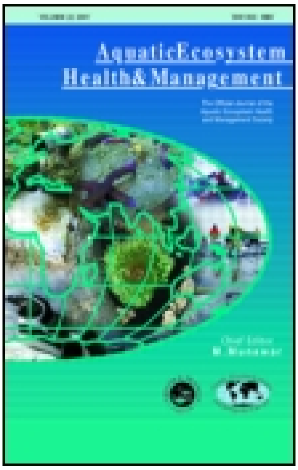

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A review of environment problems in the coastal sea of South China

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A review of environment problems in the coastal sea of South China

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The coastal sea of South China provided an important habitat for protection and propagation of marine organisms. Rapid economic development and human activities, such as wastewater discharge, reclamation, overfishing and aquaculture in the South China Sea had already resulted in environmental degradation, and thus caused sharp contradictions between exploitation and protection of the coastal sea of South China. In this present article, the main environment problems and degradation trends were reviewed based on literatures and other sources of information, which mainly referenced nutrient pollution, persistent organic pollution and metal pollution, decrease of biodiversity, reduction of marine habitat and frequent natural and ecological disasters. The current efforts in China on protecting the environment in the coastal sea of South China were discussed, which included improving legislation by formulating a series of laws and regulations at national or local level, setting up natural reserves, and supporting research projects. There were many challenges regarding policy, management and science research to protect and sustain the coastal sea of South China, such as imperfect legal and administrative systems, lack of public participation, poor financial support and lack of monitoring and evaluation. Finally, some recommendations were put forward for the sake of the sustainable use of the environment in the coastal sea of South China, including reinforcing the planning of marine resource exploitation and use through integrated coastal zone management, strengthening the marine environment and protection awareness of the public, and scientifically establishing the fishery spawning spots and aquatic reserves.

Keywords: nutrient, heavy metal, persistent organic pollutant, disaster, sustainable management

Introduction

The coastal sea of South China (CSSC) is located in the area affected by both tropical oceanic monsoon circulation and semitropical continental monsoon circulation. Human activities and rapid economic development in South China have already resulted in environmental degradation in the surrounding seas, which thus caused the sharp contradictions between exploitation and protection of CSSC. Identification of sources of contaminants and evaluation of current environmental status are essential to environment management.

Existing studies on CSSC focused mainly on the status quo description of pollution, biodiversity and coastal erosion (Yu, 2003; Li et al., 2005, 2007). There are few studies on the degradation trends of CSSC. Environmental deterioration and marine pollution will restrict the sustainable development of environment and economy in South China. In

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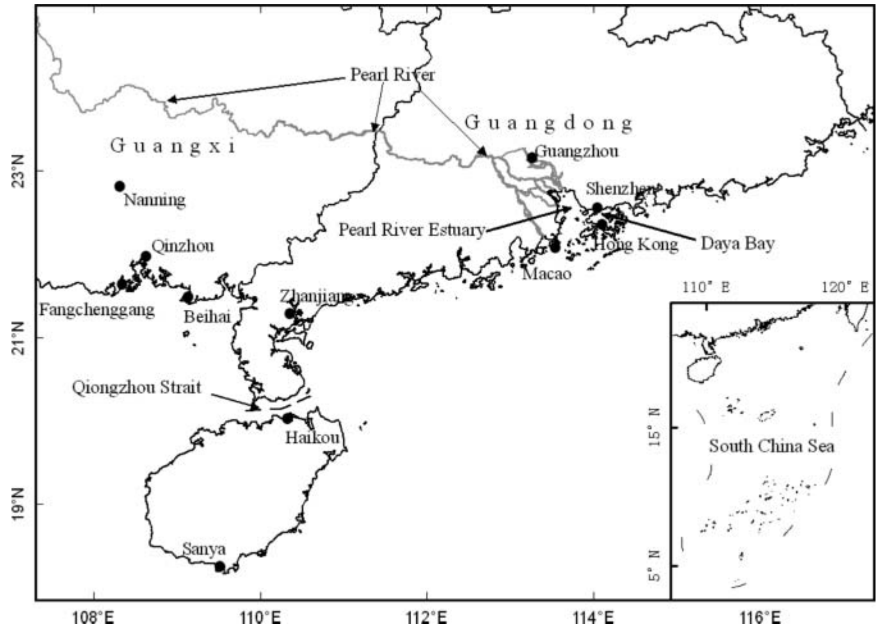

Figure 1. The map of the coastal sea of South China.

this article, environment problems of CSSC were reviewed, and recommendations for their control were put forward.

