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Historical and Current Status of Red Tides and Shellfish Poisonings in Japan

Report from Fisheries Research Agency and
Fishery Agency, Ministry of Agriculture, Forestry and Fisheries

Written by:

Yuichi KOTANI, Kyoichi TAMAI and Mineo YAMAGUCHI
Harmful Algal Bloom Division
National Research Institute of Fisheries and Environment of Inland Sea
Fisheries Research A gency
Maruishi 2-17-5, Ohno-cho, Saeki-gun, Hiroshima 739-0452, Japan

Shin OKUBO, Keiko MATUI and Takuro NAKAMURA
Resources and Environment Research Division
Fisheries Agency
Ministry of Agriculture , Forestry and Fisheries
Government of Japan
2-1,1-chome,Kasumigaseki,Chiyoda-ku, Tokyo, 100-8907, Japan

1 Red Tides

1-1 Historical events on red tides

The noxious algal blooms associating with mass mortality of marine organisms, especially culturing finfish and shellfish, have occurred frequently since 1970's in Japan, along with the development of heavy industry in coastal terrestrial zone and fish aquaculture industry in marine embayment. Fish mass mortality cases with serious economic loss also increased. Most of the noxious algal species cause water discoloration, i.e., red tides, but less than 20% of the red tides cause harmful effect. The efforts on management and scientific research have been devoted to the harmful species of raphidophytes *Heterosigma akashiwo*, *Chattonella marina*, *C. antiqua* and dinophyte *Gymnodinium mikimotoi* before 1980's. Recently, successive occurrences of novel harmful species such as dinophytes *Heterocapsa circularisquama* and *Gymnodinium* sp. type Imari along with the changes of environmental oceanographic conditions have been broken out.

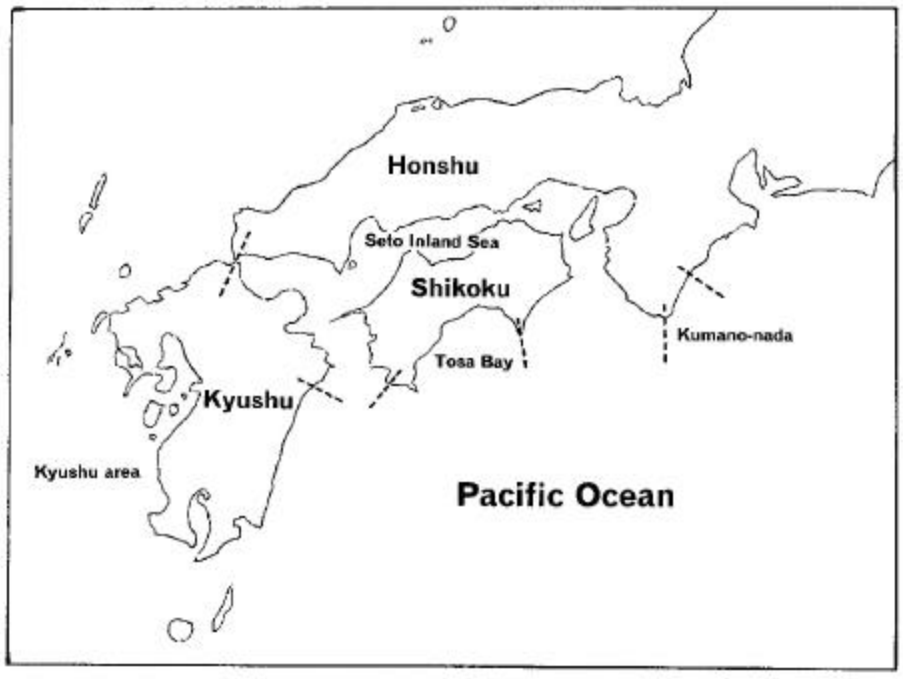

Fig.1 Map of the western part of Japan

1-2 Annual changes of red tide events and economic impacts

Annual changes in number of red tides occurrence in the western part of Japan - Seto Inland Sea, Kyushu area, Tosa Bay and Kumano-nada (Fig. 1) - are shown in Fig. 2. In the Seto Inland Sea, red tide events were very rare in the 1950's. Then, the number of them dramatically increased and reached a peak of about 300 cases per year in the middle of 1970's. After this period, it gradually decreased and recently remained stable around 100 cases per year. This is thought to be mainly due to governmental regulations against eutrophication based on some laws such as "Law concerning special measures for conservation of the environment of the Seto Inland Sea (Seto Inland Sea Law)" enforced in 1973. On the other hand, in the other three areas, the number of red tide events seems not to decrease in this two decades. The ranges are 60 to 110 cases per year in Kyushu area, 3 to 16 in Tosa Bay and 0 to 9 in Kumano-nada.

