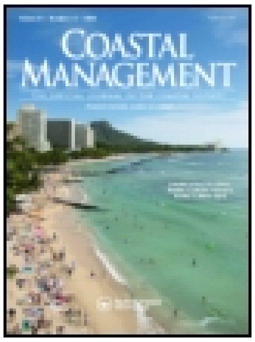

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Analysis of Coastal Wetland Changes Using the "DPSIR" Model: A Case Study in Xiamen, China

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Over the past several decades, human activities have had significant impacts on coastal wetlands worldwide. Here, using a model of "Drivers-Pressures-State-Impacts-Responses (DPSIR)" and data collected from coastal wetlands in Xiamen, China, we have analyzed temporal changes in regional coastal wetland ecosystem structure and function from 1950 through 2005. The study period was divided into four parts for comparative analysis: pre-1980s, 1980s, 1990s, and 2000 to present. Our results show that anthropogenic drivers of coastal wetland degradation in this region have increased substantially since 1950, and that this is correlated with a decline in coastal wetland function over the same period.

Keywords coastal wetland, ecological impact, Xiamen Sea

Introduction

The central role of coastal wetlands in providing critical ecosystem services (e. g., water supply, biological productivity, wildlife habitats, nutrient retention, pollution absorption and dispersion) and in regulating estuarine circulation and energy flow is well established (Bartlett & Harris, 1993; Zhou et al., 1993; Wong et al., 1997; Whigham, 1999; Elias et al., 2001; Crozier & Gawlik, 2003; Hernández-Romero et al., 2004; Schuyt, 2005). China possesses one of the largest and most diverse wetland areas in the world (Lu, 2003). Not surprisingly, given the rapid socioeconomic development and high population densities found in China's coastal regions, wetlands in these areas are increasingly subject to disturbance and human exploitation (Chen et al., 1987; Niu, 1989; Chen et al., 1992; Wan et al., 2001; Lu, 2003; Xue et al., 2004, Yang & Xue, 2004). In the coastal wetlands of China, the last several decades have been marked by a decrease in water quality, increased

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sediment loads, and losses of wildlife habitat, biodiversity, and biological productivity. When looking at these indicators, there appears to be a clear conflict between economic development and wetland conservation (Lau & Chu, 2000; Wan et al., 2001).

To provide a firm foundation for future resource and environment management decisions, we carried out a detailed analysis of the structural and functional changes in a Chinese coastal wetland over the past fifty years. Our study also analyzed the drivers and impacts of these changes. The Pressure-State-Response (PSR) model provides a logical framework for evaluating changes in coastal wetlands and their impacts. The PSR model was created by Anthony Friend, and subsequently adopted by the Organization for Economic Cooperation and Development (OECD) in 1993 to help model the cause and effect relationship between human beings and the environment (OECD, 1993,1998; Jesinghaus, 2006). The original PSR model descriptions focused on anthropogenic pressures and responses and did not consider the behavioral factors underlying these anthropogenic pressures (Bowen & Riley, 2003). The model was thus expanded by the United Nations and European Commission into the Driving Force-States-Response (DSR) and Drivers-Pressures-State-Impacts-Response (DPSIR) models (Jesinghaus, 2006; Bowen & Riley, 2003) to create a more widely applicable framework. For coastal wetlands, anthropogenic factors are the major pressures affecting both the structural organization and functional characteristics of the ecosystem recently. By using this modified PSR framework management problems and solutions can be simplified into variables that stress the cause and effect relationships among human activities, the condition of the coastal wetland, and society's response to this condition. This article uses the DPSIR model to analyze the historical changes in the coastal ecosystem of Xiamen, a city in southeastern China. The problems described in this paper may be similar to those experienced in many coastal areas around the world, and we hope this case study will provide a useful example of how the PSR framework can be used to make informed management decisions.

Description of Study Area

Xiamen City is located on the southeast coast of China (Figure 1) and is one of the five fastest growing Special Economic Zones in the country. It serves not only as one of the

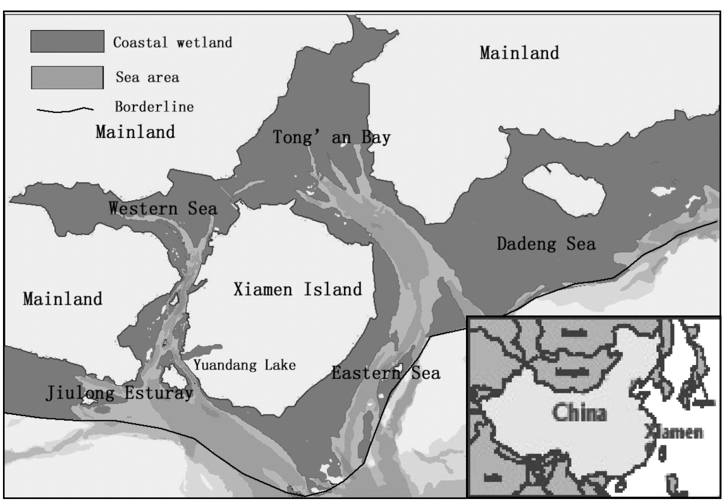

Figure 1. Map of Xiamen's coastal wetlands.