Description of the study area

CSSC includes the coastal area of Guangdong, Hainan provinces, and Guangxi Zhuang Antonomous Region, as well as Macao and Hong Kong (Figure 1). One of the major world rivers, the Pearl River drains into CSSC, carrying vast amounts of suspended sediments and dissolved substances (State Oceanic Administration of China, 2010). There are 4.14×10^5 km^2 land area, 55.8% forest cover, 5.18×10^4 km^2 and 5.98×10^4 km^2 agriculture and urbanization, 254.8×10^4 km^2 sea area and 6669 km of coastline length along South China (Tao, 1998).

There is abundant biodiversity in CSSC due to its unique geographical location and complicated climate character. There are 1403 species of phytoplankton, 945 species of zooplankton (Li et al., 2004), and 341 families, 1545 species of tidal flats biology (Yu et al., 1990) and seagrass bed, mangroves and coral reefs are main coastal habitats in CSSC. The total area of seagrass beds is about 2400 ha, including 8 species, such as *Halophila ovalis, Halodule uninervis, Halophila beccarii, Zostera japonica, Enhalus acoroides, Thalassia hemperichii, Ruppia martime* and *Cymodocea rotundata* (Huang et al., 2006). The total area of mangroves is 17422 ha in CSSC (Li and Lee, 1997) and there are 13 species of true mangroves and 6 species of semi-mangroves in Guangdong, 11 species of true mangroves and 7 species of semi-mangroves in Guangxi, 25 species of true mangroves and 10 species of semi-mangroves in Hainan (Fan, 2003). There were 110 species of corals in Hainan and 45 species in Guangdong and Guangxi (State Oceanic Administration of China, 2008). There are 18 species of planktonic Ostraacoda in Guangxi, including *Cyridina nanan*, *Cypridina nana*, *Cypridina dentate*, *Cypridina acuminate*, *Cypridina nami*, *Euconchoeia aculeate*, *Euconchoecia elongate*, *Euconchoecia maima*, and other taxa in Guangxi coast (Zhao et al., 2007).

Main environment problems

Environment pollution

Pollution is one of the major challenges to sustainability of CSSC. The area of polluted seawater was about 2.46×10^4 km^2 in CSSC, mainly distributed in Pearl River Estuary, and inorganic nitrogen, active phosphorus and oil were the main pollutants entering in 2010 (State Oceanic

Administration of China, 2010). The total amount of pollutants entering into CSSC from the Pearl River was 7.17×10^5 t in 2010 (State Oceanic Administration of China, 2010). The area of polluted seawater was 3.14×10^3 km^2 in Guangxi coast, mainly distributed in Fangchenggang and Dafeng River Estuary of Qinzhou Bay in 2010 (The Oceanic Administration of Guangxi, 2010). The total amount of pollutants entering into CSSC from the Dafengjiang River was 3.96×10^4 t in 2010 (State Oceanic Administration of China, 2010).

Nutrient pollution

With the rapid economy development, the seawater and sediment in CSSC were affected by nutrient pollution. The concentration of active phosphorus was 0–0.23 μmol dm^{-3} in the surface water in CSSC in summer with average 0.04 μmol dm^{-3}, and 0.05–1.87μmol dm^{-3} in winter with average 0.34 μmol dm^{-3} (Pan et al., 2004). The contents of nitrate, nitrite, and phosphate in water mass increased in Pearl River Estuary (Pan et al., 2004). Agriculture fertilizer, foreshore/coastal reclamation and marine aquaculture increased the concentration of dissolved inorganic nitrogen and dissolved inorganic phosphorus in the water of Lingdingyang sea area in Pearl River Estuary (Ma et al., 2009). In Daya Bay, total phosphate was one of the major pollutants (Wu et al., 2010). Since 1991, soluble inorganic nitrogen in seawater had been more than ever before in Daya Bay (Peng et al., 2002; Qiu et al., 2005). Seawater in Daya Bay changed from oligotrophic to medium trophic level, and partial seawater had been eutrophic (Wang et al., 2004). The net discharge of total nitrogen and phosphorus in Shenzhen was from 2.48×10^7 and 4.52×10^6 kg in 1991 to 3.02×10^7 and 5.34×10^6 kg in 2001 (Jiang et al., 2007).