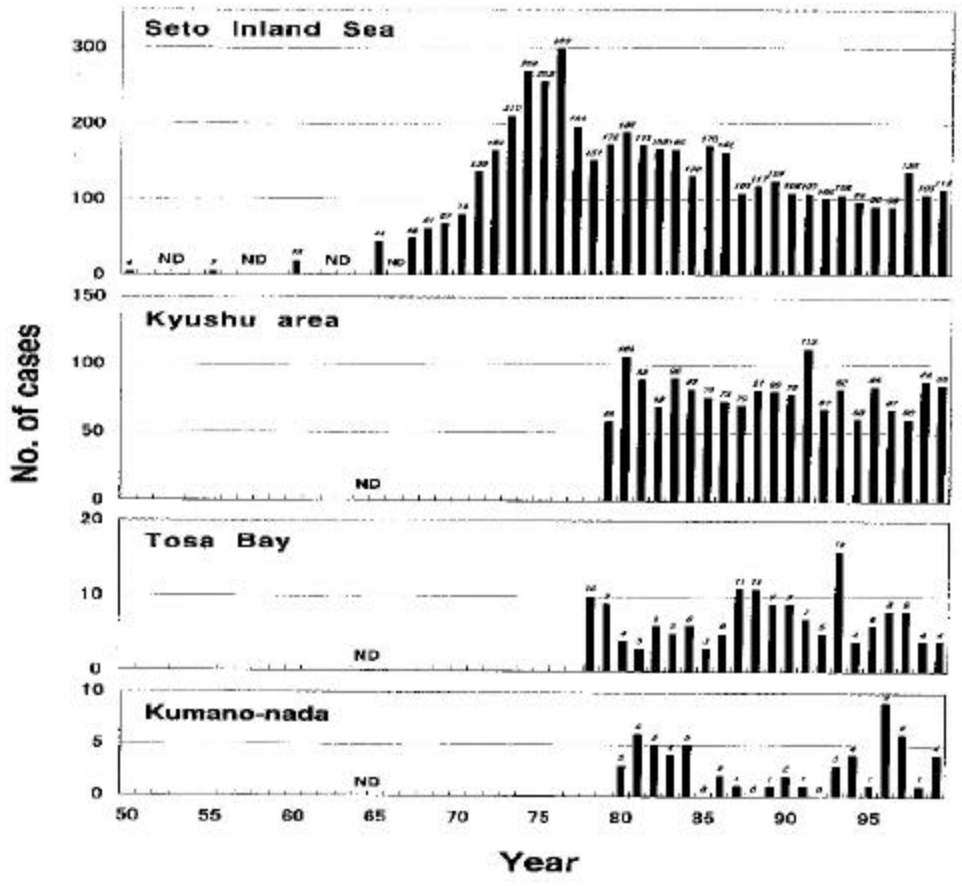

Fig.2 Number of red tide occurrences per year. ND indicates No Data. Refer to Fig.1 for the names of area (Fisheries Agency 1973, 1999a, 2000b)

Annual change in number of red tides which caused fisheries damages in Japan is shown in Fig. 3. In these three decades, it seems to be stable. The numbers of cases range from 20 to 50. Annual change of the economic loss caused by red tides in Japan is also shown in Fig. 4. Maximum loss was recorded in the summer of 1972. Because, *Chattonella* red tides caused severe damage to cultured yellowtail in the eastern part of the Seto Inland Sea. In this case, the loss was about seven billion yen (about 70 million US$). Since then, even in the 1990', severe fisheries damages were sometimes recorded.