Table 1
Types of coastal wetlands in Xiamen, China

Coastal wetland	Area (km^2)	Proportion (%)
Tidal wetlands[a]	136.8	57.00
Mud area	108	45.00
Sand beach	20	8.33
Rock beach	8.8	3.67
Shallow sea area[b]	≈100	41.67
Lagoons	1.1	0.46
Mangroves[c]	0.434	0.18
Total	≈240	100.00

[a]Calculated from Fujian Ocean Research Institution (2001).
[b]Calculated from satellite imagery of January 30, 2004 by using Arcview 3.2a.
[c]Refer to Lin et al. (2005).

prominent international trading ports of China, but also as the leading economic mainstay of Fujian Province. Xiamen's roughly 230 km of coastline includes tidal wetlands, shallow sea areas, lagoons, and mangroves, covering a total area of about 240 km^2 (Xiamen Marine & Fisheries Bureau, 2004) (Table 1). The tidal wetlands, which consist of rock beaches, sand beaches, and mud beaches, are the most common type of coastal wetland in Xiamen. Xiamen's shallow sea areas occur where the depth of seawater does not exceed six meters at low tide. Yuandang Lake, which used to be a natural port in the west of Xiamen Island, was reclaimed as an artificial lagoon in 1971. Mangroves are mainly located in Haicang and some small islands around Xiamen Island.

Analysis Methods and Data Processing

Study Procedures

We used the DPSIR model as an analytical framework to trace the changes in coastal wetland structure and function over time, to look at the drivers of these changes, and to evaluate the impacts of these changes on Xiamen. Within this model, drivers are defined as the underlying factors causing or influencing a variety of pressures on coastal wetlands (i.e., ultimate cause of change). Pressures are defined as the variables that directly cause the changes in these wetlands (i.e., proximate cause of change). State is the measure of the physical, chemical and biological conditions within the ecosystem. Impacts describe the effects of changes in coastal wetland states on measures of ecosystem function. And finally, response is defined as the efforts of society (i.e., politicians, decision-makers) to solve the problems resulting from changes in wetland function. The DPSIR flow chart for the present study is shown in Figure 2 and has four major steps; (1) interpreting the drivers and the pressures; (2) describing the state changes; (3) describing the impacts; and (4) reviewing the human response.

As one of the fastest growing cities in China, human population growth and economic development are undoubtedly the two major drivers in Xiamen. These two drivers cause increases in a variety of pressures and this article focuses on the four major pressures on the wetlands: resource exploration, urbanization, industrialization and aquaculture development. Such activities lead directly to changes in the physical, chemical, and

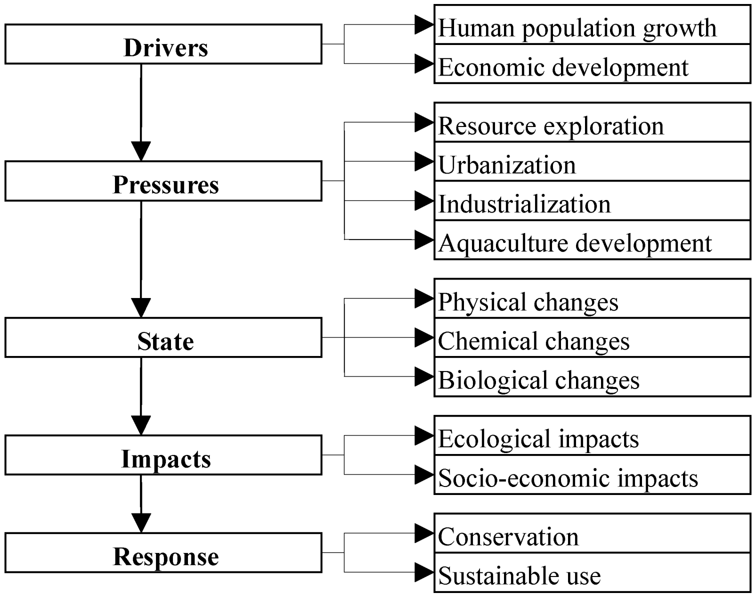

Figure 2. Flow chart for the analysis of coastal wetland changes and their impacts in Xiamen, China.

biological conditions within the wetlands, which leads in turn to negative ecological and socioeconomic impacts including algal blooms and red tides, degradation of fishery production, decreasing populations of rare marine wildlife, and siltation of navigation channels. Human response to these changes has included control of pollution discharge, conservation, marine functional zoning, and public involvement in the management decision-making process.

