Hydrobiologia **512:** 145–151, 2004.
P.O. Ang, Jr. (ed.), Asian Pacific Phycology in the 21st Century: Prospects and Challenges.

Solving the coastal eutrophication problem by large scale seaweed cultivation

Xiugeng Fei
Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China
E-mails: fei@ms.qdio.ac.cn

Key words: environment, eutrophication, *Laminaria*, *Gracilaria*, *Porphyra*, red tide, seaweed cultivation, China

Abstract

Eutrophication is becoming a serious problem in coastal waters in many parts of the world. It induces the phytoplankton blooms including 'Red Tides', followed by heavy economic losses to extensive aquaculture area. Some cultivated seaweeds have very high productivity and could absorb large quantities of N, P, CO_2 , produce large amount of O_2 and have excellent effect on decreasing eutrophication. The author believes that seaweed cultivation in large scale should be a good solution to the eutrophication problem in coastal waters. To put this idea into practice, four conditions should be fulfilled: (a) Large-scale cultivation could be conducted within the region experiencing eutrophication. (b) Fundamental scientific and technological problems for cultivation should have been solved. (c) Cultivation should not impose any harmful ecological effects. (d) Cultivation must be economically feasible and profitable. In northern China, large-scale cultivation of *Laminaria japonica* Aresch. has been encouraged for years to balance the negative effects from scallop cultivation. Preliminary research in recent years has shown that *Gracilaria lemaneiformis* (Bory) Daws. and *Porphyra haitanensis* Chang *et* Zheng are the two best candidates for this purpose along the Chinese southeast to southern coast from Fujian to Guangdong, Guangxi and Hong Kong. *Gracilaria tenuistipitata* var. *liui* Chang *et* Xia is promising for use in pond culture condition with shrimps and fish.

Introduction

Coastal environment is usually associated closely with intensive human economic activities. It is a very important part of the human society. Coastal marine environment receives all the water run off from land through river or ground water systems. With it are all the organic and inorganic wastes. In the later part of the last century, the coastal environment of China and many other parts of the world have experienced a tremendous increase in mariculture activities. These coastal zones have thus become an important center for the exploitation of marine fisheries resources. Because coastal environment is usually quite narrow, with shallow water depth and restricted water circulation, flushing rate is usually limited. One important consequence of this is that the heavy use of the coastal environment often resulted in the accumulation of wastes from different human activities that eventually lead to serious pollution problem. This in turn leads to the deterioration of the coastal environment that triggers a chain of negative reactions and consequences, including coastal eutrophication, frequent occurrence of red tides, and breakdown of sustainable economic development. Eutrophication, with excessive amount of N, P, CO_2 and insufficient amount of dissolved O_2, is becoming a serious problem in coastal seawater environment all over the world and has attracted much attention in recent years. Many researchers believe that it it possible but very difficult to address this problem.

For years, large-scale cultivation of *Laminaria japonica* Aresch. has been encouraged in northern China to balance the negative environmental effect due to scallop cultivation. This strategy works well at a preliminary stage. But to use this strategy as an ultimate solution to eutrophication due to mariculture, more basic and applied researches are needed. Per unit area production of cultivated seaweeds is high. Productivity of cultivated seaweeds is much higher than that in their natural habitats. Cultivated seaweed grows much better at those areas where N and P are abundant (Lobban & Wynne, 1981; Miura, 1992; Ohno & Critchley, 1993; Critchley & Ohno, 1998; Fei, 1996). For cultivation of *Porphyra yezoensis* Ueda in China, good harvest and good quality could only be achieved in those regions where N concentration (NO_3-N + NH_4-N) in the seawater is over 100 mg m^{-3} (>7.2 mM). When N-nutrient level is below 50 mg m^{-3} (3.6 mM), the quality and yield will go down and application of N fertilizers becomes necessary (S.E.P.E. & S.A.T.M., 1978). On the other hand, seaweed requirement for P is not as sensitive as that for N. From many years of practice and observation this author has found that this is true not only for cultivated *Laminaria* and *Porphyra* but also for cultivated *Gracilaria*. This author has thus proposed that large scale seaweed cultivation could be a possible solution to the problem of eutrophication by decreasing nutrients in seawater (Fei, 1978, 1983, 1996; Fei *et al.*, 1998, 1999). Cultivation experiments have been conducted since 1987 along the coastal region in South China. Most of the results were encouraging. This idea of using seaweed to reduce excessive nutrient, hence solving the problem of eutrophication, is thus very promising and further research efforts are now being continued to evaluate its potentials.

