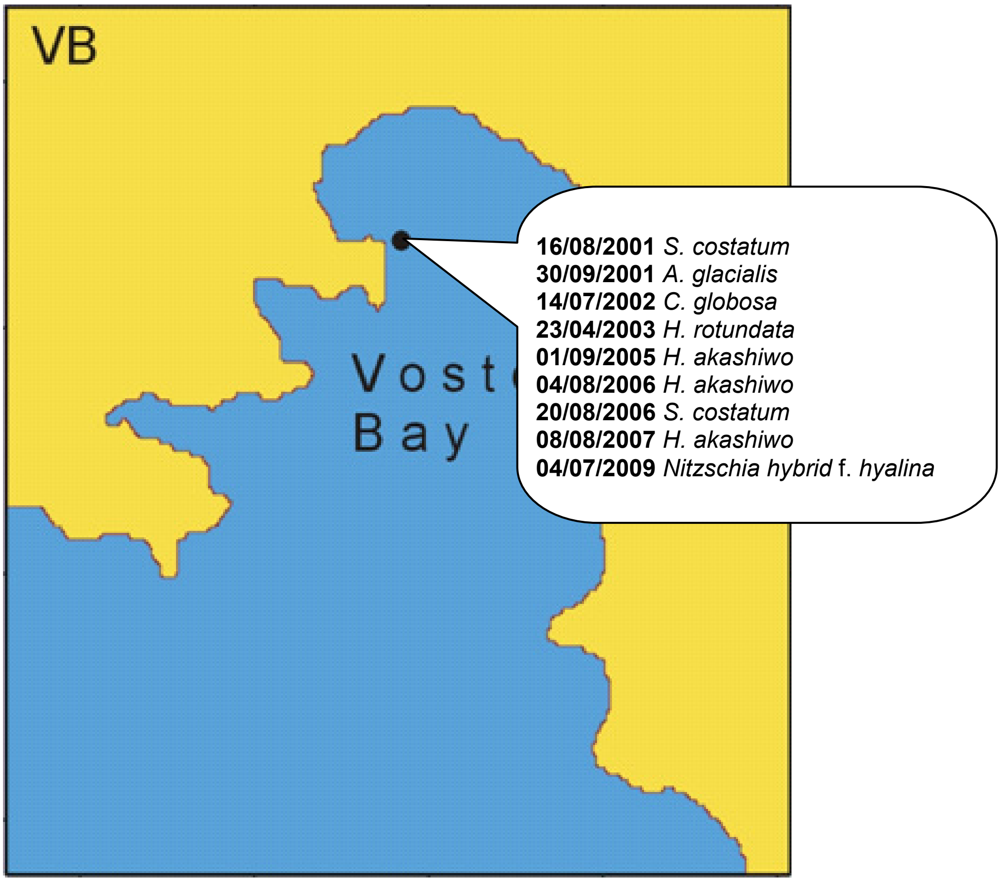
**Table 3.8** Continued

| Occurrence date | Occurrence location | Causative species | Occurrence area |
|---|---|---|---|
| 23 Apr, 2003 | Vostok Bay | *Heterocapsa rotundata* | |
| 17 Nov, 2004 | Amurskii Bay | *Chaetoceros salsugineus* | |
| 12 Jul, 2005 | Amurskii Bay | *Euglena pascheri* | |
| 1 Sep, 2005 | Vostok Bay | *H. akashiwo* | |
| 5 Jun-3 Jul, 2006 | Amurskii Bay | *Thalassionema nitzschioides* | |
| 4 Aug, 2006 | Vostok Bay | *H. akashiwo* | |
| 20 Aug, 2006 | Vostok Bay | *S. costatum* | |
| 6-20 Aug, 2007 | Amurskii Bay | *S. costatum* | |
| 8 Aug, 2007 | Vostok Bay | *H. akashiwo* | |
| 20 Aug, 2007 | Amurskii Bay | *H. akashiwo* | |
| 30 Oct, 2007 | Amurskii Bay | *H. akashiwo* | |
| 7 Jun, 2008 | Amurskii Bay | *H. akashiwo* | |
| 29 Aug, 2008 | Amurskii Bay | *P. minimum* | |
| 15 Sep, 2008 | Amurskii Bay | *P. reticulatum* | |
| 11 Jan, 2009 | Amurskii Bay | *P. reticulatum* | |
| 8 Jun, 2009 | Amurskii Bay | *P. reticulatum* | |
| 4 Jul, 2009 | Vostok Bay | *Nitzschia hybrid f. hyalina* | |
| 2 Aug, 2009 | Amurskii Bay | *P. triestinum* | |
| 9 Sep, 2009 | Amurskii Bay | *P. minimum* | |
| 30 Mar, 2010 | Amurskii Bay | *H. akashiwo* | |
| 30 Jul, 2010 | Amurskii Bay | *Dactyliosolen fragilissimus* | |