Persistent organic pollution

Persistent organic pollutants (POPs) have a negative effect on the marine biology by biomagnifications through the transport process in the food chain (Wang et al., 2005). Polycyclic aromatic hydrocarbons (PAHs) in the environment had been of special concern for several decades due to their acute toxicity and sublethal effects to both terrestrial and aquatic organisms (Phillips and Grover, 1994). In Pearl River Estuary and Hong Kong, coastal waters were heavily contaminated by PAHs (Zheng et al., 2004). Total PAHs concentration increased from 138 to 6793 ng g^{-1} dry weight in the surface sediments from the northern continental shelf of the South China Sea to the Guangzhou Channel of the Pearl river in 2002 (Luo et al., 2008). Riverine discharge was the major input pathway for PAHs to near-shore sediments (Chen et al., 2006; Luo et al., 2008). The average concentration of PAHs in Deep Bay, located in the eastern Lingdingyang of Pearl River Estuary, was 69.4 ± 24.7 ng l^{-1} in the seawater, 429.1 ± 231.8 ng l^{-1} in the suspended particulate matter, and 353.8 ± 128.1 ng l^{-1} dry weight in the surface sediment, respectively. PAHs concentrations in core sediment generally increased from 1948 to 2004, with highest concentrations in top or sub-surface sediment, implying the recent input of PAHs was due to the rapid economic development in Shenzhen (Qiu et al., 2006, 2009). The concentration of dimethyl sulfide (DMS) was 61–148 ng l^{-1} in the surface seawater of CSSC, and the higher concentration of DMS was found in the productive regions (Yang, 2000). The correlativity between the concentration of DMS and the seawater temperature, dissolved oxygen was positive, but the correlativity between the concentration of DMS and the nutrients was negative (Yang, 2000). The total concentration of chlorobenzenes (CBs) in Pearl River Estuary was from 16.44 to 963.20 ng l^{-1} in the top water layer, from 7.83 to 40.09 ng l^{-1} in surface sediments, 38873.0 ng l^{-1} in shellfish, 2360.3 ng l^{-1} in fish and 565.0 ng l^{-1} in shrimp, implicating significant magnification phenomena of CBs from water to sediment and aquatic animals (Wei et al., 2007).

Metal pollution

Heavy metal contamination in the sediment and seawater was one of the largest threats to environmental quality and human health (Li et al., 2001). It was well-known that increased concentration of heavy metal in surface sediments may be a result of recent anthropogenic effects, and the sediments in deeper layers may provide records of past contamination (Li et al., 2001). Metal concentrations in the sediment of Pearl River Estuary had increased over the last 20 years (Li et al., 2001). Compared with historical monitoring results, the west side of Pearl River Estuary tended to be more contaminated by heavy metal than the east side due to the contaminant inputs from the major tributaries and different sedimentation conditions (Li et al., 2000). The main sources of heavy metal contaminants had been reported to come from the industrial