Data Collection and Processing

The importance of wetlands in Xiamen's coastal ecosystem has not been widely recognized until recently, and thus the majority of published studies on coastal wetlands in this area have been either short-term or limited in scope. The data used in this study were derived primarily from research reports, monitoring reports, government reports, field surveys and other related databases. Drivers and pressures were chosen by reviewing the population and socioeconomic trends in the Xiamen area as well as the associated anthropogenic activities over the past fifty years. The state changes and impacts resulting from these pressures were identified as indicators and quantified using the research and monitoring reports noted earlier. The response mainly refers to the established policies, plans or projects to reduce the pressures and the negative impacts on coastal wetlands in Xiamen. Under the framework of the DPSIR model, the time span addressed in this study was divided into four periods for comparative analysis: pre-1980s, 1980s, 1990s, and 2000 to present.

Results

Anthropogenic Drivers and Pressures on Coastal Wetlands

Rapid growth of human population and economic development lead to the expansion and increasing of human activities and were the two major anthropogenic drivers on

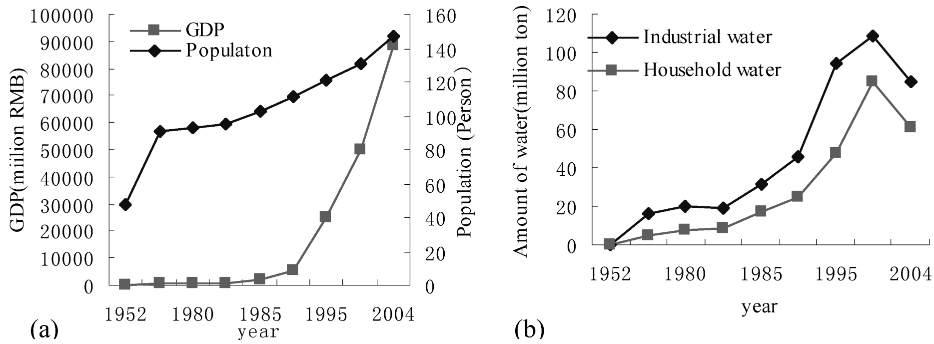

Figure 3. (**a**) Population and GDP growth from 1950 to 2005. (**b**) The industrial and household. water use from 1950 to 2005. (Drawn from Xiamen Statistics Bureau, 2005.)

resource utilization and land/habitat occupation. Figure 3a shows the population growth and economic development of Xiamen since the 1950s. Human activities, including resource exploration, urbanization, industrialization and aquaculture caused the most serious pressures on the coastal wetland of Xiamen. From the 1950s to 2000, a total of 90.13 km^2 of coastal wetland were reclaimed into urban, industrial or aquaculture area to meet the city's socioeconomic requirements. Industrial and domestic demands for water increased, which directly caused an increase in the industrial and municipal sewage discharged into coastal wetland. At the same time, aquaculture and coastal fishery increased sharply. Up until now, over 80% of the coastal wetland of Xiamen has been utilized for aquaculture practices. Figures 3b and 4 show the changes of those pressures from the 1950s to the present time.

State Changes of Coastal Wetland

Physical state changes. Reduction of the shallow sea area and tidal flux volume during the past 50 years were the two great physical state changes of Xiamen coastal wetlands. Most of the reduction occurred in the Western Sea and Tong'an Bay. The shallow sea surface

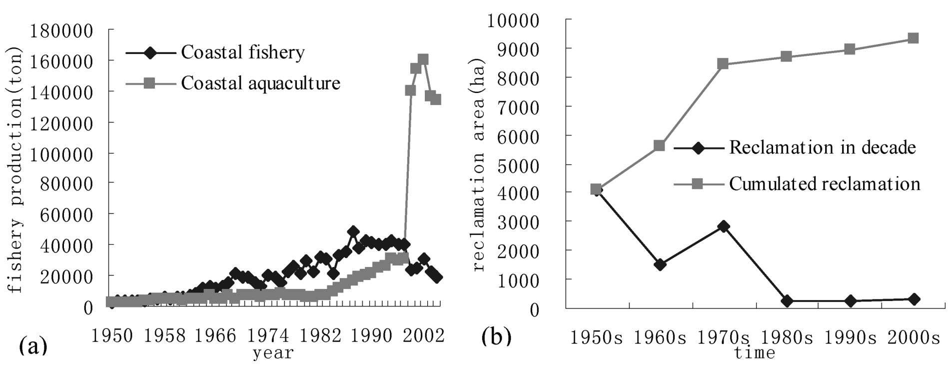

Figure 4. (**a**) Changes in coastal fishery and aquaculture production from 1950 to 2005 (Drawn from Xiamen Statistics Bureau 1980–2005 and Lu, 2000). (**b**) Wetland reclamation area in Xiamen from 1950 to 2005.