08/07/1991 *P. minimum*
19/11/1993 *Chattonella* sp.
28/02/1996 *H. akashiwo*
02/07/1996 *N. scintillans*
08/07/1996 *C. affinis*
22/07/1996 *S. costatum*
05/08/1996 *C. curvisetus*
04/11/1996 *L. minimus*
04/05/1997 *C. contortus*
29/07/1997 *T. mala*
19/08/1997 *P. reticulatum*
26/01/1998 *T. nordenskioeldii*
05/03/1998 *Plagioselmis* sp.
17/11/2004 *C. salsugineus*
12/07/2005 *E. pascheri*
05/06/2006 *T. nitzschioides*
06/08/2007 *S. costatum*
20/08/2007 *H. akashiwo*
30/10/2007 *H. akashiwo*
07/06/2008 *H. akashiwo*
29/08/2008 *P. minimum*
15/09/2008 *P. reticulatum*
11/01/2009 *P. reticulatum*
08/06/2009 *P. reticulatum*
02/08/2009 *P. triestinum*
09/09/2009 *P. minimum*
30/03/2010 *H. akashiwo*
30/07/2010 *D. fragilissimus*

**Figure 3.9a** Location of red-tide events in Amurskii Bay



**16/08/2001** *S. costatum*
**30/09/2001** *A. glacialis*
**14/07/2002** *C. globosa*
**23/04/2003** *H. rotundata*
**01/09/2005** *H. akashiwo*
**04/08/2006** *H. akashiwo*
**20/08/2006** *S. costatum*
**08/08/2007** *H. akashiwo*
**04/07/2009** *Nitzschia hybrid* f. *hyalina*

**Figure 3.9b** Location of red-tide events in Vostok Bay

**15/06/2005** *H. akashiwo*

**Figure 3.9c** Location of red-tide events in Aniva Bay

## 3.2 Toxin-producing plankton and shipment stoppage in the target sea areas

Table 3.9 shows the status of toxin-producing plankton and damage caused to fisheries and human health in the target sea areas of each member state. In this report, toxin-producing species are separated into paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP) inducing species, rather than their taxonomic classification. All of the NOWPAP member states regularly monitor the status of shellfish toxin, and toxin producing plankton species of PSP, DSP and/or ASP events.

A total of 20 toxin-producing plankton species were recorded in the last 'HAB Integrated Report'. In the 'HAB Case Study Reports', the number of toxin-producing plankton species decreased to a total of 18 species including, 4 new *Pseudo-nitzschia* species (Table 3.10).

Six species were PSP-inducing species, including *Alexandrium* spp. and *Gymnodinium catenatum*. The most commonly recorded PSP species in the NOWPAP Region was *A. tamarense*, but in recent years *G. catenatum* has induced more PSP contamination in Japan.

The PSP species, *A. tamarense*, *A. catenella* and *G. catenatum* were reported in the 'HAB Case Study Report' of all NOWPAP member states. In China, Korea and Russia, poisoning is not recorded. However, in Japan PSP was detected 13 times from 2006 to 2008. In four of these cases, shipment stoppage was imposed as the toxin level exceeded the safety limit.

Nine of the ten DSP species recorded in the NOWPAP Region belong to the genus *Dinophysis*. The other was *Exuviaella marina*, which was recorded only in China. Among the *Dinophysis* species, *D. fortii* and *D. acuminata* were recorded in all of the NOWPAP member seas. In the 'HAB Case Study Report', *Dinophysis* species were reported in Japan and Russia.

DSP species have been recorded in China, Japan and Russia.

In the Dalian Bay in China, an *E. marina* bloom occurred and DSP was detected. However, no damage to fisheries or human health by this poisoning was reported.

Damage from DSP was not recorded in Japan during 2006-2008 and Russia has not been affected by DSP as of yet.

ASP-inducing *Pseudo-nitzschia* species were mainly recorded in Russia. In Korea, only *Pseudo-nitzschia pungens* were observed. ASP-inducing species probably also exist in China and Japan, but they are not targeted in regular monitoring. In the NOWPAP region, the damage caused by ASP has not been reported to date, but this should be investigated in the future.

