The DPSIR model for Analysing the Experiences of Environmental Restoration in Xiamen, China

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Abstract: It is well known that the urbanization has many deleterious ecological effects. Rapid urban growth has increased the importance of restoring degraded habitats. This paper synthesizes existing information and knowledge on environmental restoration to understand the major cause and effect relationship of ecological restoration actions in Xiamen by using the DPSIR (Driving force – Pressure – State – Impact - Response) approach as the framework of analysis. Suggestions are made for further improvement in dealing with the changing conditions and requirements.

Keywords: Environmental restoration; DPSIR; Xiamen

1 Introduction

In Africa, Asia and Latin America, the urban population is expected to increase from 1.9 billion in 2000 to 3.9 billion in 2030 [1]. This rapid urban growth is contributing to the loss of habitat, which often includes areas of high species diversity [2,3]. The need for habitat restoration in coastal areas, especially those subjected to intensive agriculture, urbanization and tourism has increased because of a large historical loss and alternation of habitats and therefore adverse ecological impact [4].

Xiamen, located in the southeast coast of Fujian Province, to the west of Taiwan Strait, covers land and seas areas of 1565 km^2 and 390 km^2, respectively. It has a coastline of 234 km. As a special economic zone of China, Xiamen has many of the characteristics of a free port and is becoming an attractive site for foreign investment. However, Xiamen has experienced a range of environmental impacts arising from the rapid economic development with little regard for the environment in the past decades.

This research applies the Driving force – Pressure – State – Impact - Response (DPSIR) framework to analyse the factors that contribute to the degradation of the habitat, the response to the changes in Xiamen. The DPSIR framework is a functional analysis scheme for structuring the cause-effect relationships in connection with environmental and natural resource management problems [5-8]. The main aim of DPSIR is to identify policy options and to evaluate the efficiency of responses [5].

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2 Methodology

2.1 Datasets

A wide range of environmental restoration data are available in Xiamen. Table 1 lists the different database resources on the ecological restoration in Xiamen. After data gathering, attempts have been made to combine different data from different source into coherent datasets and then analysis, synthesis and validate them.

Table 1. Different dataset resources on the ecological restoration in Xiamen

Data resources	Name of dataset
Research reports	Xiamen: An ICM Journey; Integrated Coastal Management in Xiamen, 1994-1998; A perspective on the environmental and socioeconomic benefits and costs of ICM: The case of Xiamen, PR China
Monitoring reports	Xiamen Environmental Quality Report, 1991-1995, 1996-2000; Bulletin of marine environmental quality in Xiamen (2003-2009).
Government reports	Yearbook of Xiamen special economic zone (1990-2009).
others	Relative papers published in journals; Relative local research reports.

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2.2 Analysis model of DPSIR

In order to organize the large amount of information we collected from different datasets, it is necessary to establish a logical analysis framework to find the complex relationship among the information and data. Based on the DPSIR model, we developed a concept analysis model to analyze and classify the dispersed information (see Figure 1).

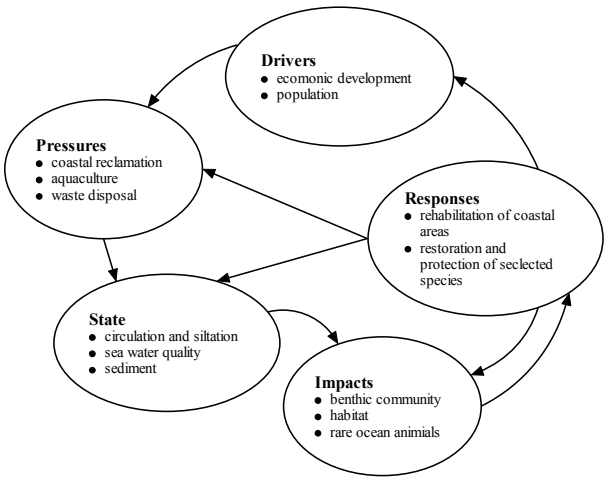

Figure 1. DPSIR framework and ecological problems

3 Results

3.1 Driving forces (D)

The unprecedented growth of economic and population, especially during the early stages of development in the urban coastal areas are the common driving forces that exert pressure and cause changes of environment problems. Since Xiamen Special Economic Zone (SEZ) was established in 1981, it experienced fastest-growing economic in China. The GDP per capita increased from 1980 to 2008, and from 1990s, the trend was more obvious (Figure 2). The annual growth rate has always been keeping on the level of higher than 10% (Figure 3). An average annual growth rate of 15.12% was observed for the period of 1981 to 2008.