area in the Western Seas was accumulatively reduced by 50% from 110 km^2 in the 1950s to 52 km^2 now. At the same time, the tidal influx volume was reduced 0.12 billion m^3, 38.7% less than that in the 1950s. In Tong'an Bay, the original surface area was only 90 km^2, and this has been reduced 25.5% since the 1950s (Xiamen Demonstration Project Regional Programme for the Prevention and Management of Marine Pollution in the East Asian Seas, 1998). Yuandang lagoon, which was originally a natural shallow bay with an area of 10 km^2 before 1971, was transformed into an artificial salty lake with an area of 1.1 km^2.

As the tidal influx volume was reduced significantly, the suspended solid (S.S.) load was increased and sedimentation processes were accelerated. The average S. S concentration was increased from 70 mg/L in the late 1980s to 188 mg/L in the later 1990s. In Baozhu Island and Dongyu Bay of the Western Seas, Dongju of Tong'an Bay, the north and west of Dadeng Island, and the estuary of the Jiulong River, the rates of siltation are generally beyond 5 cm/a, with some places exceeding 10 cm/a. The sediment in coastal areas has changed significantly from gravel sand (GS, MdΦ $-0.86\sim2.67$) and coarse sand (CS, MdΦ $0.81\sim2.31$) in the early 1980s to fine sand and clay (STY, Md $\Phi1.72\sim7.85$) and tiny clay (TY, MdΦ $7.50\sim9.80$) in the late 1990s (The Committee of Integrated Investigation on Resources of Islands in Fujian Province, China, 1996).

Chemical state changes. Pollutants from industrial, domestic and aquaculture sources directly cause the degradation of water quality and sediment quality of coastal wetland. Dissolved inorganic nitrogen (DIN) and Dissolved reactive phosphorous (DRP) in sea water have become the most severe pollutants and their concentrations have increased since the 1980s. Figure 5 shows the changes of DIN, DRP, COD_{Mn}, DO and pH of wetland water during the 1980s to the present. According to China's national standard of sea water quality, water quality in the Western Seas and Tong'an Bay has dropped to Class 4 in 2004 from Class 2 in the early 1980s.

High levels of organic pollutants, sulfides and heavy metals were found in the coastal wetland sediment as a result of siltation and waste discharged from the coast (Yang & Xue, 2004). The content of organic pollutants in the sediment of the Western Seas was 1.5% in the 1980s. This increased to over 2.0% in the 1990s and to 3.48% in 2003. Meanwhile, heavy metals, such as Hg, Pb and Zn, formed obvious cumulative pollution in the sediment (Chen et al., 1987, 1992). In the aquaculture areas of Tong'an Bay and the Dadeng Sea, a high COD content of the sea water and a great amount of Fe-Mn oxide have been found, and this will easily lead to heavy metal enrichment.

Biological state changes. The species composition and community structure of coastal plants, phytoplankton, nekton (fish), and benthos have changed; whereas wild species abundance and diversity are decreasing. Coastal reclamation has led directly to the reduction of the mangrove areas in many places. The area of the remaining natural mangrove is now less than one tenth of that in the 1960s (Table 2). The concentration of Chl-*a*, which can be used to indicate the population of phytoplankton in the wetland water, increased in the late 1980s but decreased in the middle of the 1990s. Then it increased significantly from the late 1990s to the present time, see Figure 5c. The dominant species of the fish communities have changed from long-living, high trophic feeding and large sized species to short-lived, low trophic level feeding and small sized species (Lu et al., 1999). With coarse sand being replaced by fine sand, enriched with organic matter, the composition of benthic species has changed accordingly, with increasing dominance of polychete worms replacing the echinoderms (Xue et al., 2004).