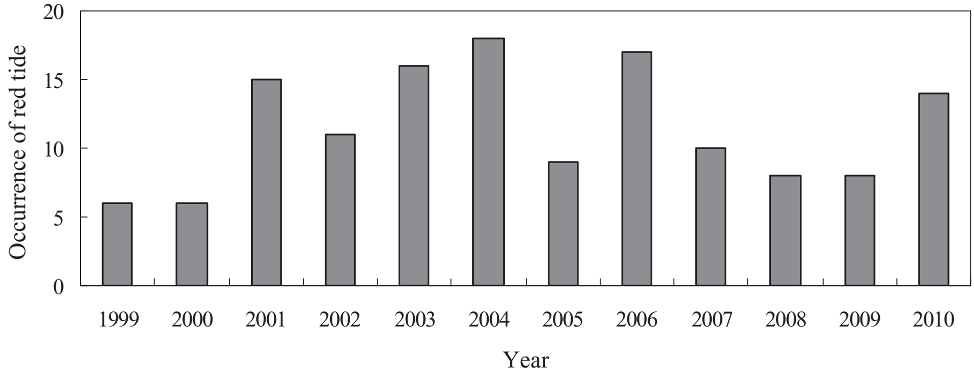

Figure 2. Occurrence time of red tide in CSSC from 1999 to 2010 (State Ocean Administration of China, 2010).

wastewater, domestic sewage, marine traffic and runoff from upstream mining sites in the Pearl River (Li et al., 2001). In Daya Bay corals had higher concentrations of metals than other reported corals from both pristine and seriously polluted locations, such as the Red Sea and India (Chen et al., 2010). In Daya Bay corals, significantly higher Fe and Mn concentrations were observed from 1984 to 1989, which coincided with the construction of the Daya Bay Nuclear Power Station (Chen et al., 2010). The concentration of Zn in the Daya Bay corals increased dramatically relative to the baseline value since 1994, corresponding well to the period of rapid local population and industrial development, which had gradually increased through to the present and was most likely caused by domestic and industrial sewage discharge into the bay (Chen et al., 2010).

Red tide

As a result of anthropogenic activities, red tides caused by eutrophication frequently occurred in CSSC (Liang et al., 2000; Yin, 2003; Hu et al., 2008). One hundred twenty three occurences of red tide from 1980 to 1998 and 138 from 1999 to 2010 were observed (Figure 2). The total area of red tide was 6380 km^2 from 2000 to 2010 (State Ocean Administration of China, 2010) (Figure 3). The species of red tide mainly included *Aureococcus amophageffereus*, *C.affinis Lauder*, *Chattonella marina*, *Dinophysis forti, Gyrodinium instriatum*, *Gyrodinium spirale, Heterosigma akashiwo*, *Karenia mikimotoi*, *Noctiluca scintillans*, *Phaecystis cf. globosa Scherffel*, *Polykrikox schwartzii* and *Skeletonema costatum Alexandrium* (Wu et al., 2005; State Ocean Administration of China, 2010).

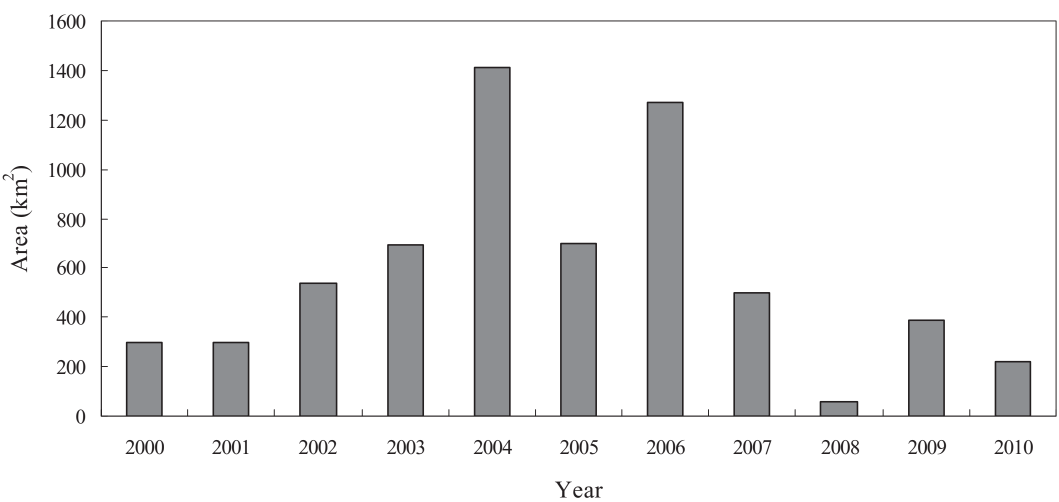

Figure 3. Area of red tide in CSSC from 2000 to 2010 (State Ocean Administration of China, 2010).