The sources of organic eutrophication in the sea and the coastal environment in mainland China

Fast growing large coastal cities and increasing population in these cities produce large amount of CO_2 and refuses containing large quantity of N and P. Large quantities of N and P fertilizers are applied in agriculture on land and only a part of these are absorbed by the plants, with the rest being eventually released to the environment. Culture of livestock releases huge amount of excrement to the environment as well. All these eutrophication products are created by human activities on land. They will eventually reach the coastal seawater via sewage and other pathways and become the main source of eutrophication in the sea.

The secondary pollution elements in coastal water are created by extensive mariculture of animals itself. The animal cultivation develops so fast in a vast area of coastal waters, such that in many places almost every space is occupied and exceptionally dense population of these cultivated animals has been formed. Large amount of N, P and CO_2 released from these dense populations of cultivated animals are being recycled back to the cultivation area, creating the secondary source of eutrophication (Zhang et al., 1994). Other than the above two sources, over feeding of shrimp in ponds and fish in cages also produces great amounts of nutrient rich sediment to their surrounding environment. This becomes another major input source of N, P and CO_2 to the mariculture environment (Zhu & Li, 1996).

Since the 80's, coastal mariculture development in China has increased tremendously. More than 40,000 km^2 of the coastal area are now being used for mariculture and more than three million people are directly engaged in mariculture related activities. The production output from mariculture in 1982 was 86 million tons. Ten years later in 1997, this reached 792 million tons, and in 1999, 974 million tons. For several years now, mariculture production in China, now stands at 39% of its total fisheries production, is the highest in the world. Over this same period, however, the occurrence of red tide event has increased from an average of 50 times annually in the 80's to 250 times annually in recent years. Because many aquaculture facilities are placed in the water for prolonged period of time, fouling by all sort of benthic organisms is serious. Heavy sedimentation of organic materials, e.g. from excessive feeds used in mariculture and from animal excrement, led not only to increase in the amount of organic nutrients in the surface water, but also to poor oxygen condition in the near bottom water. The quality of water in mariculature zones deteriorated, inducing diseases and red tide occurrence. This vicious cycle of events led to heavy economic losses. In 1998 alone, the occurrence of diseases in mariculture animals reached a high rate of 30%, with a direct loss of more than 10 billions Chinese Yuan.

In 1998, the coastal areas in China with water quality that was below the first class water quality standard reached 228,000 km^2. This was a 100% increase over that recorded in 1992. Of this, about 40,000 km^2 of the coastal areas were below the fourth class water quality standard. These areas could no longer satisfy the requirement for mariculture, water sports and coastal tourism activities. In some areas, the concentration of N is 10 times higher than that allowed for mariculture zone.

Pollution created by human activities induces eutrophication in the sea. The sources of pollution mainly come from the land and also from coastal waters by mariculture itself. This should be taken into consideration if this important problem is to be solved.

Effect of marine plants on eutrophication in the sea

Autotrophic and heterotrophic organisms are the two main inhabitants in the sea. All animals like fish and shrimp are heterotrophic; they feed on other organisms to obtain energy and raw material for their growth and release N, P and CO_2 via excrement and respiration. All marine plants like seaweeds or diatom are autotrophic; they feed themselves by absorbing N and P from the seawater for their nutrition and CO_2 also from the seawater for their photosynthesis. Living plants release O_2 via photosynthesis, release few N and P compounds via excretion but the amount is very small in comparison to those of the animals. Therefore, heterotrophic animals are the producers of N, P and CO_2 in the sea and autotrophic organisms are the removers. The activities of the autotrophic organisms balance those of the heterotrophic organisms (Lobban & Wynne, 1981; Tseng, 1990).

