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QINGDAO'S GREEN-TIDE OUTBREAK: MANAGEMENT AND COUNTERMEASURES

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Abstract From 2007 to 2011, green tides annually invaded Qingdao coastal areas on China's Yellow Sea coast. These green tides are mainly *Enteromorpha prolifera* and be harmful for the coastal areas. With great efforts by various organizations, the outbreak of green tides was brought under control each year. Based on the possible deep-rooted reasons for the outbreak, the authors outline their knowledge of Qingdao's green-tide outbreaks and summarize the successful emergency management experiences learned from controlling the outbreaks. This article also discusses related countermeasures.

I. INTRODUCTION

Following the major green tide events in Qingdao, Chinese scientists have discussed how to improve the government's coordination mechanism, the reaction mechanism, and the mechanism of social participation during the emergency from a marine environmental emergency management perspective (Chen, 2009; Teng, 2009; Wang and Zhao, 2009; Wang et al., 2010; Yang, 2010). However, these mechanisms are not perfect and there are a series of problems in these mechanisms, it is difficult to play their role.

Chinese and foreign scholars studying the outbreak of Qingdao's green tide. (Liu et al., 2009) concluded that 'the rapid expansion of *Porphyra yezoensis* aquaculture in Jiangsu province provides a greatly enhanced source of *E. prolifera* and seems very likely to be responsible for the massive green-tides. Li Daqiu et al. (2008) believe that through investigation, laver breeding of Yancheng and Nantong in Jiangsu is the root cause of Qingdao green tide outbreak. While others are all for that global climate change and water eutrophication are the root reason. Leskinen et al. (2004) believe that at present the main reasons appear to include: sea water eutrophication, water temperature changes during spring and summer, the low water exchange in proliferation sea leading to local race intensive degree increase.

This paper will summarize the successful experiences of emergency managements taken by organizations in Qingdao. This can help exchange with, and learn from, similar cities and areas both in China and abroad. On the other hand, to wholly investigate the evoked factors of the green-tide outbreak in Qingdao, some fundamentally measures are put forward.

II. UNDERSTANDING OF GREEN TIDE AND ITS IMPACT

1. Overview of Qingdao's green tide

Chlorophyta is the largest phylum of algae, having about 350 genera and 5000-8000 species. Chlorophyta are widely distributed. Its fresh water species are common, often found on submerged rocks and wood, or seen floating on the surface of water. The phenomenon of a greenbelt along the coast is caused by the excessive proliferation of *E. prolifera*, Ulva, Chaetomorpha, Cladophora, and other chlorella-like green tides. Chlorella out breaks that form green tides are mainly Ulva and Enteromorpha (Wang, 2010).

Local green tides occur in soft substrate areas. Multiple species of green algae may be found growing together in the intertidal or subtidal zones, either attached to the substratum or floating freely (Timothy et al., 2007). Green tide algae are generally reported to have broad tolerance ranges for salinity, irradiance, and temperature (Taylor et al., 2001). Differential performance among green algal species in response to salinity, nutrients, and light also play important roles in determination of green-tide species composition (Timothy et al., 2007). The location and extent of green tides (i.e., ulvoid algal blooms) may be predictable as a functional-form group, but understanding of the causes of species-specific distribution patterns is more difficult (Robert and Megan, 1994).

The term 'green tide' has been applied to the phenomenon observed since time immemorial (Morand and Merceron, 2005). It was reported to have occurred as early as 1905 in Belfast Lough (Letts and Richards, 1911). In America, green tides firstly occurred in the shallow bays of eastern and southern Long Island, New York in the 1950s (Sunda et al., 2006).

A more detailed study of Qingdao's green tides was carried out at Ghent University, Algarve University, and Belfast University. (Frederik et al., 2009) have shown that, morphologically, the algae unmistakably belong to the green macro-algal genus Ulva. Species level identification in the genus, however, is confounded by the lack of distinguishing characters and a high degree of morphological variability. Using phylogenetic analysis, it has been shown that the bloom forming Ulva in Qingdao is very similar to *U. procera* and *U. linza*, with the Chinese Ulva genetic sequence being identical to those of specimens collected from Finland, Portugal, New Zealand, and Japan. (Leliaert et al., 2008)

Green tide was reported in Qingdao in 2007. From that time, green tide out breaks occurred every year for 7 years, with the largest scale even happening in 2008. According to the existing data, outbreaks of green tide will occur ever year in the future.

