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The ecological risk assessment of the Chinese White Dolphins in Xiamen coastal waters

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To protect the endangered Chinese White Dolphins in Xiamen coastal waters, an ecological risk assessment was made. This assessment was based on an evaluation framework using the Driver-Pressure-State-Impact-Response method, integrated with the guidelines given by the United States Environmental Protection Agency. Aside from chemical stressors, other factors (including environmental investment, sewage treatment and others) were also taken into account. An integrated ecological risk assessment was applied using quantitative methodology, including eleven indicator parameters. The results demonstrated that the ecological risk for dolphins had increased with the urbanization process and economic development during 1996–2007. The highest risk occurred in 2003, and the lowest in 1996. Interestingly, the risk decreased significantly from 0.5629 in 2006 to 0.4745 in 2007. It was discovered that there were several crucial risk sources, including fishery outputs, port throughput, industrial effluent, and domestic sewage. These results could serve as a guide for protecting Chinese White Dolphins and other marine species that are being harmed by the booming urbanization process.

Keywords: marine protected area, marine animal, Driver-Pressure-State-Impact-Response

Introduction

The recent development of coastal economic zones has resulted in the decrease in population of several marine animal species listed in the Red Data Book, including the Chinese White Dolphin. As a national grade I protected animal, Chinese White Dolphins are mainly living in the southeastern coast of China, enjoying the abundant food brought by the combination of ocean saltwater and inland freshwater. Xiamen is one of the most important habitats of Chinese White Dolphins, whose population never reached more than 1,000 in this area in the past century. Affected by the urbanization and industrialization of Xiamen city, the total number of these dolphins declined sharply to less than 100 (Liu and Huang, 2000; Zhang and Tang, 2008). To protect these endangered dolphins, many studies had been conducted in the past few years. Chen, Zheng et al. (2008) and Wang et al. (2007) investigated the distribution, abundance and conservation status of the dolphins. Chen, Zhai, et al. (2008) analyzed the genetic diversity in Xiamen waters and the Pearl River Estuary. Moreover, the causes of death of dolphins in Xiamen coastal waters were discovered, and a trace of metal pollution in the dolphin bodies was analysed (Chen et al., 2007; Bian et al., 2007). However, these investigations were mostly confined to the field of biology. The relationship between socio-economic mechanisms and the ecological state of dolphins has not yet been studied.
In this paper, we brought forward a framework of ecological risk assessment for the Chinese White Dolphins in Xiamen waters, using the Driver-Pressure-State-Impact-Response (DPSIR) method and guidelines given by the United States Environmental Protection Agency (US EPA).

Ecological Risk Assessment (ERA) is a process used to evaluate the likelihood that adverse ecological effects may occur, or are occurring, as a result of exposure to one or more stressors (US EPA, 1998). The stressors include: the release of chemicals, other anthropogenic activities, and natural hazards. ERA is often used to help understand and predict the relationship between stressors and ecological effects, which is usually crucial for environmental decision making. The current research work on ERA mainly focused on chemical stressors (Zhao et al., 2008; Micheletti et al., 2007; Bennett et al., 2007; Chen and Liu, 2006). However, it has been recognized that multiple stressors (human activities, physical and biological stressors) are also important factors. By taking all these aspects into account, we made a retrospective estimation of the ecological risk for Chinese White Dolphins in Xiamen coastal waters using the DPSIR model. The objectives of our study were: (1) to analyze the stressors of Chinese White Dolphins in Xiamen coastal waters, especially from human activities; (2) to assess the ecological risk for dolphins during the period of 1996-2007; (3) to analyze the relationship between human activities and the ecological risk.