**Table 3.9** Status of toxin-producing plankton and damage to fisheries and human health in the target sea areas of the NOWPAP member state

| | China | Japan | Korea | Russia |
|---|---|---|---|---|
| Targeted toxin-producing species in regular monitoring | *Alexandrium tamarense* | *A. tamarense*, *A. catenella*, *Gymnodinium catenatum, Dinophysis fortii*, *D. acuminata*, *D. caudata* | No targeted species | *A. tamarense*, *Dinophysis fortii*, *D. acuminata*, *D. acuta, D. norvegica, D. rotundata, Protoceratium reticulatum Pseudo-nitzschia calliantha, P. delicatissima, P. fraudulenta, P. multistriata, P. multiseries, P. seriata/pungens,* |
| Observed toxin-producing species in recent years | *A. catenella*<br>*Exuviaella marina* | *A. catenella*<br>*G. catenatum*<br>*D. fortii*<br>*D. acuminata*<br>*D. caudata* | *G. catenatum*<br>*Pseudo-nitzschia pungens* | *A. tamarense*<br>*D. fortii*<br>*D. acuminata,*<br>*D. acuta D. norvegica,*<br>*D. rotundata*<br>*Pseudo-nitzschia calliantha*<br>*P. multiseries,*<br>*P. pseudodelicatissima*<br>*P. pungens,*<br>*P. delicatissima*<br>*P. fraudulenta, P. multistriata P. seriata* |
| Affected species | No information | PSP: *Mytilus galloprovincialis*, *Crassostrea gigas*, *Chlamys senatoria nobilis*<br>DSP: *Mytilus galloprovincialis*, *Mizuhopecten yessoensis* | No information | PSP: *Mizuhopecten yessoensis*<br>DSP: *Crenomytilus grayanus*, *Mytilus trossulus*<br>ASP: *Crenomytilus grayanus*, *Mytilus trossulus*, *Mizuhopecten yessoensis* |
| Damage | In 1999, damage to human health by DSP occurred. | DSP exceeded safety limit caused by *G. catenatum* in the Sensaki Bay in 2006, 2007 and 2008, in the Yuya Bay in 2007 and in the Tamanoura Bay in 2007. | No shellfish poisoning was reported | No damage to fisheries or human health was reported, however, toxin levels higher than the standard were observed in each area. |
| Mitigation measures | Regular monitoring to check abundance of toxin producing species and toxin content in shellfish meat.<br>PSP toxin safety limit is 80 μg(saxitoxin)/100 g meat. | Regular monitoring to check abundance of toxin producing species and toxin content in the shellfish meat.<br>PSP toxin safety limit is 4 MU/g wet weight of meat.<br>DSP toxin safety limit is 0.05 MU/g wet weight of meat.<br>In principal, shipment of shellfish will be stopped until the toxin levels return to acceptable levels for three consecutive inspections. | Regular monitoring to check abundance of toxin producing species and toxin content in the shellfish meat at over 100 stations around shellfish aquaculture farms.<br>PSP toxin safety limit is 80 μg/100 g meat. | Regular monitoring to check abundance of toxin producing species and toxin content in the shellfish meat.<br>PSP toxin safety limit is 0.8 mg(saxitoxin)/kg meat.<br>DSP toxin safety limit is 0.16 mg(okadaic acid)/kg meat.<br>ASP toxin safety limit is 20 mg(domoic acid)/kg meat for mollusks and 30 mg(domoic acid)/kg meat for crab's internal. |

**Table 3.10** Toxin-producing plankton species recorded in the NOWPAP region

| | Species name | China | Japan | Korea | Russia |
|---|---|---|---|---|---|
| PSP | *Alexandrium acatenella* | | | | (✔) |
| | *Alexandrium tamarense* | | (✔) | (✔) | (✔) ✔ |
| | *Alexandrium catenella* | (✔) ✔ | (✔) ✔ | | |
| | *Alexandrium pseudogonyaulax* | | | | (✔) |
| | *Alexandrium tamiyavanichii* | | (✔) | | |
| | *Gymnodinium catenatum* | | (✔) ✔ | ✔ | |
| DSP | *Dinophysis fortii* | (✔) | (✔) ✔ | (✔) | (✔) ✔ |
| | *Dinophysis acuminata* | (✔) | (✔) ✔ | (✔) | (✔) ✔ |
| | *Dinophysis acuta* | | | | (✔) ✔ |
| | *Dinophysis caudata* | | (✔) ✔ | | |
| | *Dinophysis infundibrus* | | (✔) | | |
| | *Dinophysis mitra* | | (✔) | | |
| | *Dinophysis norvegica* | | | | (✔) ✔ |
| | *Dinophysis ovata* | (✔) | | | |
| | *Dinophysis rotundata* | | (✔) | (✔) | (✔) ✔ |
| | *Exuviaella marina* | (✔) ✔ | | | |
| ASP | *Pseudo-nitzschia calliantha* | | | | (✔) ✔ |
| | *Pseudo-nitzschia multiseries* | | | | (✔) ✔ |
| | *Pseudo-nitzschia pseudodelicatissima* | | | | (✔) ✔ |
| | *Pseudo-nitzschia pungens* | | | (✔) ✔ | (✔) ✔ |
| | *Pseudo-nitzschia delicatissima* | | | | ✔ |
| | *Pseudo-nitzschia fraudulenta* | | | | ✔ |
| | *Pseudo-nitzschia multistriata* | | | | ✔ |
| | *Pseudo-nitzschia seriata* | | | | ✔ |