There is a large diversity of marine plants in the sea including the small sized micro-algae (such as diatoms) and the large sized macro-algae (such as *Laminaria* and *Porphyra*) (Radmer, 1996). Micro-algae grow well in nutrient rich seawater and some species grow very fast and could make a bloom in the sea within a few days during warm season. They do remove large quantity of nutrients from their surrounding seawater and perform as an eutrophication remover. However, they would not last very long because of their short life span of only a few days. They eventually die and huge amount of dead bodies would accumulate in the water. Consequently the bacteria will decompose their dead bodies, thus creating a low dissolved Oxygen environment. The nutrients from these dead bodies will eventually be released back into the seawater. The micro-algae started as a nutrient remover but turned to become the source of eutrophication. Macro-algae (seaweeds) on the other hand could accumulate considerable biomass within months and years. This is especially so for cultivated species during cultivation season. Based on this author's data so far, biomass (wet weight) of cultivated *Laminaria* just before harvest is 80–120 tons ha^{-1}, that of cultivated *Porphyra* is 30–60 tons ha^{-1} and that of cultivated *Gracilaria* 40–80 tons ha^{-1}. When they grow in large-scale, macro-algae accumulate large amount of C, N and P in their body.

Table 1 shows the C, N and P contents of some of the common cultivated species like *Laminaria, Porphyra* and *Gracilaria*. This shows that these cultivated species have a special ability to remove the main eutrophication elements of C, N and P from their surrounding seawater. Because their life span is at least several months longer than that of micro-algae, this makes them very effective removers of these elements. When cultivated macro-algae are harvested from their culture ground, 25–79 kg (mean 52 kg) of C and 2.5–6.2 kg (mean 4.4 kg) of N will be removed from the water with every ton wet weight of these algae harvested. As mentioned above the magnitude of productivity of cultivated seaweed is 30–120 wet ton ha^{-1}. That means that within 2 m depth of the surface seawater that is usually occupied by the cultivated algae, the cultivated population will remove 1560–6240 kg C or 132–528 kg N from 20 000 m^3 of seawater within one ha of cultivation area. Take N as an example, the removing rate will be 6600 mg N m^{-3}, 16.5 times higher than 400 mg N m^{-3} which is the indication level of N eutrophication. These figures make cultivated macro-algae ideal candidate as nutrient removers and point to their potential application for this purpose.

Possible ways to solve the problem of eutrophication

Given that the main elements causing eutrophication in the sea originally come from land through human activities, a solution to this is to control these activities at their source. Decreasing the export of terrestrial nutrients should be taken into first consideration. This is, however, not an easy task and needs huge amount of effort and investment on infrastructure development, research, careful planning and coordination before the goals could be achieved. This will take time and hence could only be considered as a long term target. Under the present situation, there may be palliative but workable short term solutions to these problems.

Seaweeds are nutrients remover. There is, therefore, a great potential to remove large amount of C, N, and P nutrients with extensive seaweed cultivation. Seaweeds produced from these cultivations have many commercial and industrial applications. They could be

Table 1. Nutrient contents (%) of cultivated seaweed[a]

Contents	*Laminaria*		*Porphyra*		*Gracilaria*	
	Dry	Wet	Dry	Wet	Dry	Wet
Protein	8.20	1.40	39.00	3.90	16.30	1.30
Carbohydrates[b]	62.70	10.50	43.00	4.30	78.80	6.30
C	23.60	7.90	27.30	2.70	31.30	2.50
N	1.30	0.22	6.20	0.62	2.60	0.25
P	0.20	0.03	0.58	0.06	0.03	0.03

[a]Resources Council, Science and Technology Agency, Japan (1982).
[b]Includes Carbohydrate, lipid and fiber.

widely used as food, as major raw material for the extraction of chemicals and pharmaceuticals, as fodder for livestock or as organic fertilizer. For instance, agar, carrageenans and alginates are the three major phycocolloids extracted from the seaweeds (Tseng & Fei, 1987; Yarish et al., 1988; Miura, 1992; Jensen, 1996). They are in great demand and have extensive commercial and industrial applications. It is thus possible to promote large-scale cultivation of commercially important species. This will not only be a powerful method for removing large amount of nutrients, it could also benefit the local economy by providing jobs and sources of marketable products.

Seaweed cultivation would complement the cultivation of animal ecologically. At present, in most Chinese cultivation regions, animal cultivation prevails over seaweed cultivation and in extreme cases animal is the only organism under cultivation. There is an economic explanation for this phenomenon as animal products tend to command a higher price than seaweed products. However, the author believes that adding seaweed cultivation to these regions as much as possible will help to form a better ecologically balanced culture environment. This is far more critical than purely economic consideration alone.