Study area

Xiamen is located in the southeastern Fujian province, and is one of the fastest growing special economic zones in China. It covers a land area of 1,565 km², and a sea area of 340 km² with 234 km of coastline. Three types of regions were considered in this study: mainland, island, and coastal water areas. Xiamen coastal waters are usually divided into five sections: Jiulong River Estuary, Western Sea, Tongan Bay, Southern Sea, and Eastern Sea (Figure 1). Jiulong River, the second largest river in Fujian province, brings a wealth of freshwater resources, and is an important habitat which attracts Chinese White Dolphins. Therefore, the whole coastal water area of Xiamen is labeled as protected area. The state-level marine protected area for rare marine species is located at Western Sea and Tongan Bay.

Methodology

The DPSIR model, developed from the Pressure-State-Response (PSR) model brought forward by the Organization for Economic Cooperation and Development (OECD), was often used to study the relationship between human activity and corresponding environment degradation. It has been widely used for coastal zone studies and fishery management (Mangi et al., 2007; Uriarte and Borja, 2009). This model is based on the concept that human activities exert pressures on the environment and change its quality and the quantity of natural resources. We divided the DPSIR framework into six steps:

1. Describe the driving forces (including the economic development, the population, and the tourism industry);
2. Identify the ecological pressure—the stresses of the ecological risk which is originated from the anthropogenic system and will affect the water environment;
3. State description—figuring out the environment conditions of the waters;
4. Analyze the impacts—the measure of the effects resulting from the pressures and the states;
5. Discuss responses—management strategies for solving the marine environmental problems;
6. Evaluate the ecological risk for the Chinese White Dolphins based upon the above results.

Results

Drivers

Economic development

Having benefited from a unique geographical advantage, economy reform, and Chinese opening up policy, urbanization is significantly developed in Xiamen city. It has turned into a large city from a small fishery village. Between 1996 and 2007, the national income of Xiamen achieved an annual growth of 15%, higher than the national average of 8% during the same period. Xiamen is a strategic center in the economy of Fujian province, with the gross domestic product (GDP) increased from 64,003 million RMB in 1980 to 137,526 billion RMB in 2007. It accounted for nearly 30% GDP of Fujian province, due to the fast development of the market economy, as well as the establishment of the export industry.

Population and tourists

Although the rate of natural population growth is low, the total number of inhabitants reaches more than 2 million. Migration contributes significantly to the overall population growth. Xiamen is also a tourism oriented city with rich resources such as sea sight-seeing, attracting many tourists around the world every year. In 2007, more than 20 million people traveled to Xiamen, which set a new record.

Pressures

Socio-economic drivers, such as population growth and urbanization, have created many environmental pressures, and caused great impacts (eutrophication, algal blooming, and contamination) on the water resources, threatening the survival of the Chinese White Dolphins. In order to assess the present pressures in Xiamen waters, four elements were considered: wastewater discharge, harbor transportation, fishery industry, and the pollutants from Jiulong River. These pressures might induce significant changes in the coastal environment.

Wastewater discharge

There was a substantial increase in the total amount of wastewater discharge. As shown in Figure 2, the industrial wastewater discharge has been relatively stable (basically unchanged), but the amount of domestic sewage increased remarkably from 1996 to 2007. With the expansion of cities, the wastewater discharge will further increase in the future.

Harbor transportation

Xiamen harbor, located in Western Sea, is the main port linking Taiwan and the mainland. It is one of the fastest growing ports for national and international transportation. The core, Dongdu, is the most comprehensive port of Xiamen. Cargo throughput increased with an average annual growth rate of 15.8% in 1996–2007 (Figure 2). The various vessels, including large tankers, passenger ships and high speed fishing boats brought great economic benefits, but also threats for the survival of the endangered dolphins. These threats have been on the rise with the development of the Xiamen port, due to the noise and physical injuries caused by ships. According to economic projections, the total cargo turnover of Xiamen port will reach 100 million tons by 2010, presenting a challenging living condition for the Chinese White Dolphins.