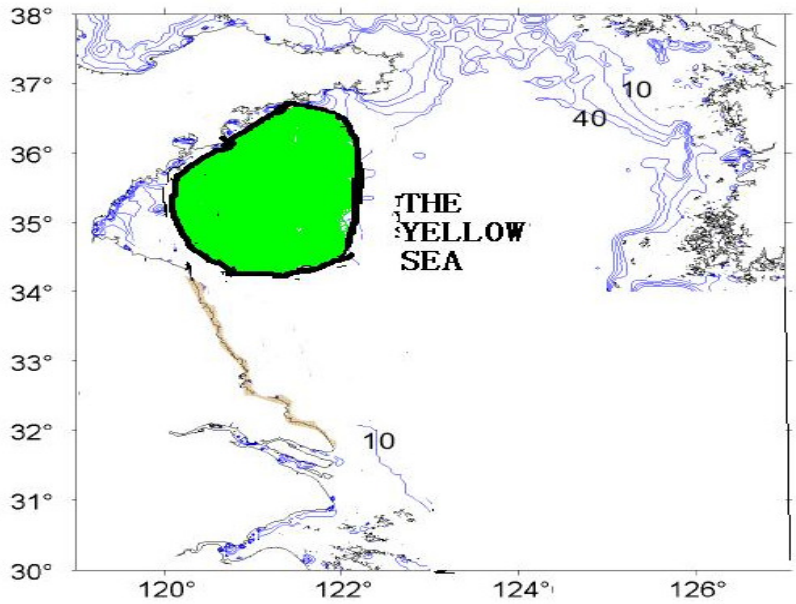

Figure 1. Geographical map of proximate range of green tide of the Yellow Sea in recent years

2. Influence of green tide on the environment

The sudden appearance of massive amounts of algae will always influence the ecological system to some extent. The seaweed covers the ocean surface in large scale and results in low solar transmission, leading to hypoxia under the seaweed. It takes time for recovery to occur. It can also influence the drainage system in the intertidal zone to some extent (Pang et al., 2010). Floating algal substances can gather in creeks during low tides. The seaweed's digestion and degradation of large amount of protein saccharides have certain influence on offshore water body environment. Meanwhile, a series of secondary environmental harm may be brought about, such air pollution during the decay process. When the tide is gone, the algae will stay on the beach, having a bad effect on the beach landscape. The piling up of algae provides conditions suitable for harmful insects to reproduce, and therefore may cause pest problems. If the algae settle on the seabed, they can cause anoxia and substrate decay, and change the physicochemical property of the sediment. This may lead to the death of hydrobionts due to anoxia, and therefore greatly influence the benthic ecological system. For example, polychaetes and meiobenthos will be affected by anoxia and in the sediment (Donald et al., 2002).

3. The origin of green tide in Qingdao costal area

Green-tide researchers at the National Marine & Environment Monitoring Center of China, with the support of the national emergency project, carried out investigations on the origin of the green tides from December 2008 to June 2009 (China Ocean news, 2010). They built a small fenced basin in the sea near Qingdao, in order to carry out a sea barricading experiment on the samples collected within Haizhou Bay to the northeast and Nantong to the southeast near the Yantze River Delta. Meanwhile, a large ship was specifically deployed from Yancheng and Nantong districts to inspect the entire process of the emergence of sea grass, including how it came down from the raft rack, and how it floated and grew. Through in situ observations they determined that the provenance is Jiangsu province. The Yancheng and Nantong areas of Jiangsu province are the primary regions for aquaculture of *Porphyra yezoensis* in China, with a culture area of laver covering 2760 hectares (2008 statistics). The original bulk of green tide separated from the raft davit was very large. The green tide drifted northward driven continuously by the southerly winds. During the drift, due to adequate water temperature, suitable climate, and appropriate environment, the algae quickly grew and produced the observed green tide along the Qingdao coast (China Ocean News, 2010).

In short, the provenance is the laver aquaculture areas of Jiangsu province - Yancheng and Nantong cities.