In most of the urban areas, the high population growth rate is accompanied by rapid growth in the economy. From the late 17th century to the 1940s, the population of Xiamen changed only slightly. However, by 2008 its population reached a record high of 1.74 million, 82.65% higher than its population of 1981 (Figure 2). An average annual growth rate was shown in Figure 3.

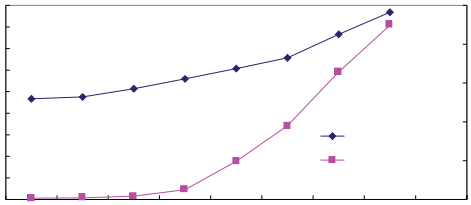

Figure 2. GDP per capita and population from 1980 to 2008 [9]

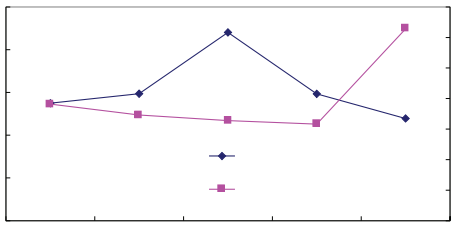

Figure 3. GDP per capita and population annual growth rate from 1980 to 2005 [9]

3.2 Pressures (P)

3.2.1 Coastal reclamation

Because of the lack of land to accommodate all the new developments and increased population, coastal reclamation was conducted around the Xiamen Island to serves as the backbone for economic development.

Coastal reclamation has potentially detrimental effects on environment, e.g. accelerated erosion, unacceptable siltation patterns, and loss of fish spawning grounds. From the 1950s to 1970s, the causeway of Gaoji, Xinglin, Maluan and Yuandang were constructed for reclamation and transportation purpose. There have been 43 reclamation projects affecting a reclamation area of 90.13 km^2 since 1955 [10,11].

3.2.2 Aquaculture

Similar to typical coastal communities, fishing is a prime industry in Xiamen. The prospect of lucrative re-

turns from the sea led to the mushrooming of aquaculture farms in the western and eastern coasts of Xiamen. By 1994, aquaculture activities occupied 18.28 km^2, including shallow seas, inter-tidal flats and reclaimed areas, accounting for 77.38% of the total area available for utilization [12]. By 2006, the number went up to 51.28 km^2, spreading throughout the Western Sea, Tong'an Bay and Dadeng Sea areas [10]. The high densities and poor distribution of aquaculture produced a huge amount of pollutants including organic material and clay, heavy metals and other biochemical pollutants, which sunk into the sea water and sediment thus polluting the benthic material and causing severe sediment pollution.

3.2.3 Waste disposal

Waste generated increases with the increase in population and economic development. During the late 1980s, the city was annually generating approximately 200 000 tons of solid and 55.5 million tons of sewage. There was only one sanitary landfill servicing the entire city, and collected waste was usually dumped in four existing dumpsites. As of 1989, there was only a single sewage treatment facility with treatment capacities of 134 000 and 37 000 tons/day for primary and secondary treatment, respectively. Clearly this was not sufficient to cover the volume of wastewater being generated. As a result, wastewater was usually discharged through open channels into bodies of water without any treatment [11].

3.3 Changes in the state of environment (S)

The coastal reclamation, aquaculture and waste disposal changed the physical and chemical elements of the coastal ecosystem, specifically relating to circulation and siltation, sea water quality and sediment.