Parentheses indicate that the species was reported in the last HAB Integrated Report.

## 3.3 Common issues on HABs in the NOWPAP region

### 3.3.1 Severe fishery damage caused by *Cochlodinium polykrikoides*

Red tides have frequently resulted in large mortality rates in fishery resources and huge economic loss to fisheries in the NOWPAP Region. For example, in 1999 approximately USD7 million of fishery damage was recorded in Imari Bay, Kyushu, Japan. Even greater economic losses were recorded in Korea in 1995 and 2003, worth approximately USD95 million and USD19 million, respectively. Red tides often occur in semi-enclosed areas, such as inlets and embayments, where aquaculture often operates. Although various species are known to cause red tides, *C. polykrikoides* has caused the most damage to fisheries in Japan and Korea in recent years. In Korea, *C. polykrikoides* is the causative species of all HAB events in the last 15 years.

Since 2005, *C. polykrikoides* blooms have occurred frequently in Japan and Korea, but the number of occurrences and damage to fisheries has decreased in the past years. The locations of *C. polykrikoides* blooms in the Japanese and Korean regions are plotted in Figure 3.10, the data of which are derived from national reports, recent research papers and the 'HAB Case Study Reports'.

To prevent or reduce future damage from *C. polykrikoides*, various studies have been conducted to understand the ecology of the species. Several studies have focused on the transportation mechanisms of *C. polykrikoides*. Miyahara et al. (2005) traced the movement of *C. polykrikoides* blooms along the Sea Area A coast in the Chugoku region in 2003, by referring to satellite images showing chlorophyll-*a* concentration (field measurements verified that the high chlorophyll-*a* concentration in the satellite images was predominantly due to *C. polykrikoides*). Figure 3.11 shows how the *C. polykrikoides* blooms moved along the coast of the Chugoku region. Miyahara et al. concluded that this particular bloom was most likely transported to the coast of the Chugoku region through the Tsushima Warm Current.

Kim et al. (2004) studied the impact of water temperature, salinity and irradiance on the growth rate of *C. polykrikoides*. The highest growth rate was recorded when the water temperature was 25 ºC, salinity was 34 ppt and irradiance was >90 µmol/m$^2$/s. Such physical parameters might explain the *C. polykrikoides* blooms in the Japanese (Kyushu) and Korean regions, all of which occurred between August and October when the water temperature was close to 25 ºC. However, optimum growth conditions for *C. polykrikoides* require further investigation through the collection of field data.

To predict and provide warning of *C. polykrikoides* blooms based on the scientific data, Korea conducts specific *C. polykrikoides* monitoring. This monitoring is conducted before, during and after *C. polykrikoides* blooms, usually from June to October. For detection of the spatial distribution of *C. polykrikoides* blooms, satellite images of SST and Chlorophyll-*a* are applied. *C. polykrikoides* blooms in Korea occur over huge scales in offshore areas. The information on SST and Chlorophyll-*a* are helpful parameters for the prediction of *C. polykrikoides* blooms. In 2008, *C. polykrikoides* blooms tens of kilometers long were detected using satellite images (Table 3.11).

### 3.3.2 Fishery damage caused by *Chattonella antiqua* in Yatsushiro Sea

Since 2008, Fishery damage caused by *C. antiqua* has been quite serious in the Yatsushiro Sea. The Yatsushiro Sea, outside of the NOWPAP region, is adjacent to the Ariake Sea and contains many aquaculture farms. In 2008, the amount of fishery damage was 184 million Japanese yen (about 2 million USD). The damage increased to 2.9 billion Japanese yen in 2009 and 5.3 billion in 2010. The damage caused by *C. antiqua* expanded throughout the Ariake Sea and Omura Bay. *C. antiqua* is the species of greatest concern in the Kyushu region.

**Figure 3.10** Locations of *C. polykrikoides* blooms in Japan and Korea
Blue circles indicate locations of C. polykrikoides blooms before 2005. Red circles indicate blooms after 2005.