Aquaculture industry

Aquaculture industry in Xiamen developed quickly and reached its peak in 2002. The expansion of the aquaculture area produced many problems, including water pollution, a huge increase in the discharge of nutrients, eutrophication in waters, and the narrowing living space of dolphins. Fortunately, the government has recognized the risks caused by aggressive aquaculture and reduced the size of the breeding, for the purpose of sustainable development.
Pollutants from Jiulong River

Jiulong River has two major tributaries: the North River and the West River. The main river course crosses eight cities and flows into Xiamen Sea. It is believed that this river is the main source of nutrients which caused eutrophication hazards in Xiamen waters. The amount of pollutants (nitrogen, phosphorus, heavy metals, etc.) discharged into Xiamen waters are considerable.

State

Water quality

The significant amount of pollutants discharged into Xiamen waters over the past decade through Jiulong River, domestic sewage, industrial wastewater and others, exceeded the carrying capacity of the waters, and finally resulted in the eutrophication events.

The main pollutants in Xiamen waters were inorganic nitrogen (N) and active phosphate (P), as a result of the interaction between ecosystem and socio-economic system. The concentration of P was stable, about 0.020–0.040 mg l$^{-1}$; also, the concentration of N fluctuated in the range of 0.200–1.200 mg l$^{-1}$. With the accumulation of N and P elements, the overall water quality often exceeded the fourth-category standard. Under the appropriate conditions, a large number of marine algae will propagate, which will consequently result in a red tide.

On the other hand, the concentration of heavy metal pollutants presented a declining trend, owing to the strict environmental governance in the past few years.

Habitat

Xiamen coastal waters, especially Western Sea, were once the center of aquaculture. There were several kinds of fishing activities, such as cage culture, beach culture and others. These activities exerted pressures on the marine environment in different ways, leading to the destruction of habitat, over-fishing, compression of the living space of the dolphins, and reduction in water exchange rate. Over-fishing affected the biodiversity in Xiamen waters, and the dolphins are now facing a serious problem: they can no longer obtain sufficient food to maintain their population. Thus, the number of dolphins decreased consequently.

In only half a century, in order to maintain rapid economic development and accommodate more people, Xiamen city gradually expanded from an island city to a bay city. Because of the shortage of land resources, reclamation became the main solution for this problem. The reclamation area was 90.13 km$^2$ during 1955–1997, 7.61 km$^2$ from 1998 to 2001, and 10.64 km$^2$ for the period 2002–2005 (Li et al., 2008). A series of marine facilities (e.g. seawalls built at Gaoji, Maluan, Xinglin, and Xi Sea) were constructed, which caused the area of Western Sea to decrease sharply from 108 km$^2$ to 45.4 km$^2$. Reclamation provided the geographic space for urban development; however, it caused great damage to the survival environment of dolphins and other marine animals, and also disturbed the balance in the marine ecosystem.

The feeding sites were narrowed and the types of inter-tidal organisms became monotonous. These changes led to the decrease in population supporting capacity of resources in Xiamen coastal waters. The coastal ecosystem became more fragile, the ecological environment of the coastal zone was destroyed, the natural mangrove was deforested, estuary waters were narrowed, and traditional natural spawning grounds were destroyed. Of utmost importance, underwater explosions accompanying the reclamation activities often caused deadly physical injuries to dolphins directly.

Impact

Red tide

With eutrophication and degradation of coastal water quality in Xiamen, the number of red tide occurrences has increased since 1980. The largest red tide event happened in early 2000s (Cai, 2008). There were only seven red tides between 1986 and 2000, but became more frequent between 2001 and 2007. Red tides mostly occurring in Western Sea, the most severe one occurring in Western Sea and Tongan Bay in 2005. This tide covered more than 200 km$^2$, almost half of the whole Xiamen coastal water area. Red tide, even a non-toxic ones, is one of the most serious threats for coastal aquaculture, especially for dolphins. Tides covered the entire surface, impeding the exchange process between water and atmosphere and the availability of dissolved oxygen decreased causing fish to die. Decomposition of fish and dead red tide organisms further consumed the dissolved oxygen in water, causing further deterioration of water quality. Most importantly, the decomposing process released hazardous substances such as algal toxins and hydrogen sulfide. These toxins can accumulate in the body of
dolphins which reside at the top of the food chain in an aquatic ecosystem.