3.3.1 Circulation and siltation

The reclamation activities mentioned above had direct impacts on geomorphology and water surface area. The surface area of shallow seas in Xiamen has decreased sharply during the last 50 years. In addition, the tidal flushing area declined greatly. Until 2000, the surface area in Western Seas was accumulatively reduced 58.3% and the tidal influx volume was reduced 38.7%, compared to that in 1952. In Tong'an Bay, the surface area has been reduced 25.5% since 1964 [13].

Since the direction and velocity of the tidal current are controlled by geomorphology, indirect impacts occurred include changes in the hydrological circulation pattern and siltation velocity. As the tidal influx volume was reduced significantly, the tidal flushing capacity was weakened and sedimentation processes were accelerated in the Western Seas. From a ^{210}Pb study in 1985, the sedimentation rate at both sites of the Gao-Ji dike increased between two- and six-fold, and the areas were seriously silted. Siltation occurred rapidly and the channel became shallow, making an obstacle to navigation. Compared the water depth in 1934 with 1976, the Songyu-Gulangyu channel water depth was reduced by 10 meters [12].

3.3.2 Sea water quality

Xiamen's Western Seas receive 80% of the total land-based waste. Western Seas and Tong'an Bay suffered great pressures from reclamation and aquaculture activities, which changed the sea water quality states. Nowadays, the standard of sea water quality in Western Seas and Tong'an Bay has dropped into to level four from level two in the 1980s, according to the national standard of sea water quality. The concentrations of inorganic phosphorous and nitrogen in sea water have increased from the 1980s. With the decrease in sea water quality, several red tides occurred in the Western Sea and Tong'an Bay from the end of 1980s to the end of 1990s [10].

3.3.3 Sediment

Sediment components changed with hydrodynamic conditions of sea water. The sediment can be a sink for pollutants, thus representing an historical record of pollution. As a whole, the sediment of shallow seas in Xiamen has been changing significantly into smaller particles. In the 1980s, the major components of sediment in Tong'an Bay changed into fine sand and pulpy mud from grit and gravel in 1938. Similarly, the major components of sediment in the Western Seas has mostly changed from fine sand into mud, while the amount of mud in the sediment increased from the southern to the northern area [10].

3.4 Impacts (I)

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3.4.1 Benthic community

The deterioration of water and sediment quality may have impacts on the flora and fauna of benthic community. Thus, benthic community can be used as an indicator of ecological changes. As mentioned before, in Western Seas of Xiamen, the coarse sand was replaced by fine mud, enriched with organic matter. The composition of benthic species has changed accordingly, with increasing dominance of polychete worms during the past 20 years [14]. From 1980 to 1988, the biodiversity of the benthic community decreased. Several benthic species have changed dramatically, such as *Saccella cuspolitana*, which was not detected in 1962, became the prevalent species in 1980, and then decreased dramatically in 1988.

3.4.2 Habitat

One of the most obvious impacts of human activities on coastal habitats of Xiamen is the large-scale destruction of mangrove forests. In the past few years, as the social and economic development and exploration, the mangrove habitats in Xiamen suffered great pressures, which caused loss of biodiversity, change of community structure and degradation. In 1987, there were 179.3 hm^2, while in 1995 just 20.8 hm^2 left [15]. Moreover, in some locations, mangroves were totally destroyed. For example, mangroves in Dongdu were lost due to construction of the harbour while those in Yuandang Lake area were removed for human settlement.

3.4.3 Rare ocean animals

Xiamen's marine ecosystem is prolific. Over 1 300 marine species are found in its coastal waters, including some endangered species such as prehistoric lancelet, egrets and the Chinese white dolphin [16]. However, the habitat alteration and degradation, deterioration of seawater and sediment quality had a negative effect on Xiamen's biodiversity and placed the Chinese white dolphin, Chinese egret, and lancelet on the verage of extinction. Before the 1980s, the egrets can be seen in many places throughout Xiamen. Over the past twenty years, the population decreased dramatically. At present, only Dayu Island and the Jiyu Island, where wetland and mangrove habitats are still well preserved, provide fixed habitats for the birds. Estimates from 2004 predicted that no more than 70 000 egrets currently live in Xiamen areas [10].