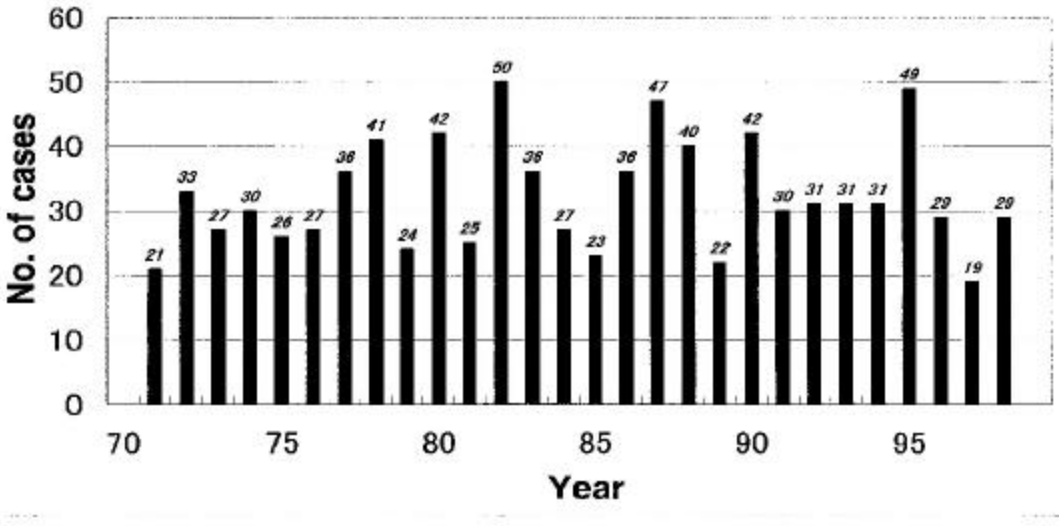

Fig.3 Number of red tides which caused fisheries damages in Japan (Fisheries Agency 1999b)

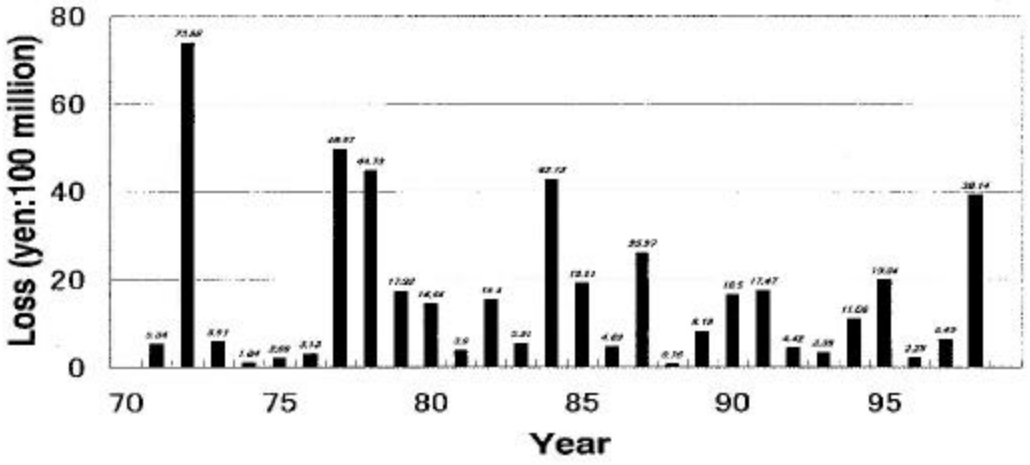

Fig.4 Economic loss caused by red tide in Japan (Fisheries Agency 1999b)

1-3 Major noxious species and their harmful effects

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

Table 1 Major red tide causative species and the number of fisheries damages due to these species in Japan

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

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

(Fisheries Agency 1999a, 2000a)

2 Shellfish Poisonings

2-1 Historical events on shellfish poisonings

In early the 1970s, techniques to mass culture the Yesso scallop (*Patinopecten yessoensis*) were developed, and the aquaculture industry spread mainly along the coasts of northern Japan. On the other hand, the occurrence of shellfish poisonings along the coasts of the northern Japan became frequent since late 1970s. Simultaneously, events of human illness due to eating the contaminated shellfishes occurred. To minimize the effects of the increases of the PSP (paralytic shellfish poisoning) and DSP (diarrhetic shellfish poisoning) outbreaks, administrative measures were set up to

regulate the harvesting and shipping of shellfish. In 1978, the Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries (FA/MAFF), Government of Japan set guidelines for monitoring the scallop culture grounds and marketing regulation together with the Ministry of Health and Welfare. Self-regulation of shellfish shipments by fishermen was implemented when the PSP or DSP contaminations in shellfishes exceeded the quarantine levels of 4.0 and 0.05MU/g edible parts respectively. Since then, various administrative measures have been taken, and monitoring programs for shellfish poisonings planned under the cooperation with the Prefectural Fisheries Departments and Sanitation Departments. As a result, a regional monitoring network has been functioning since 1981 in the northern waters and was expanded to cover the whole of Japan in 1984. Since then, the occurrence of poisoning events caused by marketing shellfish has been avoided.