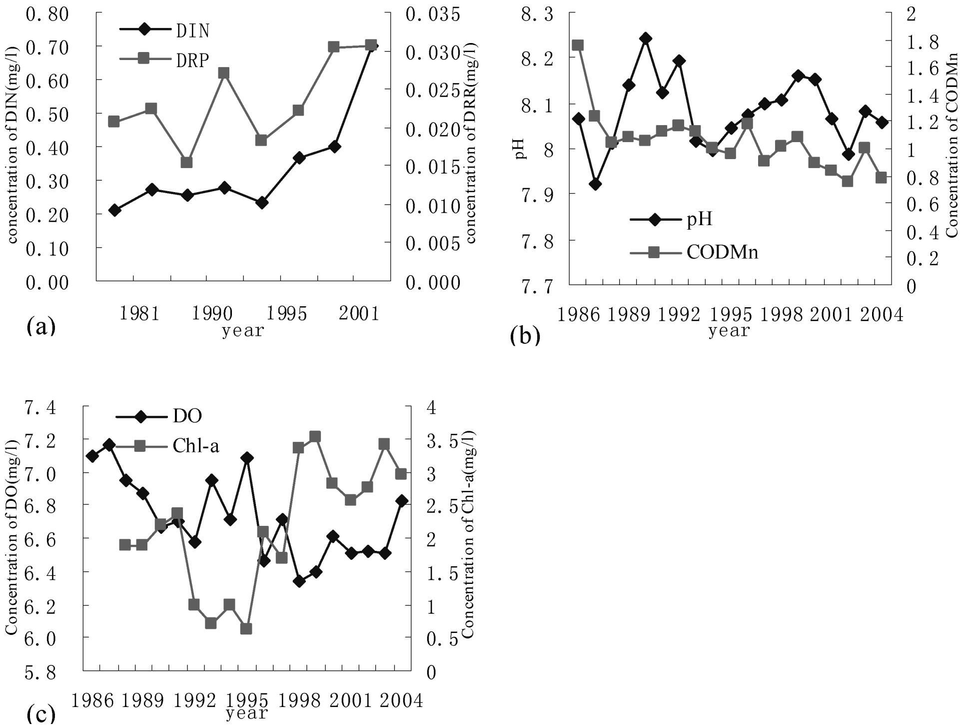

Figure 5. (**a**) Concentration of the major pollutants DIN and DRP in coastal wetland water from 1981 to 2005. (**b**) COD_{Mn} and pH from 1986 to 2004. (**c**) Changes in DO and Chl-*a* from 1986 to 2004. (Drawn from Xiamen Environmental Protection Bureau 1985–2004.)

Impacts of Coastal Wetland State Changes

Algal bloom and red tide occurrences. With the degradation of coastal water quality and the increasing trends of Chl-*a* and DO, algal blooms and red tides occurred frequently from the late 1980s. Table 3 reviews the historical record of algal blooms observed along the Xiamen coast. Totally 35 algal blooms were observed during the past 20 years and an increasing trend for red tides occurred from the late 1990s to the early 2000s. The main red tide algaes were *Skeletonema costatum* and *Chaetoceros gracilis,* which caused 13 red

Table 2
Changes in mangrove areas in Xiamen

Time	Area/Ha	Haicang	Tong'an	Maluan	Xinglin	Yuandang	Gaoqi	Jimei	Other
1960	320	166.7	80	20	22.7	13.3	13.3	0	4
1979	106.7	83.3	16.7	0	2	0	2	0	2.7
2000	32.6	24	0.1	0	0.4	0	0.1	7.3	0.7
2004*	43.4	21.9	0.1				0.2	13.8	7.3

The mangrove area in 2004 is the sum of natural mangrove and artificial mangrove with 22.4 ha. The area of natural mangrove is 21 ha and the artificial is 22.4 ha. The data are derived from Lin (2005).

Table 3
Historical observations of algal blooms and red tides along the Xiamen coast

Year	WS	ES	TB	JE	DS	Total
1986	2					2
1987	3					3
1996	1					1
1997	3					3
1998	1		1			2
2000	1					1
2001	2					2
2002	3		1			4
2003	6			1		7
2004	3					3
2005	6		1			7
Total	31		3	1		35

WS is Western Sea; ES is Eastern Sea; TB is Tong'an Bay; JE is Jiulong Estuary; DS is Dadeng Sea. The data for 1986 and 1987 are from Zhang et al. (1994); Data from 1996 to 2005 are from Xiamen Marine and Fisheries Bureau (2000–2004).

tides and 10 red tides respectively. Nearly 90% of the red tides occurred in the Western Sea, around which is located the most developed urban and industrial zone of Xiamen city. The area of algal blooms and red tides ranged from 5 km^2 to 50 km^2. The most severe red tide occurred in the Western Sea and Tong'an Bay in 2003 and, with an area of 200 km^2, covered more than half of the whole Xiamen sea area. Algal blooms and red tides are one of the most serious threats to coastal aquaculture.