From idea to real application and prerequisite conditions

Theoretically, to apply seaweed cultivation for eutrophication improvement is possible. To put this idea into practice, some prerequisite conditions should be fulfilled. Firstly, oceanographic conditions should be suitable for large-scale seaweed cultivation. Usually, near-shore or offshore area with 20 m water depth is ideal. Social acceptance is also an important condition for conducting cultivation activities in these areas. Second, in order to prevent failure, scientific and technological problems for cultivation of the species should have been fundamentally solved before taking on large scale cultivation. Third, transplantation and introduction of ‘good’ species or strains from outside is often necessary. Harmful ecological effects caused by invading species should be carefully considered and avoided. Finally, There should be a market for the product of seaweed cultivation in order to make the whole exercise economically viable.

Promising cultivated seaweed species as candidates for eutrophication cleaner

Based on extensive research experiences on cultivation biology of economically important seaweeds, this author believes that all cultivated seaweeds have actually played and are continue to play the role of cleaning their surrounding environment by removing large quantity of nutrients. In north China, *Laminaria* and*Undaria* have been the most important seaweeds traditionally cultivated. *Porphyra* is the most important seaweed cultivated traditionally in central China and *Gracilaria* is a newly developed seaweed species cultivated along the southern coast of China in a much smaller scale. China is producing about 3 million tons of *Laminaria* each year. This means about 237 thousand tons of C and 660 tons of N are fixed within a year in cultivated *Laminaria*. Scientific and technological problems for large-scale cultivation of these species have already been solved. It is not difficult to use them as a tool for solving the coastal eutrophication problem. For this new application, the cultivation scale should be much larger than the original. The main problem is how to deal with the huge amount of product from these large-scale cultivations. In northern China, *Laminaria* has been under cultivation for

Table 2. Results of transplantation experiment on *Gracilaria lemaneiformis*. The algae were transplanted from Qingdao and grown in Lianjiang, Fujian, SE China

Culture rope length (m)	Start 11/12/98	Finish 10/05/99	Increase (times)	Growth (% d^{-1})
92	3.22 kg	356.5 kg	110.7	3.14
273	8.19 kg	814.4 kg	99.4	3.06
Total 365	11.4 kg	1170.9 kg	102.6	3.09

many years and is still the best candidate for eutrophication treatment. In southern China, more seaweed cultivation is needed because the problems of eutrophication are more serious. But seaweed cultivation in southern China is largely under-developed at present. Our recent research and experiment has shown that *Gracilaria lemaneiformis* and *Porphyra haitanensis* are the two promising candidates for southern China. The main characters of the four most promising species are described briefly below.

Gracilaria lemaneiformis

This species belongs to Rhodophyta (red algae), growing well along the coast of Shandong. Standing crop in natural habitat is very low. Research and experimental cultivation has been carried out since 1981. In Qingdao it grows in spring and autumn with a growth rate of 6.6% d^{-1} and a 20 times biomass increase in 45 days has been recorded. Its favorable growing temperature is 12–23 °C. Because the cold season is very long in Qingdao, the fast growing period for this species is very short. Twenty times increase in biomass is not good enough for initiating a good cultivation industry in the Qingdao region. But if one could transplant it to southern provinces where favorable culture period in the winter and spring is much longer, we expect much higher harvests. On December 11, 1998 an experiment on transplanting *Gracilaria lemaneiformis* from Qingdao to Lianjiang, Fujian was started. The experiment was completed 150 days later on May 10, 1999 and the result is summarized in Table 2. The result shows a 100 times increase in the biomass of *G. lemaneiformis* within 150 days. In 1997 similar experiment on transplanting this species from Qingdao to Zhanjiang, Guangdong was carried out and we obtained 63 times increase of biomass within 45 days. In early 1999, to research on eutrophication improvement we transplanted *G. lemaneiformis* from Qingdao to Santou, Guangdong and obtained 207 times biomass increase within 64 days. All these transplanting results have convinced us that this species introduced from further North to the South will grow much better in its new environment than in its native old region (Brawley & Fei, 1988; Zhang et al., 1993; Fei, 1996; Fei et al., 1998). Because of high temperature during most time of the year, *G. lemaneiformis* could not pass the summer in the southern provinces in China. Harmful ecological effects by invading species could not happen. *Gracilaria lemaneiformis* is a high quality raw material for agar industry and a good fodder for industrialized abalone cultivation. It is in big demand in southern China. This makes it a very promising species at present for both purposes, i.e., for removing nutrient from coastal water and for providing the product to feed the mariculture abalone.