The microalgae responsible for shellfish poisonings such as ASP (amnesic shellfish poisoning) and NSP (neurotoxic shellfish poisoning) are distributed in Japanese coastal waters. However the occurrence of ASP and NSP events has not been officially recorded and domoic acid contamination over the safe limit of 20μg/g has not been detected in shellfish in spite of intensive surveys during the period 1993-1998 in Japanese coastal waters. Therefore, there have been no monitoring programs for those poisonings, except in Mutsu Bay where ASP monitoring is carried out in the culture grounds of Yesso scallop.

2-2 Changes in the areas and the number of shellfish species affected by PSP and DSP

The five yearly changes in the areas of coastal waters, which have been restricted for shipping and marketing affected bivalves and sea squirt due to PSP outbreaks, are shown in Fig. 5. Shadowed areas indicate the coastal areas where the PSP quarantine limit of 4.0MU/g in shellfishes has been exceeded during each period, with the affected shellfish species. Between 1978-1982 and 1998-2001 July, the number of areas affected by PSP has increased from 10 to 32 and the number of affected shellfish species has increased from 8 to 12. Recently, PSP affected areas which have experienced PSP values exceeding the quarantine limit have shown a trend of expanding from northern to southwestern waters.

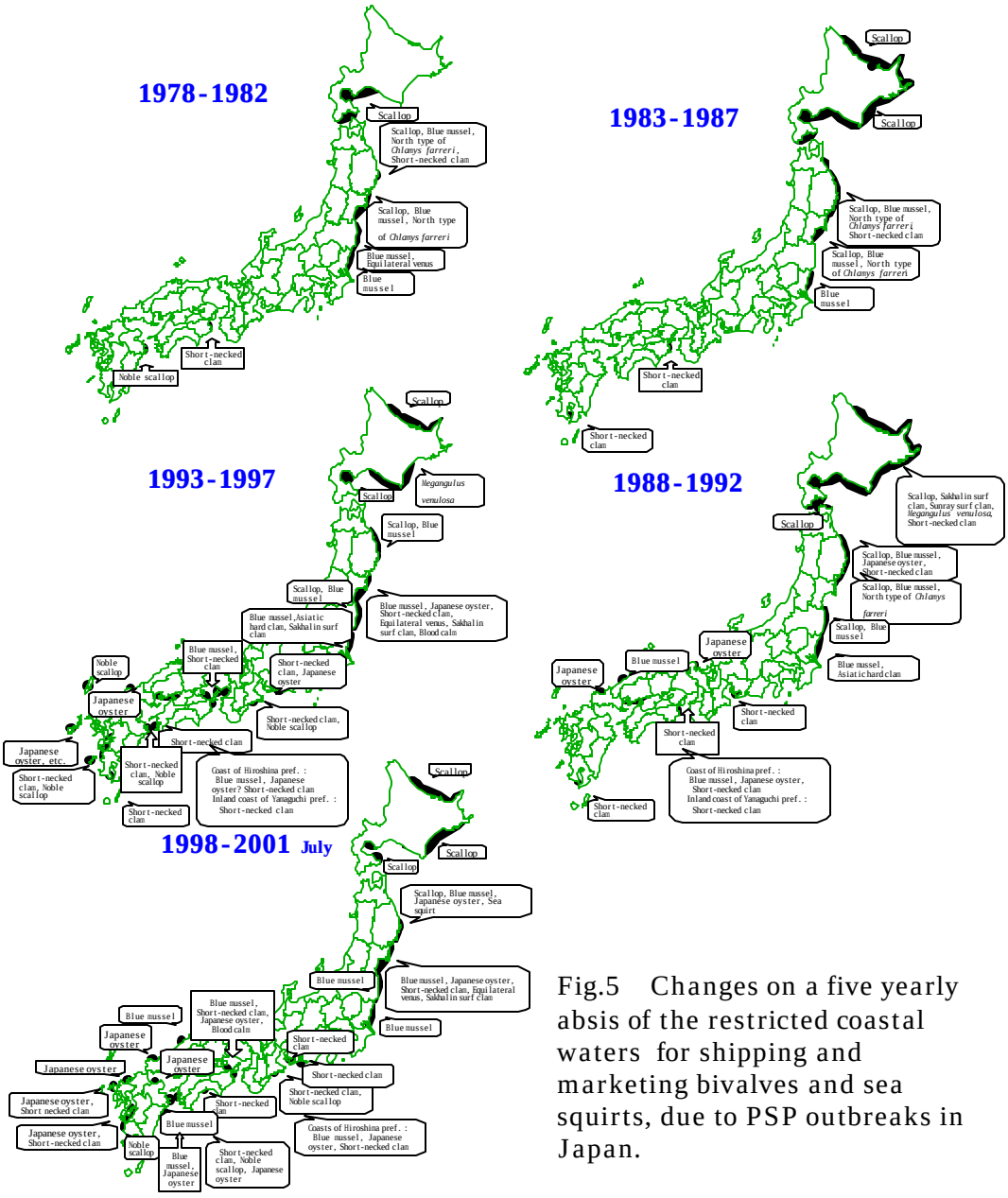

Fig.5 Changes on a five yearly absis of the restricted coastal waters for shipping and marketing bivalves and sea squirts, due to PSP outbreaks in Japan.

Fig. 6 shows the five yearly changes in the areas of restricted coastal waters for shipping and marketing affected bivalves due to DSP outbreaks. Shadowed areas also indicate the coastal waters where the DSP quarantine limit of 0.05MU/g has been exceeded leading to the restrictions. Between 1978-1982 and 1998-2001 July, the number of areas and shellfish species affected by DSP has been almost constant.