Decline in fishery production. Under the pressures of overfishing and the state changes in the coastal waters in Xiamen, coastal commercial fishery production showed a seriously decreasing trend from the 1980s to 2000s, after an increase of about 30 years from the 1950s to the 1980s. Table 4 shows the production changes in the eight major commercial coastal fishery species in the past half century. The production of the major commercial species is decreasing rapidly except for the Genuine porgy. The amphioxus fishery of Liuwudian had disappeared since the early 1980s as a result of the great changes in the sediment environment. After a stable increase during the 1950s to 1980s and a striking increase in the late 1990s, the production of coastal aquaculture began decreasing from the early 2000s as a result of the degradation of water and sediment quality. The aquaculture area in 2000 was expanded by 63% over that in 1998, but the annual production of 2000 was even lower than that in 1998 (Figure 3a).

Decrease of rare marine wildlife. The amphioxus mentioned earlier has become rare as part of the marine wildlife in the Xiamen Sea. Meanwhile, the Chinese white dolphin and egret, typical rare marine wildlife of the Xiamen coastal ecosystem, are confronting threats from habitat degradation and loss. The Chinese white dolphin's habitat covered the whole Xiamen sea before the 1980s and the Western Sea was the most important breeding habitat for the dolphins. The dolphin population has decreased sharply since the 1980s and it is estimated that less than one hundred exist along the Xiamen coast now, compared the population of thousands in the 1960s (Liu & Huang, 2000). During 1994 to 1999, 11

Table 4
Production changes for the main commercial fish species over the past half century

Commercial fish	1950s	1960s	1970s	1980s	1990s	2000s
Amphioxus	50t	25t	10t	0	0	0
Genuine porgy		20∼40t	↓	15∼20t	↑	
Chinese herring		150∼200t	↓	↓	5∼10t	↓
Large yellow croaker	3071∼4341t	↓	988∼3370t	25t	↓	↓
Scombermorus niphonius				19∼719t	60∼150t	↓
Eel fry				1585∼2629t	759∼2398t	↓
Penaeus penicillatus	50t	3t	↓	↓	↓	↓

0 indicates collapse of fishery; ↓ represents decline; ↑ represents recovery. Derived from Lu et al. (1998).

dolphins were found dead (Huang & Liu, 2000) and the same number of dolphins were found dead from 2002 to 2004. In 2004, the Chinese white dolphins could only be found in the Western Sea and Eastern Sea. Mangroves are the natural breeding and foraging habitat of the egret, and the reduction of the mangroves has affected the population and distribution of egrets along the Xiamen coast. Before the 1980s, egrets existed along most parts of the coast. Nowadays, only Dayu Island and Jiyu Island remain as the major breeding sites of the egret population of about 7000.

Siltation in the navigation channel. Navigation is a major part of Xiamen's economy. As siltation in the shallow sea accelerated and filled up the natural channel, the sustainable development of navigation was badly affected. Comparing the depth of the sea channel from 1934 to 1976, the channel between Songyu Island and Gulang Island was seriously silted and the depth decreased by 10 m in 30 years (Xue et al., 2004). A similar situation occurred in Baozhu islet, Hou islet, etc. (Liu et al., 1984). As a result, the frequency and volume of dredging had to be increased in order to maintain a sea-route. In 1984, 150000 m^3 of deposits were dredged from the channel for the first time. In 1993, 190000 m^3 were dredged, and two years later, a further 160000 m^3 needed to be dredged to maintain the sea passage. From 1996, a dredging of 80000 m^3 was needed annually.

Response of Human Society to the Coastal Wetland Changes

Rational use of coastal wetland. For rational use of coastal wetland, the Xiamen government implemented marine legislation, particularly the *Regulation on Management of Sea Area Use* (Li, 1999), as the legal framework for managing coastal wetland changes and use conflicts. This is among the local regulations enacted since the 1980s concerning coastal wetland use including resource exploration, transportation and environmental protection, to complement national laws (Table 5). Meanwhile, the Xiamen Marine Functional Zoning Scheme (XMFZS) was established in 1996 as a crucial means seeking to determine

Table 5
Coastal wetland related legislation in Xiamen since the 1980s

Type of legislation
Legislation specific to coastal wetland utilization
Regulations on land management
Regulations on city planning
Regulation on the management of sand, soil and stone
Regulation on the management of waterway transportation
Regulation on the use and management of sea areas
Regulation on aquaculture management in the shallow seas and intertidal zones
Measures on management of changing sea area uses
Regulations on coastline planning and management
General environmental protection legislation
Regulations on environmental protection
Measures on the management of Yuandang lagoon region
Regulations on the management of protected area for Chinese white dolphin
Measures on the management of protected area for white egret in Dayu islet
Public notice on the reinforcement of management of sea eel fishing in the sea area around Xiamen
Regulation on the protection and management of the marine environment
Measures on the management of the lancelet protected area