4. The impact of green tide on Qingdao

Although green tides can reduce the nutrients in the sea water to some extent and prevent the redevelopment of red tides, such outbreaks also greatly affect marine ecosystems in general including around Qingdao. For example, the later period of green tide lead to large number of death of breeding sea cucumbers and abalone, which cause huge economic losses. Including marine aquaculture, green tide caused an economic loss of up to 1.3 billion yuan ($200 million) in 2008. Research shows that: firstly, green tides can influence other algae's growth by allelopathy (The inhibition of growth in one species of plants by chemicals produced by another species) nutrition competition; secondly, long term green tides are likely to be a threat to the survival and reproduction of ocean zooplankton; thirdly, green tide can also threaten marine macroorganisms, such as scallops, abalone,...(Wang, 2010). When

green tides die down, they decay gradually and give off a foul odor in the irradiance of sunlight. This in turn causes environmental pollution, and interrupts sightseeing and marine sports. In the case of 2008, it especially brought negative image to the city of Qingdao when it hosted the Olympic sailing competitions.

III. COUNTERMEASURES ADOPTED BY THE PEOPLE AND MILITARY IN QINGDAO BEFORE THE OLYMPIC SAILING GAMES AND THE EFFECTS

1. Joint monitoring (after 2008)

After the emergency management was started, on 31st May 2008, the National Satellite Oceanic Application Center used satellite remote sensing, including 17 satellites, to monitor chlorophyll, sea surface temperature, and other indicators, including Yellow and East Seas for about 3 months, in order to identify possible sources of green tide and large-scale changes of its space-time distribution characteristics. After that China become to use its own satellites to monitor and observation period, the scope, the objects are fixed.

At the same time, the State Oceanic Administration Branch of the East China Sea has also launched remote sensing monitoring. In order to achieve high resolution and multiband marine monitoring, three ocean surveillance ships and 2 surveillance aircrafts are equipped. The monitoring scope is from Lianyungang to Qingdao. The monitoring objects include the distribution area, concentration, weight estimation, dynamic analysis, and Qingdao Olympic sailing competition waters and the surrounding waters of dynamic monitoring information. By remote sensing monitoring, which can grasp the green tide from overall situation, and provide accurate data and decision support for government decision-making.

On July 18, 2008, Institute of Oceanlogy of the Chinese Academy of Sciences and Qingdao Municipal Science and Technology Commission jointly organize the implementation of the third shared voyage "2008 China offshore marine scientific research and open sharing voyage". The open voyage completed eight sections of Huang Donghai typical sea, the investigation of 67 position observations, including marine hydro-meteorology, chemistry, biology, ecology, geology and so on. The open voyage has obtained a large number of basic data and information, which are useful to study the typical marine biological resources and ecological environment change of Huang Donghai, protection of marine ecological environment, disaster prevention and governance, provides the scientific basis. In a word it has very important scientific significance.

2. Crossover study in green-tide sciences

On 2nd July 2008 the Green Tide Disaster Experts Committee was established in Qingdao including 26 experts, 4 expert groups (the monitoring and predicting group, the fence salvage group, the disposition group and the bio-ecology group) from National Ministry of Science and Technology, the Chinese Academy of Sciences, the State Oceanic Administration, Department of Shandong Province, and the Qingdao Science Agency. According to the data and information obtained during the outbreak of green tide by systematic monitoring its duty included 4 aspects: (1) Study morphological characteristics and molecular biology of biological samples, and analyze Internal Transcribed Spacer (ITS) of the nucleic acid sequence of green algae; (2) Combine with historical data, analyze current field, heat flux, temperature and salinity, and other dynamic factors through the establishment of high-resolution flow and transport diffusion numerical models, study possible drifting path and incidence, area of different green algae source under different tide and wind-driven currents, predict potential impact on

the Olympic sailing competitions, establish the system of follow-up, and provide early guidance for the dynamic changes of distribution area and density of the green tide; (3) Marine biologists use cell separation and training methods to establish the pure training culture of filamentous algae, and use molecular markers to complete the extraction of genetic material of different samples of green algae and determination of related sequences; (4) Obtain the photosynthetic rate, germ cell concentration, and other growth index of green tide, and explore the correlations of growth and breeding with water temperature, salinity, transparency, turbidity, dissolved oxygen, pH value, chlorophyll, various nutrient concentrations, microbial, plankton, and other eco-environmental indexes.