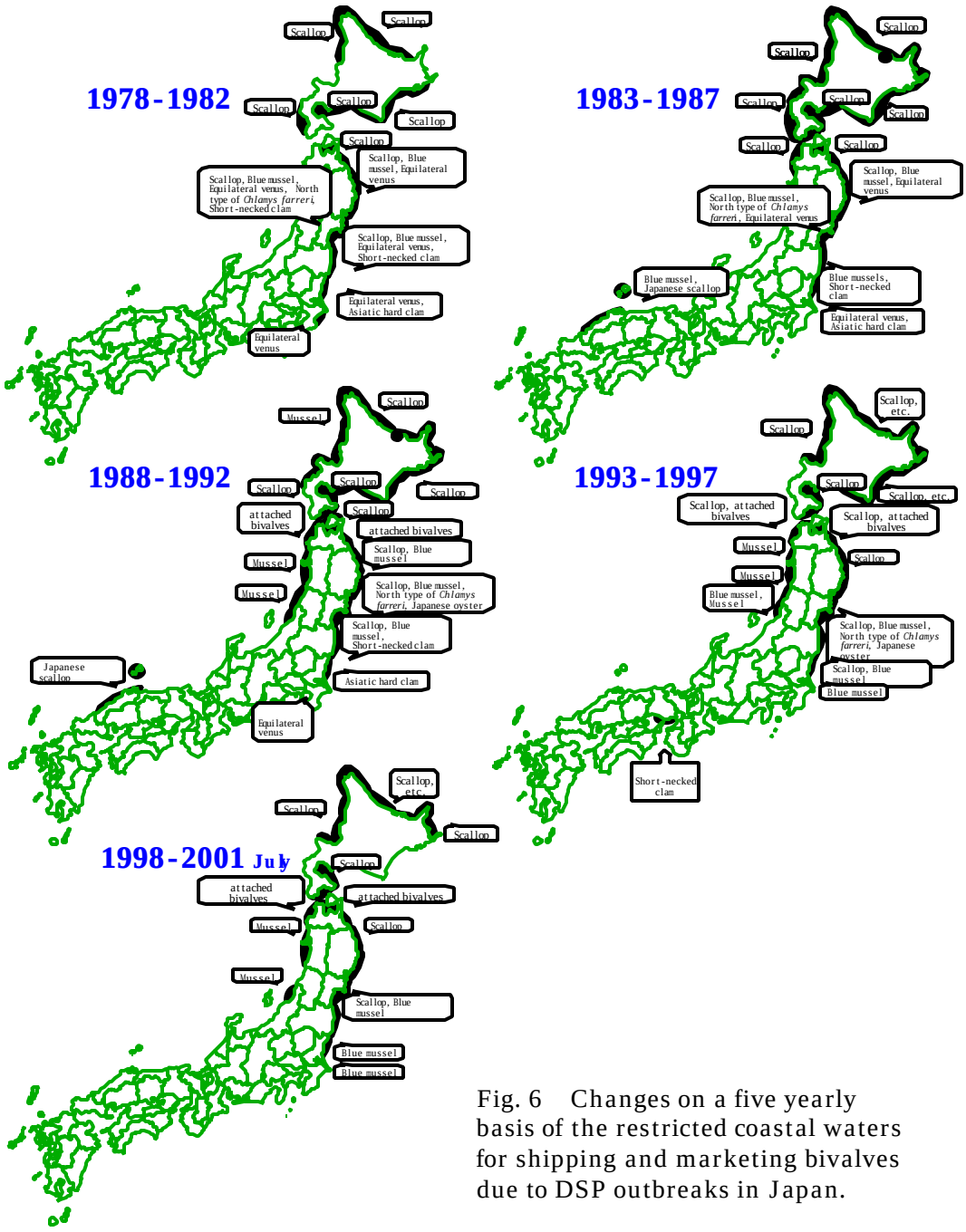

Fig. 6 Changes on a five yearly basis of the restricted coastal waters for shipping and marketing bivalves due to DSP outbreaks in Japan.

2-3 Major toxic microalgae responsible for PSP and DSP

The main species responsible for PSP in Japan are *Alexandrium tamarense*, *A. catenella* and *Gymnodinium catenatum*. Those for DSP are *Dinophysis fortii* and *D. acuminata*. Initially, the PSP problems were involved with scallop culture in northern Japan, but the areas affected by PSP have continued to expand to southwestern waters

(Fig. 5). Based on the results from recent investigations, one of the main causes of the PSP expansion is considered to be due to the occurrence of *G. catenatum* in the coastal waters of western Japan. Recently, PSP events by *G. catenatum* have been increasing in the coastal waters of Kyushu and western Shikoku. Recently, two cases of PSP events by *A. tamiyavanichii* have occurred in Japan. One was along the coasts of Kagawa and Tokushima Prefectures in 1999, and another was in Okinawa Prefecture in 1997 and 1998. While for DSP, the affected areas have not been expanding from the northern waters ever since the early 1980s (Fig. 6) and the main causative species are still *D. fortii* and *D. acuminata*.

2-4 Affected marine organisms by PSP and DSP

From the results of recent surveys, the bivalve shellfishes affected by PSP have diversified and currently affect such species as short-necked clam (*Tapes philippinarum*), equilateral venus (*Gomphina melanaegis*), noble scallop (*Chlamys nobilis*) and so on, and as ascidian species of sea squirt (*Halocynthia roretzi*) in addition to