From: Li (1999).

multi-use priorities, reduce use conflicts and increase the socioeconomic benefits as a whole obtained from various uses, while sustaining the resource base and ecosystem functions (Ruan & Yu, 1999). It provides a basis for the rational use of coastal wetland through allocation of coastal wetland on functional characteristics of a given area. The XMFZS defined use priorities in terms of dominant, compatible or restricted functions. For example, land reclamation is strictly forbidden in the Western Sea, where the dominant function is port development.

Pollution emission control and treatment. Regulations on controlling waste water emission have been enacted and seven sewage plants have been built in Xiamen since 1984. The capacity of waste water treatment reached 625,000 ton/day and 60.1% of domestic waste water were treated before being discharged into the sea in 2004, compared to no treatment in 1985. For industrial waste water emission, a regulation was established requiring that sewage emission according with the national standard be achieved by the early 1980s. The rate by which industrial sewage emissions have satisfied the regulations in Xiamen has increased rapidly since the late 1990s. Figure 6 shows the increasing rate of treatment of domestic and industrial waste water discharge from the 1980s to the present time.

Ecological conservation and restoration. In order to protect the rare marine animals in the Xiamen coastal wetland, a nature conservation area was designated in the XMFZS and established in 1991, when the amphioxus conservation area was founded with an area of 63 km^2, covering Tong'an Bay, Eastern Sea and Dadeng Sea. Then, the Egret conservation area with an area of 0.55 km^2 and Chinese white dolphin conservation area with an area

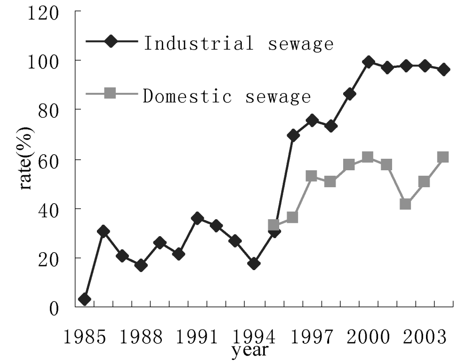

Figure 6. Treatment rate for domestic and industrial waste water discharge from 1985 to 2004. (Drawn from Xiamen Environmental Protection Bureau 1985–2004.)

of 55 km^2 were established, respectively, in 1995 and 1997, at Dayu Islet and Jiyu Islet for egret, Western Sea and Tong'an Bay for the white dolphin. In 2000, the three nature conservation areas were united into a national class nature conservation area of 330.88 km^2, covering about 80% of the Xiamen sea area. The Xiamen government decided to protect the remaining mangrove and began to restore it in the inter-tidal area of Haicang from the 1990s. They made great progress and, in 2004, the area of artificial mangrove reached 0.224 km^2, covering more than 50 percent of the total mangrove area in Xiamen.

Public involvement and scientific support. With social and economic development and environmental quality degradation, the public's environmental protection awareness has been enhanced and widely recognized as an effective method to keep the balance of human society and the natural Xiamen ecosystem.For example, the Bird Watching Club, a nongovernment organization (NGO), obtained valuable knowledge and information about the coastal wetlands changes from their long-term work on tracing the footprints of the egrets along the Xiamen coast and played an important role in the foundation of egret conservation. The Marine Expert Group, comprising marine scientists, legal experts, and economists, was established by the Municipal Government in 1996, as a mean to integrate science into policymaking and management. The responsibility of the group is to provide essential socioeconomic, ecological and technical advice to policymakers and to provide the best available information that will minimise costs and maximise benefits associated with a proposed development project. XMFZS is one of the important accomplishments of this group.

Integrated Assessment of the Coastal Wetland Changes in Xiamen

Based on the earlier analysis of the coastal wetland changes from human drivers, pressures, coastal wetland state changes, impacts and human response, a set of comprehensive indicators can be deduced to make an integrated assessment, see Table 6. The indicator system encompasses two drivers indicators, 5 pressures indicators, 14 state indicators (including 4 physical, 6 chemical, and 4 biological indicators), 6 impacts indicators and 6 response indicators. The pressures indicators express the external disturbance to the coastal wetland ecosystem, and the larger they are, the more harmful their influence and impact on the coastal wetland state. On the contrary, the responses indicators express the positive

Table 6

Integrated assessment results for coastal wetlands in Xiamen using the "DPSIR" indicators