3. Fence salvage

The use of chemical methods is the simplest and quickest way to remove green tides, but a survey shows that this is not a good approach. The region of Yantai utilized algaecide to kill the green tide in pond water of 20 hectares in 2007, resulting in the water turning black. After death green tide algae are suspended in the water and be difficult to remove. This may result in large-scale death of farmed shrimp and other biological species (Yin and Wang, 2008). In addition, green tides fix many nutrients during their growth, so it can further purify the water quality after the salvaging, ensuring an active balance of ecosystem. Therefore, after much discussion and debate, the Green Tide Disaster Experts Committee ultimately determined to use the physical method – fence salvage – to eliminate green tides.

Decision makers use oil containment booms to divide the green tide into pieces and block some of them based on their possible paths of impaction to the Qingdao coast based on the change of near shore tides and growth cycle. From the point of fact, fence salvage has obtained the good effect, but it costs much manpower and financial resources.

Facing the large-scale disaster of green tide in Qingdao, China's maritime sector invested in hundreds of ships and more than 1,000 people, rapidly placed oil containment booms in the sea area of the Olympic Sailing Center, and implemented an isolated protection in the sea area of the Olympic Sailing Center. However, available oil containment booms in Shandong province covered only one million meters, the full containment of green tide in the sea area of the Olympic Sailing Competition needed 3.2 million meters of oil containment booms.

On 2 July 2008, the Maritime Safety Administration of the Ministry of Transport started across-the-region contingency plans, transferring 1.8 million meters oil containment booms from the maritime sectors of nine provinces to deal with the emergency. A large number of oil containment booms were flown to Qingdao within two days, providing timely protection for the security zone.

Salvaging adopted the approach of 'a combination of mechanical operations and manual salvage, the combination of clearance in the sea area and removal on the land'. After the outbreak of the green tide offshore of Qingdao, all its citizens went into action. Large numbers from all social circles carried out comprehensive salvaging and clearing on the sea, at the intertidal zone, and along the shore, including military, general public, college students, fishermen. Old people and children were seen in the crowd. During the period of clearing, tens of thousands of people, thousands of ships, and dozens of shipping machineries were committed to the clearing activity.

4. Effective handling

The Green Tide Disaster Experts Committee puts forward disposal methods not only protecting the environment but also making full use of the green tide,

including reserves with diversion systems, simple and orderly cofferdam seepage by professional companies, pile, or dry preservation or fermentation. At the same time, the experts of the emergency environmental protection system carried out the evaluation of nutrition value and safety, the utilization of material processing into animal feed and farming fertilizer and extraction of functional components, in order to use the green tide.

As a result of an effective salvage campaign organized by the Qingdao Municipal Government the disaster of green tide was controlled effectively. According to the monitoring data on 9 July 2008, the percentage of the area of green tide dropped from 32.04% to about 2.8% in the security zone around the sea area of the Olympic Sailing Games in 12 days (from 29th June to 9th July). The water quality indicators in the sea area of the Olympic Sailing Games and surrounding waters of Qingdao were kept at the national fluid matter standard and national sea water quality standard Ⅱ. By 16 July 2008, Qingdao had recovered more than 70 million tons of algae, set the oil containment booms of about 24 km, and effectively prevented the invasion of green tide in the sea area of the Olympic Sailing Games.

IV. KNOWLEDGE AND COUNTER-MEASURE

At present, several reasons have been suggested for the outbreak of green tides (Eaton et al., 1966). Firstly, ocean circulation in the spring. The rise of sea surface temperature leads to the formation of "spring circulation" off the coast, causing a large number of bottom nutrients (such as nitrogen, phosphorus, etc.) to come to the sea surface via upwelling. This provides the nutrients needed for a green tide's growth. A green tide has a better adaptive ability to environment and enormous reproductive capacity. It can also reproduce in great quantities and very rapidly at warm temperature. Therefore, it may spread over large sections of coastal ocean in a short time. Why only in these areas is unknown. Secondly, ocean currents may contribute to green tides. The green tide could not come into being without algae in the suitable marine environment. In recent years, green tides have been gaining in scale and frequency in both marine and estuary environments all over the world. The sudden outbreak of green tide in a given sea area is likely caused by green tide moving from other sea areas by currents. Thirdly, water body eutrophication may impact the relevant algae. As with red tides, outbreaks of green tide are mostly a consequence of sea water eutrophication. Water body eutrophication is impacted by environmental policies and management issues where such policies affect the concentrations of nitrogen and phosphorus. There is a cure–improve waste water management, but, this takes time.