Sources: NOWPAP CEARAC (2005): Integrated Report on HABs for the NOWPAP Region
Yoon Y. H. (2001); A summary on the red-tide mechanisms of the harmful dinoflagellate, *Cochlodinium polykrikoides* in Korean coastal waters, Bull. Plankton Soc. Japan, 48 (2): 113–120.
Matsuoka K. (2004); Present status in study on a harmful unarmored dinoflagellate *Cochlodinium polykrikoides* Margalef., Bull. Plankton Soc. Japan, 51 (1): 38–45.

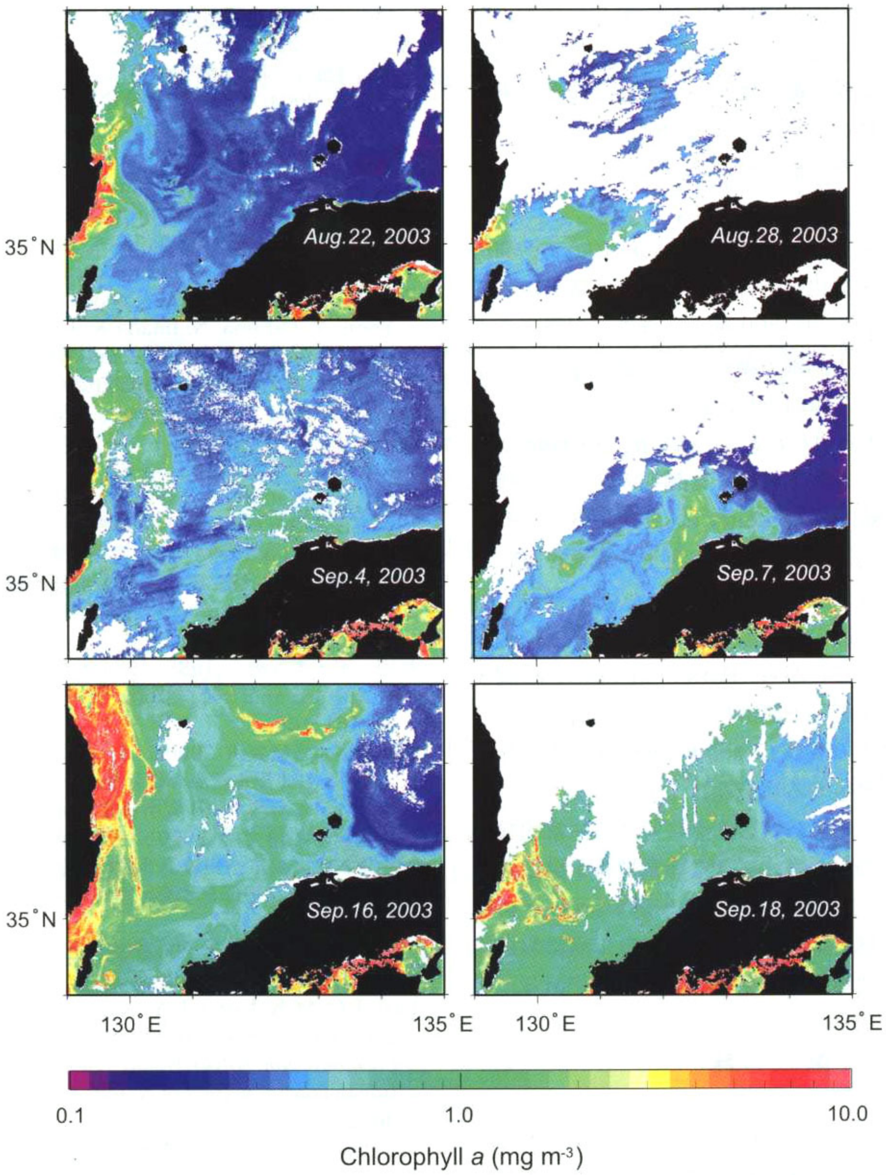
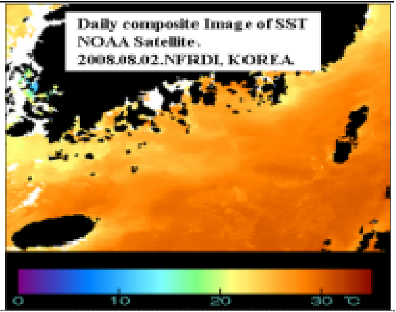
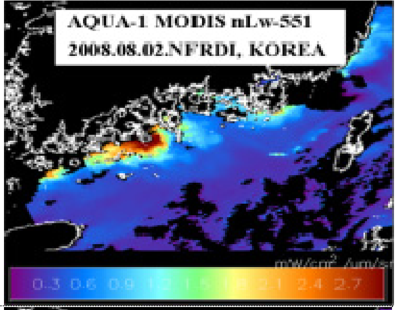
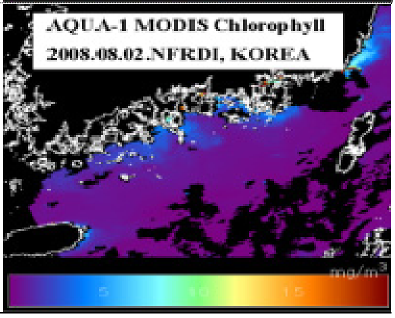