Assessment indicators		Temporal assessment
Drivers		Order from small to large
	Human population	Pre-1980s < 1980s < 1990s < 2000s
	Gross domestic production (GDP)	Pre-1980s < 1980s < 1990s < 2000s
Pressures		Order from small to large
	Coastal reclamation area	1990s ≈ 1980s < 2000s < Pre-1980s
	Commercial fishery production	Pre-1980s < 1980s < 2000s < 1990s
	Aquaculture production	Pre-1980s < 1980s < 1990s < 2000s
	Industrial use water	Pre-1980s < 1980s < 1990s < 2000s
	Domestic use water	Pre-1980s < 1980s < 1990s < 2000s
States		Order from good to bad
Physical	∗Loss of coastal wetland area	1990s ≈ 1980s < 2000s < Pre-1980s
	Influx volume	Pre-1980s < 1980s < 1990s < 2000s
	Suspended solid (S.S.)	Pre-1980s < 1980s < 1990s < 2000s
	Siltation and sediment changes	Pre-1980s < 1980s < 1990s < 2000s
Chemical	DIN concentration	Pre-1980s < 1980s < 1990s < 2000s
	DRP concentration	Pre-1980s < 1980s < 1990s < 2000s
	COD_{Mn} concentration	2000s < 1990s < 1980s
	DO concentration	1980s > 1990s > 2000s
	Organic pollutants	Pre-1980s < 1980s < 1990s < 2000s
	Heavy metal pollutants	Pre-1980s < 1980s < 1990s < 2000s
Biological	Concentration of Chl-*a*	1990s < 1980s < 2000s
	Mangrove area	Pre-1980s < 1980s < 2000s < 1990s
	Species abundance	Pre-1980s < 1980s < 1990s < 2000s
	Species diversity	Pre-1980s < 1980s < 1990s < 2000s
Impacts		Order from small to big
	Number of red tides	Pre-1980s < 1980s < 1990s < 2000s
	∗Commercial fishery production	Pre-1980s < 1980s < 2000s < 1990s
	∗Aquaculture area	Pre-1980s < 1980s < 1990s < 2000s
	Population of white dolphin	Pre-1980s > 1980s > 1990s > 2000s
	Distribution area of egret	Pre-1980s > 1980s > 1990s > 2000s
	Siltation in navigation channel	Pre-1980s < 1980s < 1990s < 2000s
Responses		Order from weak to stong
	Rational use of coastal wetland	Pre-1980s < 1980s < 1990s < 2000s
	Waste water emission control	Pre-1980s < 1980s < 1990s < 2000s
	Waste water treatment capacity	Pre-1980s < 1980s < 1990s < 2000s
	Natural conservation area	Pre-1980s < 1980s < 1990s < 2000s
	Public involvement	Pre-1980s < 1980s < 1990s < 2000s
	Scientific support ability	Pre-1980s < 1980s < 1990s < 2000s

*"Loss of coastal wetland area" can be used as both a pressures indicator and state indicator. "Commercial fishery production" and "aquaculture area" can be used as both a "pressures" indicator and an "impacts" indicator.

feedback from human society, and the larger they are, the better the influence and impact on the coastal wetland state. The indicators are assessed based on the earlier analysis and are ranked into a temporal order (Table 6). The results show that the temporal order of human drivers and pressures from small to large are as follows: pre-1980s < 1980s < 1990s < 2000s. The coastal wetland state from good to bad is: pre-1980s < 1980s < 1990s < 2000s. The negative impacts from small to big are: pre-1980s < 1980s < 1990s < 2000s and response from weak to strong are: pre-1980s < 1980s < 1990s < 2000s.

Conclusion

By using "DPSIR" as a study framework, this article traced the changes recurring in the coastal wetland of Xiamen and their causes and impacts. Drivers, pressures, state, impacts and response indicators were used to assess the changes in the coastal wetland. It can be concluded that the pressures from human population growth and economic development have increased during the past half century in Xiamen, China. Coastal reclamation, fisheries including commercial and aquaculture fishery, and water pollution have directly caused the degradation of the coastal wetland state in physical, chemical, and biological aspects, and led to negative ecological and social economic impacts, including algal blooms and red tides, degradation of fisheries production, decreases in rare marine wildlife and siltation of the navigation channel. Great human efforts have been expended to protect the coastal wetland, such as rational use of coastal wetland, waste water emission control and treatment capability, biological conservation and restoration, public involvement and scientific support ability. On the whole, the state of the Xiamen coastal wetland is getting worse and the negative impacts are becoming more severe. Although human efforts to protect the coastal wetlands have been put into practice, there still seems to be a long way before we reach the goal of sustainable use of coastal wetland and maintaining a health state.

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