All in all, the reason is comprehensive. Only one aspect does not alone leading to the outbreak of green tides. The natural factors causing green tides are beyond human control. At present the only thing that we can do, from the perspective of human factors that induced the outbreak of green tide in Qingdao, is to find a fundamental and feasible countermeasures as soon as possible. Though it's outbreaks are in Qingdao, it is a trans-provincial problem. So the national measures must be taken. The most important component is the precautionary principle.

1. Build domestic governmental cooperation

The government played an important role in coping with the green tide that broke out in 2008, including the close cooperation between the central government and the local governments, which is a useful and precious experience. But the cooperation is temporary. In order to play a bigger role, it needs to establish long-term cooperation mechanism. So we should build a

permanent institution, which is unified by the state council.

Besides it needs to build cooperation among local governments. The control of the source should be on the basis of natural and economic systems together, rather than principally on political or administrative boundaries. Currently it involves at least five cities in two provinces: Nantong, Yancheng, and Lianyungang in Jiangsu province, and Rizhao and Qingdao in Shangdong province. In other words, the trans-provincial and trans-municipal cooperation of the source control needs the coordination of many work organizations. The membership consists of the director of local departments and they should hold regular meetings to exchange information.

Figure 2. Geographical map of the Qingdao, Rizhao, Lianyungang, Yancheng, Nantong

2. Promote CJK (China, Japan, Korea) cooperation on dealing with green tides

Enteromorpha, Ulva and gulfweed drift and accumulate off shore in other countries and regions (such as Japan and Europe). For these phenomena some in-depth researches have been developed in the international region, such as the mechanism of breakouts, draft pathways, ecological impacts, and counter measures, etc. Presently, China should cooperate with Japan and South Korea in order to conduct a joint research on the green tide. The joint research should include the following three aspects:

2.1. Set up the marine disaster emergency response mechanism for the Yellow sea

The Yellow Sea is the economic heart of northeastern China. It is one of the important international waterways, between China, South Korea, Japan, and North Korea. The Yellow Sea has an important strategic significance in the economic and social development of these neighboring countries. Marine disasters occur with high frequency in the Yellow Sea, due to the lack of cooperation among these neighboring countries on dealing with common marine problems.

China, Japan, and South Korea are three largest countries around the Yellow Sea. In recent years, economic development and cooperation in the coastal areas of these countries has grown quickly, so it is necessary to strengthen the construction of marine disaster emergency response mechanism among the three countries.

2.2. Establish cooperation organization in which national and local marine departments in China, Japan and Korea are involved

The main recommendations are as follows: Firstly, set up a Yellow Sea Cooperation Committee of Marine Disasters Emergency Response among three countries; Secondly, set up the Yellow Sea Cooperation Committee of Marine Disasters Emergency Response in the Chinese Marine Administrative Department and in the relevant departments of Japan and South Korea. Though we have disputes in the sea, we are faced with environmental problems. Three parties can benefit from a mechanism of the above construction.

2.3. Matters of cooperation and exchanges

Three countries should work closely with their cooperative offices, discuss and cooperate in the following five aspects.

Firstly, enhance the cooperation of marine disasters detection forecasting technology and research field of the Yellow Sea in three countries.

Secondly, strengthen communication and collaboration within the International Ship Owner's Association and within monitoring and evaluation organizations of international oil polluting monetary fund in marine oil spill pollution.

Thirdly, strengthen cooperation in preventing red tides and green tides by establishing a organization of monitoring cooperation of the Yellow Sea algal bloom; forming the action of joint prevention and governance, and sharing information in real-time. In the present management system, the state oceanic administration will be the executor of the cooperative organization.

Fourthly, strengthen the cooperation and exchange by establishing a system of frequent consultation and communication and holding annual academic meetings.

Fifthly, discuss the establishment of funds for the Yellow Sea marine disasters. The main source of this fund is the national financial allocation, and sewage charges of the enterprises is also a source. At the same time it is important to absorb social capital and ask international organizations to support the fund's construction.

3. Reducing discharge of nitrogen and phosphorus pollutants

Although the unhealthy cultural mode of *Porphyra yezoensis* is the biggest culprit of Qingdao's green tides, we can not overlook the factor of eutrophication of sea water.