**Figure 3.11** Movement of *C. polykrikoides* blooms along the coast of the Chugoku Region in Sea Area A

Note: The movement of *C. polykrikoides* blooms along the coast of the Chugoku region from September 4 to 7 is clearly seen in green. The spread of primary production on September 16 and 18 is thought to be caused by the typhoon on September 12.

Source: Miyahara et al. (2005): A harmful bloom of *Cochlodinium polykrikoides* Margalef (Dinophyceae) in the coastal area of San-in, western part of the Japan Sea, in September 2003, Bull. Plankton Soc. Japan, 52(1), 11–18.

**Table 3.11** Satellite images during HAB events in the South Sea of Korea

| Year | Event No. | Duration | Area | SST, nLw 551, Chl-a |
|---|---|---|---|---|
| 2008 | SE-2008-1 | 2 Aug, 2008 | South Sea of Korea |  |
| 2008 | SE-2008-1 | 2 Aug, 2008 | South Sea of Korea |  |
| 2008 | SE-2008-1 | 2 Aug, 2008 | South Sea of Korea |  |

### 3.3.3 Threats from PSP and DSP

Shellfish poisoning is a common threat in the NOWPAP Region. In China, more than 600 people have suffered shellfish poisoning since 1967, of which 30 cases were fatal. The majority of these fatalities were from PSP. In Japan, approximately 900 people have suffered from DSP and PSP poisoning since monitoring began. In Korea, shipping of shellfish was temporarily suspended in 2002 and 2003 due to PSP. Although there have been no reports of shellfish poisoning in Russia, the presence of various toxin-producing species has been recorded in Russian waters. Shellfish poisoning in Russia could become a major threat in the future, particularly due to the expansion of their aquaculture industry.

### 3.3.4 The new issue by massive blooms of green macroalgae *Ulva prolifera*

Green tides, which are caused by huge volumes of green macroalgae, have been reported in many parts of the world. Such green macroalgae blooms are not directly harmful to fisheries or human health, but macroalgae often grow rapidly and huge volumes become stranded on the coast. In such cases, stakeholders have to remove them in order to keep the coast clean and safe. In recent years, such macroalgae blooms have become an issue of concern throughout the world.

In 2008, massive green macroalgae (*Ulva prolifera*) blooms occurred in the Yellow Sea and the East China Sea and became stranded in the coastal area of Qingdao. This bloom covered an area of about 2,400 $km^2$ and the total volume removed reached 1 million tons (Hu and He 2008). A similar massive bloom (1,600 $km^2$) occurred in 2009 (Hu et al. 2010). In 2008, the removal and treatment of such a large volume of *U. prolifera* cost more than USD100 million. Some scientists hypothesize that the cause of *U. prolifera* is the aquaculture of seaweed in the coastal waters of Jiangsu Province (Hu 2009; Liu et al. 2009). The study of the source of *U. prolifera* is implemented using satellite images and numerical simulation.

It is also thought that macroalgae blooms are related to eutrophication. In the NOWPAP region, eutrophication is a serious environmental issue. It is expected that improving the marine environment in this region will prevent green-tide damage.

# 4 Challenges for studies to cope with HABs

To prevent damage by HABs, appropriate countermeasures should be conducted. The first step, and maybe the last step, is to create a marine environment where HABs cannot occur. The ideal environment is the one where appropriate nutrients levels are maintained and a natural material cycle occurs. However, in determining whether the environment is appropriate, it is necessary to monitor not only the water quality, but also condition of material cycle in environment. Even if the appropriate environment is created, HABs may occur. Therefore, it is important to reduce the risks as much as possible. As of now, the reduction of nutrient loads from the land has been a primary focus, but it is desirable to develop and improve measures which take into consideration an area's ecosystems.