Gracilaria tenuistipitata *var.* liui

This is another red alga and was introduced recently from Taiwan. This can grow well under high temperature and in relatively stable water conditions like in a fish or shrimp pond. Its ability to absorb large amount of nutrient is also evident. In January 2002, introduction of this species in ponds experiencing red tide in Dongshan, Fujian Province in SE China quickly suppressed red tide bloom within one or two days. Similar to *Gracilaria lemaneiformis*, it is easy to harvest this species. Because this species is also restricted in its seasonal growth due to temperature, it is unlikely to cause negative ecological effect as an introduced species. In fact, it can alternately grow with *G. lemaneiformis*, which grows in colder months of the year, thus ensuring a year round availability of seaweed resources.

Porphyra haitanensis

This species, a traditional edible red alga, grows along the coast of Fujian in southeastern China. Artificial cultivation of this species was initiated in the sixties and large-scale cultivation has been developed mainly in Fujian and Zhejiang, SE China. Favorable temperature for its growth is 12–25 °C. Transplanting experiment was conducted in 1997 from Jiangsu to Zhanjiang, Guangdong where *P. haitanensis* has never been grown. Our experimental result showed that one harvest from a 30 m^2 net was 50 kg wet weight. That is equivalent to about 16.7 tons ha^{-1}, a level acceptable to promote cultivation in this new area (Li et al., 1992). Because of high temperature during most time of the year, *P. haitanensis* could not pass the summer there and the negative ecological effects could not happen. Therefore, *P. haitanensis* becomes the second promising species for removing eutrophication nutrients especially in southern China, including Hong Kong.

Laminaria japonica

Laminaria japonica is not a native of Chinese shores though it has been a well-known food commodity in the Chinese market for more than one thousand years. It is a native species of the Japan Sea. The species was accidentally introduced to Dalian in 1927. Modern cultivation of this species started in 1952 and has now developed greatly, growing well by the Chinese summer sporeling method. It is now under cultivation from Liaoning and Shandong to Zejiang and Fujian Provinces with annual production of more than 300 million tons wet weight. From 47 years successful history of *Laminaria* cultivation in China, effects on eutrophication have all been positive and harmful or damage examples caused by the cultivation activity have not been found. This is a good candidate for removing eutrophication nutrients especially in northern China.

Conclusions

The fast-growing coastal cities and fast-developing animal mariculture industries have resulted in eutrophication along the coastal regions of China. Actually, it is the human activity on land and in the sea, which brings about this problem. China is the world largest mariculture country and is also one that is most seriously suffering from disasters caused by eutrophication. The first and most serious victim is mariculture itself. To find a solution to this problem is a very urgent task. It is a difficult, complicated and long-term task. To use seaweed cultivation for the solution of eutrophication is just one of the ways, but it is the promising and workable one at present time. Cultivated seaweed does not only grow fast but can also be easily harvested from the water. Because the cultivation technique is already mature, it is easy to manipulate. Because the investment cost for seaweed cultivation is comparatively low it is feasible (Tseng & Fei, 1987; Crichley & Ohno, 1988; Miura, 1992; Ohno & Critchley, 1993; Fei, 1996; Yarish et al., 1998). Cultivation of seaweed can remove nutrients efficiently and could be profitable at the same time. *Gracilaria lemaneiformis* is good for sub-tidal shallow water area. *Porphyra haitanensis* is good for both inter-tidal and sub-tidal shallow water. *Gracelaria tenuistipitata* var. *Liui* is promising for shrimp pounds or fish cages. We strongly believe that large-scale seaweed cultivation in the sea will help to solve the eutrophication problem at the present stage.

Acknowledgements

This work was sponsored by the National Climbing Project B PD-B 6-4-2 of the State Science and Technology Commission of China and by the National Science Foundation of China H C0205 39770593. The author extends sincere thanks to Prof. C. K. Tseng for his encouragement, valuable comments and for reviewing this manuscript. This is Contribution No. 3360 from the Institute of Oceanology, Chinese Academy of Sciences and Contribution No. 183 from the Experimental Marine Biology Laboratory, Chinese Academy of Sciences (EMBLC).