the initially affected bivalve species of scallops, mussels and oysters. Now, the sea squirt which is popular as a seafood in Japan and is cultured mainly along the Pacific coasts in the northeastern Japan, and currently used as one of the monitoring organisms for the PSP and DSP.

The number of bivalve species which have been restricted for shipping by exceeding 4MU/g of the PSP quarantine levels has reached 14 species at present (Table 2). Whereas the number of bivalves species restricted for shipping by DSP has remained still at 9 species. Recently, the cultured green mussel (*Perna viridis*) in Shioya Bay, Okinawa Main Island, has been affected by PSP in 1997 and 1998.

Table 2. The bivalves which have been restricted from being marketed due to exceeding the quarantine levels of PSP and DSP in Japan during the period 1978 to 2001.

Toxins	Scientific name	English name	Japanese name
PSP, DSP	*Mytilus edulis*	Blue mussel	Murasakiigai
PSP, DSP	*Mytilus coruscus*	Mussel	Igai
PSP, DSP	*Crassostrea gigas*	Japanese oyster	Magaki
PSP, DSP	*Chlamys farreri nipponensis*	Farrer's scallop	Akazaragai
PSP	*Chlamys nobilis*	Noble scallop	Hiogigai
PSP, DSP	*Pecten albicans*	Japanese baking scallop	Itayagai
PSP, DSP	*Patinopecten yessoensis*	Yesso scallop	Hotategai
PSP	*Megangulus venulosa*	Great Alaskan tellin	Saragai
PSP	*Spisula polynyma*	Alaskan surf clam	Nagaubagai
PSP	*Pseudocardium sachalinense*	Sakhalin surf clam	Ubagai
PSP	*Scapharca broughtonii*	Ark shell, Blood calm	Akagai
PSP, DSP	*Tapes philippinarum*	Short-necked clam	Asari
PSP, DSP	*Gomphina melanaegis*	Equilateral venus	Kotamagai
PSP, DSP	*Meretrix lamarckii*	Asiatic hard clam	Chosenhamaguri