**Reduction of the number of the Chinese White Dolphins**

In the 1950s, Chinese White Dolphins could often be seen in First Dock and Songyu water areas of Xiamen. But they were listed in the Red Data Book in 1988 as a species of national protected animal. Eleven dead dolphin bodies were found on the beach in Xiamen from 1994 to 1999, and another eleven were observed from 2002 to 2004 (Xiamen Marine and Fisheries Bureau, 2007). The present population of Chinese White Dolphins in Xiamen coastal waters is only just about 80.

**Response**

Relevant government departments highlighted the severe survival conditions of Chinese White Dolphins. In August 1997, Xiamen local government established the provincial dolphin natural reserve, which later became the National Nature Reserve, covering 5,500 hectares in November 1999. Special funds have also been assigned and the law was promulgated to protect these dolphins.

The quality of dolphin habitats has been improved through several means, including restricting the cage culture in Western Sea in Xiamen, controlling the scale of the culture in Tongan Bay, improving the sewage treatment rate and capital investments, and controlling the effluent discharged (Figure 3). Purse-seine nets, underwater blasting, and reclamation activities are also prohibited in the reserve areas. The speed of sea vessels must be no more than 8 nautical mile $h^{-1}$ in Western Sea, and 10 nautical mile $h^{-1}$ in Tongan Bay. At the same time, high-speed motor boating, waterskiing and other profitable activities in these waters were also cancelled. A center for providing medical treatments and research institutions to protect aquatic wildlife was established at Wuyuan Bay in Xiamen.

**Integrated ecological risk assessment**

By comparing overall driving forces, pressures, state changes, environmental impacts and responses, the ecological risk for the Chinese White Dolphins in Xiamen waters was derived based on a set of comprehensive indicators. These indicators were selected according to their relevance and priority to the ecological risk. They were composed of eleven indicators, including two driving, four pressure, two state, one impacts and two response indicators (Table 1). The weighting factor of each indicator was calculated by means of Analytic Hierarchy Process (AHP), a well-known decision theory and method developed by Saaty (1977), providing an effective framework to input judgements and measurements to derive ratio scale priorities. This method has been used to develop weights to measure the importance of elements in management processes. The AHP software package known as Super Decisions is what we used here. The detailed procedures (Mardle et al., 2004; Li, 2007) can be summarized as follows:

1. Develop a hierarchy of interrelated decision elements describing the risk;
2. Perform criteria for pairwise comparison using the nine-point weighting scale;

**Table 1.** The weights for individual indicator.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Parameter</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Population</td>
<td>0.0615</td>
</tr>
<tr>
<td>D2</td>
<td>GDP</td>
<td>0.0535</td>
</tr>
<tr>
<td>P1</td>
<td>Industrial effluent</td>
<td>0.0476</td>
</tr>
<tr>
<td>P2</td>
<td>Domestic sewage</td>
<td>0.0847</td>
</tr>
<tr>
<td>P3</td>
<td>Cargo throughput</td>
<td>0.1006</td>
</tr>
<tr>
<td>P4</td>
<td>Fishery output</td>
<td>0.1351</td>
</tr>
<tr>
<td>S1</td>
<td>Concentration of P</td>
<td>0.0690</td>
</tr>
<tr>
<td>S2</td>
<td>Concentration of Pb</td>
<td>0.0706</td>
</tr>
<tr>
<td>I</td>
<td>Red tide</td>
<td>0.0807</td>
</tr>
<tr>
<td>R1</td>
<td>Environmental investment</td>
<td>0.1597</td>
</tr>
<tr>
<td>R2</td>
<td>Sewage treatment rate</td>
<td>0.1370</td>
</tr>
</tbody>
</table>
3. Compute the individual relative weights of each decision element.