The second step is to detect HABs in their early stage, and to conduct countermeasures before they grow. If early detection is possible, early announcement and/or warnings can be made, giving fishermen sufficient time to implement countermeasures. Some methods for detecting HABs in their early stage, using molecular genetic techniques and remote sensing techniques, are studied increasingly using in situ application. Molecular genetic techniques and remote sensing techniques are introduced in sections 4.1 and 4.2.

The final step is to develop and apply countermeasures to prevent damage when red tides occur. The NOWPAP region has experienced serious fishery damage in the past, and through them, various countermeasures have been developed. Countermeasures against red tides can be classified broadly as either direct or indirect measures. Direct measures are implemented directly against red-tide causative species. These countermeasures eliminate HABs through physical, chemical or biological control. Indirect measures, on the other hand, include methods such as moving fish cages from red-tide areas. There are currently no countermeasures available to prevent the poisoning of fish or shellfish by toxin-producing plankton. Instead, countermeasures focus on preventing the poisoning of consumers by, for example, regular safety inspections and shipping restrictions. Information on countermeasures in the NOWPAP region is summarized in the 'Booklet of Countermeasures against Harmful Algal Blooms in the NOWPAP Region' (http://www.cearac-project.org/wg3/publications/HAB_Booklet.pdf).

Removing causative species from water is another countermeasure option. In Korea, countermeasures to remove causative species using a centrifugal separation system have been applied. New ballast water treatment technologies are also useful for reducing the damage of HABs.

## 4.1 Remote sensing techniques

Satellites are useful tools for red-tide monitoring and offer the ability to obtain information from wider areas. Although there are some challenges, such as the difference in size between the actual red tide and the resolution of the satellite image and interference from clouds, satellites are utilized to monitor red tides in the NOWPAP region (Tang et al. 2003; Ishizaka et al. 2006; Ahn et al. 2006). In Korea, satellites are one of the most effective tools for monitoring *Cochlodinium*.

In addition to being used to identify the distribution of different Chlorophyll-*a* concentrations on the seas surface and estimating areas of red-tide occurrences, satellite images have been recently used as a tool for determining red tides by different wavelength ranges (He et al. 2008; Takahashi et al. 2009).

As high resolution images such as ALOS become available, it is expected that red-tide monitoring with satellite images will increase globally. Satellites can increasingly be used for species identifying, which was previously difficult to do. Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) established a new Working Group to increase research in this area.

Satellite images are used not only for monitoring but also for forecasting the movement of red tides and thereby reducing red-tide damage. When a red tide occurs close to marine culture areas, it may drift on ocean currents and damage these areas. The course of the red tide's movement can be forecast by the flow field and distribution of a red tide using satellite images. Appropriate countermeasures, such as moving preserves and feed withdrawal, can then be taken. These approaches are currently being tested and, when established, recommendations aimed at damage prevention will be provided.

In addition, more studies on understanding red tides by combining in situ monitoring with remote sensing monitoring and numerical simulation have been promoted (Onitsuka et al. 2010). In the NOWPAP region, there have been incidents of red-tide damage to areas remote from the area where the red tides first occur. For example, when *Cochlodinium* red tide occurred along the Korean coastal waters and was transferred by the current to the coastal area of Japan, the Sanin region was damaged by the red tide. Such trans-boundary transfer of red tide can be forecast using satellite images and numerical simulation. The application of these techniques can lead to the minimization of damage. It is therefore expected that there will be an advancement in these technologies.

## 4.2 Molecular genetic techniques

Most important in preventing red-tide damage is the early identification of the causative species and its cell density, as well as taking appropriate countermeasures. The shorter the time it takes to identify the species on site and calculate the cell density, the less damage HABs will cause to the sea area. However, not all the people conducting HAB monitoring are familiar with species identification. In situ prompt identification and measurement of cell numbers requires a high level of expertise. It is therefore necessary to develop an easy and fast way of species identification and cell density measurement which any person can apply.

At present, a molecular biological approach using a unique DNA marker of each species is applied. Fluorescent In Situ Hybridization (FISH) method, real-time Polymerase Chain Reaction (PCR) and Loop-Mediated Isothermal Amplification (LAMP) methods are based on this approach. The FISH method detects the presence or absence of target plankton in the sea by designing complementary probes in DNA markers on species-specific rRNA which are marked with fluorescent pigment. The degree of fluorescence allows the approximate cell number to be estimated (Hosoi-Tanabe and Sako 2006; Takao et al. 2007; Nishitani et al. 2007). Another common method is real-time PCR (Kamikawa et al. 2005, 2006; Kai et al. 2006; Kamikawa et al. 2007). Different from the FISH method, the real-time PRC method identifies species by primers with a peculiar DNA marker. Real-time PCR is also used for identifying cysts, so it is appropriate for species developing cysts and for identifying the presence of cysts in sediment.