3 On-going activities and research projects on red tide s and shellfish poisonings

With regard to the research and monitoring activities on red tides and shellfish poisonings in Japan, The FA/MAFF plans the majority of them which are detailed in the following paragraph. The Japan Fisheries Resource Conservation Association (JFRCA), universities, Fisheries Research Agency (FRA), and Prefectural Fisheries Experimental Stations (PFESs), etc. carry them out with budget support from FA /MAFF. There are three sections involved in the researches on red tides and shellfish poisonings in the FRA, an Independent Administrative Institution in Japan, which was established in Apr. 2001 and consists of nine research institutes. Two of the sections in the National Research Institute of Fisheries and Environment of Inland Sea (FEIS/FRA) are researching the physiology and ecology of phytoplankton causing harmful algal blooms including toxic phytoplankton. The other section in the Tohoku National Fisheries Research Institute (TNFRI/FRA) is researching the analytical methods to monitor shellfish toxins and the dynamics of the toxins in shellfish. Furthermore, the FA/MAFF, FEIS/FRA and TNFRI/FRA regularly organize meetings attended by prefectural officials for areas which are having experience of harmful algae and shellfish poisonings to share information and techniques.

3-1 On-going activities implemented under the FA/MAFF

1) Works for measures to prevent damage caused by red tides and shellfish poisonings (consignment project)

(1) Support and reinforce measures against damage caused by red tides and shellfish poisonings

The production and distribution of standard toxins which are commonly difficult to obtain and are indispensable for toxin analyses of shellfish poisonings with HPLC are carried out, in order to promote the monitoring of shellfish toxins by local administrative governments.

Moreover, seminars on the research techniques of red tides and shellfish poisonings to train researchers in local administrative divisions are held annually. With clerical support from JFRCA, FEIS/FRA trains officials from PFESs to help them with techniques for identification and investigation of harmful and toxic phytoplankton species with cooperation of the stuff from universities. With regards to shellfish toxins TNFRI/FRA trains officials from PFESs and Prefecture Institutes of Public Health to help them with techniques for analysis of PSP and DSP toxins with cooperation of the university stuff and the Japan Food Research Center. Teaching texts and videos to assist with plankton monitoring are issued, and teaching videos for fishermen are also issued

by the JFRCA with cooperation and direction of the FEIS/FRA.

(2) Urgent measures against *Heterocapsa* red tides

To reduce the damage caused by the noxious species *Heterocapsa circularisquama* etc., this work aims to develop the techniques for predicting *H. circularisquama* blooms and for preventing damage by them.

(3) Advanced use and development of an information network system on red tides and shellfish poisonings

New systems to transmit a large amount of data collectively are being developed and added to the present information network system on red tides and shellfish poisonings, with a database to achieve more highly usefulness of the system. Broad and general information on red tides and shellfish poisonings are being processed, and the functions offered to the users (administrative divisions etc.) are being developed and improved.

(4) Measures to maintain the safety of marine foods such as bivalves against shellfish poisonings

Studies to elucidate the mechanisms of toxication and detoxication in shellfish are being promoted. Handy and possible screening techniques for processing a large amount of samples are being developed and these monitoring techniques will be validated Procedures for the effective restriction to reduce the work load to fishermen caused by shellfish poisonings and for supplying the safe marine foods for consumers will be established in this work.

2) Research to encourage environmental conservation in the coastal fishing grounds (consignment project)

(1) Development of basic technology to control red tides and shellfish poisonings

The mechanisms by which red tides and shellfish poisonings occur and become an obstruction to the fishery environment will be elucidated. The development of basic technology to control red tides and shellfish poisonings will be planned in this sub-project, including the establishment of techniques for predicting the occurrence of red tides and shellfish poisonings.