The nutrients brought by human beings and the exotic species in ballast water of ships had been considered as possible causes inducing red tide blooms (Kirkpatrick et al., 2004). The frequency of red tide in aquaculture area was higher than non-aquaculture area; the harm and the frequency of red tide in seriously eutrophic seawater was higher than other marine areas in CSSC (Xu et al., 2004). The marine aquaculture area in Guangdong Province increased from 1.16×10^5 ha in 1995 to 1.95×10^5 ha in 2000 (Huang, 2002). In CSSC, most harmful algal blooms occurred in the waters near Pearl River Estuary (Wang et al., 2008). Eutrophication in Pearl River Estuary not only stimulated the growth of *Skeletonema costatum* in the nutrient-rich areas of the estuary, but also appeared to promote the growth of *Synechococcus* and pico-eukaryotes in the adjacent oceanic water (Qiu et al., 2010). In the east of Hong Kong, biogenic silica (BSi) related to diatom production and the dinosterol concentration indicating dinoflagellate production, was low and stable, lower than 1.49% before 1940 (Hu et al., 2008). BSi increased slowly and stably from 1940 to 1965, after 1965, increased and most higher than 1.49%, especially from 1980 to 2000 (Hu et al., 2008). That reflected that red tide frequency gradually increased from 1940 to 1965 and faster after 1965, especially from 1985 to 2000, indicating algal blooms and red tide were caused by increased eutrophication (Hu et al., 2008).

Biodiversity decline

With a rapid development of economy in South China, biodiversity declined seriously in CSSC (Han et al., 2006). The number of mangroves species dropped from 37 in 1988 to 27 in 1999 in Hainan (Han et al., 2006 and its references). The species of phytoplankton fell from 158 to 97, and the average dwelling density of benthos dropped from 342 to 153.33 ind m^{-2} in Pearl River Estuary (Han et al., 2006 and its references). The species of phytoplankton fell from 158 to 97 and their biomass fell from 1.71×10^7 to 0.1×10^7 ind·m^{-3} in winter, the biomass of zooplankton fell from 233.9 to 69 mg·m^{-3} in summer in Pearl River Estuary (Cui, 2004). The average dwelling density of benthos dropped from 342 to 153.33 ind·m^{-2} in Pearl River Estuary (Cui, 2004). The operation of the Daya Bay Nuclear Power Station (DNPS) had a negative effect on the phytoplankton community and resulted in the high abundances of toxic dinoflagellate species during winter (Wang et al., 2009). The eutrophic environment accelerated the growth of small diatoms and made the shift in predominant species from large diatom *Rhizosolenia* sp. to chain-forming diatoms such as *Skeletonema costatum*, *Pseudo-nitzschia* sp. and *Thalassiosira subtilis* (Wang et al., 2009). In Weizhou Island of Guangxi, the coral species dropped from 21 families and 45 genera in 1987 to 19 families, 17 genera and 8 uncertain genera in 2001 (Yu et al., 2004).

The main threats to biodiversity in CSSC included reclamation, dredging and deepening the outward channel, over-fishing, environmental pollution and the blind introduction of exotic species (Li et al., 2005). Suspended matter and the various pollution contents produced by dredging and deepening the outward channel can choke the breathing apparatus of marine life and bring on their death. Furthermore, the suspended matter can have a negative effect on the photosynthesis of marine life and reduce the primary productivity by lowering the seawater transparency (Wang and Zhang, 2001).

Reduction of marine habitat

The total area of tidal flats in CSSC was 2.8×10^7 ha (Chen et al., 2005). The total area of reclaimed marine amounted to 7×10^5 ha from 1950s to 2000 in CSSC (State Ocean Administration China, 2010). Reclamation from sea was respectively 1590.56 ha and 605.99 ha in 2009 and 2010 in CSSC (State Ocean Administration of China, 2010). The seagrass bed area in Hepu of Beihai reduced from 2970 ha in 1980s to 540 ha in 2005, and the total services value loss of seagrass bed ecosystem in Hepu was 3.47×10^7 Yuan RMB from 1980 to 2005 (Han et al., 2007). There were >12,246 ha of mangroves in the early 1980s, but only 5654 ha remained in the 1990s in Guangxi. There were 21,289 ha of mangroves fringing the Guangdong coastline in the 1950s, but only stood at 7787 ha in 1990s (Li and Lee, 1997). The breakage rate of coral reefs in the seacoast of Hainan had reached 80% since 1950 (Han et al., 2006 and its references).