3.5 Responses to ecological problems (R)

3.5.1 Rehabilitation of coastal areas

Xiamen carried out comprehensive treatment and rehabilitation to improve the marine environment. Since 2001, Xiamen Municipality has put great efforts on integrating rehabilitation of Western Sea area, Maluan Bay, Xinglin Bay, Wuyuan Bay and Tong'an Bay, reducing the rising pollutions and beautifying coastline.

The area of integrating rehabilitation in Western Sea is 70 km^2. From 2006, Xiamen Municipality invests over 18 billion RMB to conduct Tong'an Bay Integrated Rehabilitation Project, which involved 114 km^2 of land areas and 91 km^2 of sea areas. The goal of project is to build a new beachfront area of about 100 km^2 and to eventually improve the marine environment of Tong'an [17]. For uninhabited islands, by taking Monkey Island as a pilot site, Xiamen Municipality launched a project to restore the ecological and greenery sight scenes in 2006. Treatment of industrial sewage rose from 20 percent in 1994 to nearly 100 percent in the 2000s while treatment of domestic sewage rose from 27 percent in 1995 to 96 percent in 2008 [9,16].

3.5.2 Restoration and protection of selected species

Xiamen State-level Marine Protected Areas (MPA) for Rare Marine Species was formally established with the approval of the State Council in 2000 by combining the three local level MPAs. The provincial MPA for Egrets was established in 1995, and for Chinese white dolphins in 1997 and the municipal MPA for lancelets in 1991. In recent years with the depleting of Chinese horseshoe crabs, Xiamen is launching a campaign to promote its recruitment by releasing artificially hatched young crabs and under the way of conserving its spawning grounds along the coastal beaches. The same method also applied on prawns (*Penaeus penicillatus, Penaeus japonicus*) and fish (Sparuslatus sp., *Pagrosomus major, Pseudosciaena crocea*) beginning in 2002, and lancelets beginning in 2005 [18].

"Plan on mangrove planting", "Plan on wetland

protection in Xiamen", and "Program on the construction of shelter forest" were developed. In order to protect the mangrove habitats, the rehabilitation of mangroves areas extended. Protecting and replantating mangrove off Qing-Jiao Village, Hai-Cang, was conducted. By 2006, nearly 0.27 km^2 of mangrove forests had been planted. Xiamen is now launching a large scale campaign for mangrove ecosystem restoration in the Tong'an Bay.

4 Discussion

The DPSIR framework is effective in understanding the effects of rapid urbanization and industrialization on the marine ecological environment. By reviewing the ecological problems issues in Xiamen, the occurrences of problems and impacts, and the focus of responses were identified in this paper. In the early stage of economic development, Xiamen paid less attention to the environment. The urban landscape was transformed by construction projects throughout the city. Coastal and marine activities including coastal reclamation, aquaculture and waster disposal exerted great pressures on the environment. They contributed to contaminating the coastal waters, narrowing the coastal water, controlling tidal fluctuation, resulted in reduction of sea water and sediment quality, siltation and erosion, shoreline retreat and the blocking of navigational channels. And they have impacts on the benthic community, natural habitats and rare ocean animals. Fortunately, Xiamen leaders realized that a dirty environment was not good for the city and was in fact, bad for business. And they took appropriate actions toward restoration of Xiamen marine environment.

The DPSIR components identified in this article can help anticipate effects of urban development on the marine environment which will be helpful in urban planning efforts. The experiences of Xiamen will serve as lessons for other coastal cities which have not yet established effective management approaches on ecological restoration. However, much still remains to be done to repair the extensive damage to the environment. Moreover, population and economic production continue to increase very rapidly; a lot of previously disposed of waste continues to exude pollutants; a significant proportion of nutrient pollution continues to flow in from adjacent upstream cities through Jiulong River. Thus, an environmental rehabilitation program must be adaptive to changing conditions. With the complex ecological issues to confront in the future, there is a need to develop concrete indicators for DPSIR analysis in the future researches.

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