As to Qingdao's green tides, the principal sources of nutrients (N and P) include: the Guan river and Sheyang river. These two rivers are the main rivers that run through the territory of Jiangsu province, flowing eastward to the Yellow Sea. Some studies show that the Guan and Sheyang rivers are the main sources of nitrogen and phosphorus pollutants into the central and southern Yellow Sea. So, this is one of the important influencing factors of the green-tide outbreaks in Qingdao (Ma et al., 2010).

In addition, the Dagu, Moshui, Baisha, and Yang rivers of Qingdao that flow into the Jiaozhou Bay may be important. The nutrients of land-based sources in the Jiaozhou Bay are mainly transported by these four rivers. Excessive pollutants of nitrogen and phosphorus are discharged into the Jiaozhou Bay, providing favorable environment conditions for the growth of green tide in the coastal waters of Qingdao. Other studies have shown that, relative to change of phosphorus, green tide is more easily affected by change of nitrogen. (Li et al., 2010).

As for governments, we should attach importance to strengthened administration on environmental protection around these rivers, particularly putting nitrogen in the first place for managing and governing. We should reinforce with economic measures and administrative means, make a set of "combination blow"– integrated economic means and administrative means. On one hand, it is an unavoidable trend to enforce economic policies, such as taxation,

subsidy, cash pledge, and circulative license, for the environment protection departments. On the other hand, increasing the responsibility –asking the administration to further improve the frequency of using "restrictive region measure" and "restrictive drainage area measure" is necessary. "Environmental protection index" must be embraced for the evaluation of local governments. So it is important to build the integrated coastal zone management to instead of the current management system.

Figure 3. Geographical map of the Jiaozhou Bay in Qingdao (Source: Ye (2006))

4. Strengthen the control of the source

To control and reduce large-scale outbreaks, the fundamental solution is to strengthen the control of the source. In the provenance of green tides, it is the seaweed aquaculture of Yancheng and Nantong, which requires effective ways to recycle or kill green tide algae in the early stages, preventing the formation of green tide outbreaks. We must enhance the study on the reproduction patterns of seaweed and to find an effective way to remove the algae on the raft during the process of seaweed aquaculture. Although this is a difficult technique, it is the fundamental approach to reduce green tides and ensure the health and beauty of natural marine environment in Qingdao.

5. Establish a sound and responsive system of environmental protection (Yin and Wang, 2008)

In the process of dealing with these disasters, we found that China's emergency response scientific research lacks of depth and breadth. We do not know the detailed structures of the physical environment in the southern Yellow Sea. We do not clearly comprehend the coupled relation between physical processes and ecological processes, and have no cures for the outbreak mechanism of Qingdao offshore green tides. This largely restricts the effective prevention and control of green-tide outbreaks. Therefore, we should continue to uphold technological advantages of emergency protection system in the aspects of systematic monitoring, interactive research, fence salvage, and effective disposal. From now, the state oceanic administration should improve coastal environmental monitoring networks and strengthen oceanographic research. At the same time, it should actively deploy the study of evaluation and prevention control on the cumulative effect of the following year and the secondary disasters about the outbreak of green tides, in order to provide

a more solid foundation and basis for dealing scientifically with similar ecological disasters in future.

In addition, an information disclosure system, which provides the latest information for public, should be established. At the same time the disclosure of information can improve the public awareness of green tides and strengthen public participation.

V. CONCLUSION

Green tides are a double-edged sword. On one hand, green tide brings immense benefit to mankind. The extractive power of green tides has the role of inhibiting the growth of some red tide micro-algae; there are four kinds of red tide micro-algae: *Amphidinium hoefleri*, *Karenia mikimitoi*, *Alexandrium tamarense*, and *Skeletonema costatum* (Sun et al., 2010). Green tides are a kind of forage resource of marine algae that is of great developmental value. In addition, green tide material has great potential in the food, chemical, and pharmaceutical industries. It should be particularly pointed out that green tides are expected to become a new source of renewable energy. On 23 June 2010, Fudan University announced that the research group led by Associate Professor Zhang Shicheng and Professor of Chen Jianmin had successfully transformed green tide material into biofuel (The Chinese academy of sciences news, 2010). On the other hand, green tides brought negative impacts to Qingdao coastal waters, and cost a great deal of manpower and other resources. In other words, although we can turn green tides back into something useful, the price that Qingdao paid for dealing with its green tides is far more than green tide's value at the present time. To sum up, green tides will do more harm than good. So our suggestion is that Qingdao must solve the problems of green tides, to prevent its invasion in the future permanently, but it has long way to go.

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