References

Brawley, S. H. & X. G. Fei, 1988. Ecological studies of *Gracilaria asiatica* and *Gracilaria lemaneiformis* in Zhanshan Bay, Qingdao. Chinese J. Oceanol. Limnol. 6: 20–34.

Critchley, A. & M. Ohno, 1998. Seaweed Resources of the World. Japan International Cooperation Agency (JICA), Tokyo.

Fei, X. G., 1978. Principle results on the experimental phycoecology research of Haidai (*Laminaria japonica*) and Zicai (*Porphyra yezoensis*), Haiyang Kexue (Supplement): 55–56 [in Chinese].

Fei, X. G., 1983. Macroalgal culture in California and China. In Laura Mckay (ed.), Seaweed Raft and Farm Design in the United States and China. New York Sea Grant Institute, New York: 301–308.

Fei, X. G., 1996. Domestication and cultivation of seaweed. In Li Deshang (ed.), Proceedings of the International Symposium on Aquaculture. Qingdao Ocean University Press, Qingdao: 31–37.

Fei, X. G., Y. Bao & S. Lu, 1999. Seaweed cultivation: traditional way and its reformation. Chinese J. Oceanol. Limnol. 7: 193–199.

Fei, X. G., S. Lu, Y. Bao, R. Wilkes & C. Yarish, 1998. Seaweed cultivation in China. World Aquacult. 29: 22–24.

Jensen, A., 1993. Present and future needs for algae and alga products. Hydrobiologia 260/261: 15–23.

Li, S. Y., B. F. Zheng & X. G. Fei, 1992. Northward transplantation of *Porphyra haitanensis* in China. Oceanol. Limnol. Sinica 23: 297–301 [in Chinese with English abstract].

Lobban, C. S. & M. J. Wynne, 1981. The Biology of Seaweeds. University of California Press, Berkeley, CA.

Miura Akio, 1992. Cultivation of edible algae in Japan. Serial in Fisheries (88) [in Japanese].

Ohno, M. & A. T. Critchley, 1993. Seaweed Cultivation and Marine ranching. Kanagawa International Fisheries Training Center, Japan International Cooperation Agency (JICA), Tokyo.

Radmer, R. J., 1996. Algal diversity and commercial algal products. BioScience 45: 263–270.

Resources Council, Science amd Technology Agency, Japan, 1982. Standard Tables of Food Composition in Japan, fourth revised edition. Resources Council, Science amd Technology Agency, Japan [in Japanese].

S.E.P.E & S.A.T.M. (Section of Experimental Phyco-ecology and Section of Algal Taxonomy and Morphology, Institute of Oceanology Academia Sinica), 1978. Manual of Tiaoban Zicei (*Porphyra yezoensis* Ueda) cultivation. Science Press, Beijing [in Chinese].

Tseng, C. K., 1990. The theory and practice of phycoculture in China. In Rajarao, V. N. (ed.), Perspectives in Phycology (Prof. M.O.P. Lyenger Centenary Celebration Volume). Today and Tomorrow's Printers and Publishers, New Delhi, India: 227–246.

Tseng, C. K. & X. G. Fei, 1987. Macroalgal commercialization in the Orient. Hydrobiologia 151/152: 167–172.

Yarish, C. R., Wilkes, T, Chopin, X. G. Fei, A. C. Mathieson, A. S. Klein, C .D. Neefus, G. G. Mitman & I. Levine, 1998. Domestication of indigenous *Porphyra* (Nori) species for commercial cultivation in Northeast America. World Aquacult. 29: 26–29.

Zhang, S. Q., Q. L. Yang, H. H. Qiu & H .H. Lin, 1994. Red tide and it's prevention and cure. China Ocean Press. Beijing [in Chinese].

Zhang, X. C., Y. X. Wang, X. N. Wu & X. G. Fei, 1993. A comparative study on photosynthetic pigments of *Gracilaria lemaneiformis* from different habitats. Trans. Oceanol. Limnol. 1993: 52–59 [in Chinese with English abstract].

Zhu, M. Y. & R. X. Li, 1996. The monitoring of water environment and red tide in prawn ponds. In Zhu, M. Y. (ed.), Research of Red Tide in China. (Proceedings of the Second Meeting of Chinese Committee of SCOR-IOC HAB Working Group). Qingdao Press, Qingdao: 60–68.