3) Research to promote environmental conservation in the coastal fishing grounds (subsidy project)

(1) Measures to enhance the monitoring systems **in the coastal fishing grounds**

For the maintenance of good fishing conditions, plans to further enhance the efficiency of the monitoring system by the fishermen and to promote activities on waste removal in the coastal fishing grounds and the cleanup of beaches are performed in this work.

3-2 On-going research projects implemented by the FRA

1) Development of techniques for predicting phytoplankton blooms responsible for paralytic shellfish poisoning (Research period: FY 1998-2001)

The improvement of PSP monitoring systems, shellfish cultivation techniques and marketing systems based on the prediction of toxic phytoplankton blooms will reduce the economic losses to the shellfish fishery. In this study, (1) the physiological and ecological characteristics of PSP toxin-producing phytoplankton, (2) the relationships between PSP toxin-producing phytoplankton and coastal organisms, and (3) the mechanisms of toxin accumulation in bivalves will be clarified through field investigations, laboratory experiments, and analysis of toxins. Furthermore, we aim to develop a technique for predicting *A. tamarense* blooms in Hiroshima Bay. Organizations involved in this projective study are the Toxic Phytoplankton Section, Harmful Phytoplankton Section, Biological Environment Section of FEIS/FRA; Coastal Fisheries Promotion Section of TNFRI/FRA; Food Safety Section of NRIFS/FRA, and consignment partners in Kyushu and Tohoku Universities.

2) Techniques for the prevention of mass mortalities of bivalves due to the harmful dinoflagellate *Heterocapsa circularisquama* and preservation of the marine environment (Research period: FY 2000-2004)

The dinoflagellate *Heterocapsa circularisquama* is one of the most harmful microalgae in Japanese coastal waters. Recently, the distribution of *H. circularisquama* has spread rapidly in the western part of Japan. The purpose of this study is to elucidate the mutual relationship between *H. circularisquama* and other plankters and to promote predictive techniques of the occurrence of red tides, techniques to eliminate *H. circularisquama* and techniques to prevent mass mortalities of bivalves occurring due to *H. circularisquama*. Organizations in this projective study are the Harmful Phytoplankton Section, Toxic Phytoplankton Section, Biological Environment Section and Tidal Zone Ecology Section of FEIS/FRA.

3) Development of the techniques for detecting the vegetative cells and resting cysts of toxic phytoplankton species by fluorescent monoclonal antibodies (Research period: FY

1999-2001)

The fluorescent monoclonal antibodies which react specifically to the vegetative cells and resting cysts of toxic phytoplankton species is investigated. By using these fluorescent monoclonal antibodies, techniques for objectively, handily, and promptly detecting the vegetative cells and resting cysts of toxic phytoplankton species collected from the field under a fluorescent microscope are being developed. The toxic Phytoplankton Section of FEIS/FRA and Transgenic Corporation execute this study.

4) Development of a technique for eliminating *Heterocapsa circularisquama* red tides by use of lytic viruses (Research period: FY 2000-2002)

The objective of the study is the accumulation of scientific information that is necessary to develop the means for eliminating red tides by characterizing the viruses infecting the noxious red tide-causing alga *Heterocapsa circularisquama*. The Harmful Phytoplankton Section of FEIS/FRA curries out this study.

4 Present and prospective subjects on red tides and shellfish poisonings in Japan

1) The practical use of new techniques in the field monitoring system on red tides and shellfish poisonings, e.g. newly developed oceanic instruments and the immunoassay technique for detecting the harmful algae.

2) Positive introduction of molecular techniques into the studies of red tides and shellfish poisonings, e.g. the classification and identification of harmful microalgae, and the determination of their physiology and ecology.

3) Development and practical use of new technology to control red tides by using of phytoplankton control factors, e.g. algicidal bacteria and lytic viruses which exist naturally in the coastal ecosystem.

4) Urgent promotion of investigations on novel toxic algae such as *G. catenatum* and *A. tamiyavanichii*, to minimize the effects of any further outbreaks and expansion of PSP by these species in the coastal waters of western Japan.

5) Establishment of measures against ASP outbreaks in the future, and the accumulation of scientific information concerning ASP and the causative diatom species.

6) Establishment of guidelines for the careful monitoring and restriction on shellfish poisonings according to each shellfish species, each fishery ground and each causative species.

7) Reinforcement of public education and announcements on shellfish poisonings for avoiding the occurrence of poisoning due to contaminated bivalves collected by the public for personal consumption.