According to the above steps, the weights of indicators in this paper were calculated by the AHP. Normalization was implemented with the following equation to estimate the risks. The equation (1) was applied to normalize the values of R1 and R2, the equation (2) was applied to scale other parameters:

$$X_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}$$

$$X_{ij} = \frac{x_{ij} - x_{\max}}{x_{\max} - x_{\min}}$$

where $X_{ij}$ is the standardized value with respect to the ith indicator in the jth year; $x_{ij}$ is the original value of $X_{ij}$; $x_{\max}$ and $x_{\min}$ are the maximum and minimum values for the period 1996–2007, respectively. By taking into account the weight of each factor, the risk can be evaluated as:

$$R_j = \sum_{i=1}^{m} X_{ij} W_i$$

where $R_j$ is the ERA value for the Chinese White Dolphins in the jth year; $W_i$ is the weight of parameter ($i = 1, 2, 3 \ldots, m$). The results of the ecological risk assessments were shown in Figure 4.

**Discussion and Conclusions**

Traditionally, ecological risk assessments mainly focused on risks associated with the exposure to chemical stressors, especially heavy metals (Bennett et al., 2007; Chen and Liu, 2006) and persistent organic pollutants (Zhao et al., 2008; Micheletti et al., 2007). Little or no information has been available concerning the retrospective evaluation of ERA.

In this study, a conceptual framework using the DPSIR method was applied to assess the ecological risk of the Chinese White Dolphins in Xiamen’s water area. This method took into account multiple stressors; not only chemical stressors, but also physical ones and human activities. The results showed that the ecological risk had increased slowly within the period 1996–2007. A seasonal variation of the risk was obvious. The whole fluctuation curve could be divided into three time spans: 1996–2000, 2000–2004 and 2004–2007. The ERA value was the highest with 0.5670 in 2003, followed by 0.5629 in 2006, 0.5504 in 2005 and 0.5354 in 2002. The minimum happened in 1996 with 0.4373 followed by 0.4567 in 1997 and 0.4660 in 2000 (Figure 4). Significantly, it decreased from 0.5629 in 2006, and to 0.4745 in 2007.

The risk for the Chinese White Dolphins is closely related to the development of urbanization and environmental management. The periods 1996–2000 and 2000–2007 are two important stages of urbanization in Xiamen. The urban spatial expansion changed from island to bay city in 2000. The level of urbanization rose from 50.44% in 2000 to 62.03% in 2004. A higher rate of urbanization appeared in 2003, increasing about 4% from 2002. Meanwhile, the value of risk in 2003 was higher than others. The rapid decline of the risk in 2007 was due to several key factors such as environmental investment, and sewage treatment improvement (Figure 3), especially a decline in aquaculture area which dropped sharply from 69.94 km² in 2006 to 20.4 km² in 2007. These results would indicate that the risk value is moving in a positive direction, although it is still in an upward trend. Field observations in recent years can prove this point of view, by indicating the stable population of the Chinese White Dolphins in Xiamen coastal waters.

The ecological risk assessment for the Chinese White Dolphins in Xiamen coastal waters was carried out in our research using eleven indicator parameters. Other indicators, land use and landscape pattern, may be necessary for this assessment. If
continuous remote sensing images during 1996–2007 could be obtained, these data would be taken into account for further research in the future.

At present, there is a serious problem between protection of aquatic wildlife and urbanization of the local cities. To protect the Chinese White Dolphins in Xiamen waters, it is necessary to restore their habitats in these waters, and decrease the pressures. The sewage system must be sufficient to cover the population growth and economic development of Xiamen. Moreover, artificial breeding of the Chinese White Dolphins will be the next hot topic in future studies.

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