The LAMP method is the most simple. It can amplify target gene sequences at a given temperature (around 65 °C) without special reagent or tools. As the efficiency of amplification is good, it is possible to identify species at a low cost.

These methods set probes and primers for each plankton. There are probes developed for many species. These methods can be applied to detect the presence of specific plankton species which are difficult to identify by their shape. People without species identification knowledge can undertake these tests. They are therefore commonly used throughout the world.

Until recently, Mouse Assay and High Speed Liquid Chromatography have been popular methods for detecting shellfish poisoning. However, the recently developed Enzyme Linked Immunosorbent Assay (ELISA) method, which uses biological techniques, has become quicker and easier (Kawatsu et al. 2002). This method is to set the detective quantitication of an antigen by checking the enzyme reaction. Using this method, OA, DTX1, 2 and 3 can be detected quickly and accurately.

Various studies have been conducted on the HAB causative species in the NOWPAP region. These include the identification of populations distributed in each sea area at gene level, understanding how they transfer to other sea areas, the expansion of their distribution and associated mechanisms

(Hosoi-Tanabe et al. 2006; Kim and Kim 2007; Kim et al. 2008; Iwataki et al. 2008; Mikulaki et al. 2008; Nagai et al. 2009). A new method focusing on microsatellites, molecular markers with advanced polymorphism, is under development in order to understand the status of transfer by genetic variation in one species (Nagai et al. 2006A, B).

All of the above mentioned methods are useful for quick identification of red tide and shellfish poisoning causative species. Allowing a person without any profound knowledge to identify causative species can lead to quick responses to red-tide occurrences and can reduce damage. Simple low cost methods need to be developed.

# 5 Conclusion

Considering that all of the NOWPAP member states have conducted regular red tide and toxin-producing plankton monitoring, CEARAC has constructed a system to monitor HABs and regularly share information on HAB events in the region. Through sharing information and knowledge on HABs, it is expected that each member state will enhance its measures against HABs.

Although the number of HAB events in the NOWPAP region has decreased compared with decades ago, HABs still cause significant damage to fisheries. There is also the new issue of Macroalgal blooms in the region. To prevent HAB damage, it is necessary to understand the status and mechanism of these events, and to address them using existing and new technologies and methods (see countermeasures introduced in Chapter 4). Some technologies are still being developed, and their establishment will contribute to a reduction in HAB damage in the region.

The problem with these countermeasures is that they are only a response to events that have occurred. Thus, it is also necessary to create an environment where red tides are unlikely to occur. Rapid economic development in the surrounding countries, the concentration of populations along the coastal areas and the increase in agricultural production cause eutrophication, a major problem in the region, and a cause of red tides. In order to prevent red tides, it is therefore necessary to reduce the amount of eutrophication in the NOWPAP region, and to remediate the environment in the area to its natural nutrient levels and natural material circulation.

Taking the present status and goals into consideration, CEARAC developed the common procedure for evaluating the status of eutrophication in the NOWPAP region, and implemented assessments in the target sea areas of each NOWPAP member state. Assessment indicators include direct factors, such as nutrient enrichment (e.g. nutrient concentration in the sea area), nutrient input from land, the number of red-tide occurrences and chlorophyll-*a* concentration. This assessment method recommends analysis of both the current status and trends. Through these activities, the status of eutrophication in the NOWPAP region will improve in near future.

Through these assessments, each member state understands their individual challenges, and countermeasures will be tailored to improve the status of eutrophication and to reduce red-tide occurrences in the region.

Problems of eutrophication however, cannot be solved by mere reduction of nutrient loads. In Japan, for example, despite the reduction of land-based nutrient loads, the number of red-tide occurrences has not significantly decreased. This may be because current marine ecosystem conditions are not the same as they used to be. Another reason may be the deteriorated process of material circulation in the marine environment caused by human activities.

In order to solve HAB problems and to develop and apply effective countermeasures in the NOWPAP region, it is necessary to improve the status of eutrophication and to improve knowledge on the status of ecosystems including HAB causative species.

In recent years, environmental issues such as the treatment of ballast water and marine biodiversity have received more global attention. There are many busy ports in the NOWPAP region, and many ships are crossing the seas. Shipping density has steadily increased since the early 1990’s due to increasing intra-regional trade. For this reason, the region is threatened with invasive species including new HAB causative species. Such non-indigenous species could lead to ecological disorder and increased HAB damage. Therefore, it will be desirable to take action against such environmental issues.

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