Frequent natural and ecological disasters

There were frequent natural disasters, such as erosion, storm surge, and typhoons affecting the

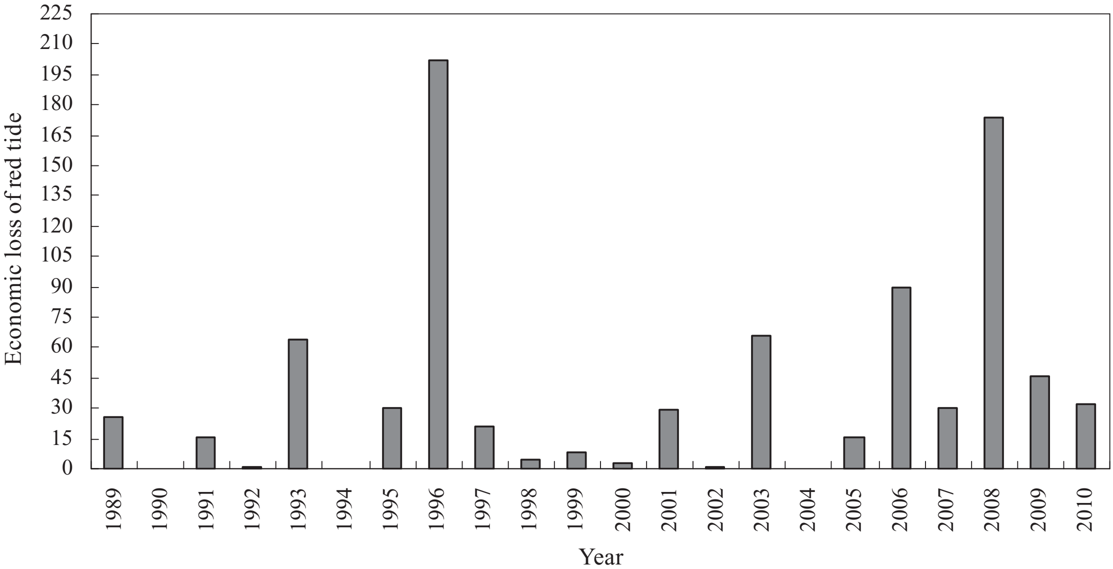

Figure 4. Economic loss of storm surge in CSSC from 1989 to 2010 (State Ocean Administration of China, 2010).

development of CSSC. Coastal line changed from filling up to erosion since 1950s (Liang, 1999). The variance of coastal line directly led to the destruction of vegetation, soil and water loss. The erosion in CSSC was mainly located in Qiongzhou Strait coast (Liu et al., 2007) and causes inducing the coastal erosion included the natural and anthropogenic factors, of which tidal current, wave and extreme climate were the main natural factors. The breakage of coral reefs in Hainan had led to the erosion of the coast (Han et al., 2006 and its references). Storm surge was one of the main natural disasters in CSSC: with an economic loss of storm surge was 8.57×10^{10} Yuan RMB from 1989 to 2010 in CSSC (Figure 4). There were very frequent marine disasters in Guangxi coast, especially typhoon, big wave and storm surge affecting the development of coastal economy and society. The direct economic loss was 2.23×10^8, 1.66×10^9 and 6.00×10^7 Yuan RMB in 2002, 2003 and 2005, respectively, in Guangxi (Liang, 2007). Approximately 5.2 occurences of tropical storm or tropical depression directly affected Guangxi coast every year (Ou, 1996). The marine geological disasters in Daya Bay mainly included coastal erosion, sand ripple, buried sedimentary ridges, sea-route gullies, faults and steep slopes (Li et al., 2002). Geological hazards in Pearl River Estuary were classified into neotectonic, erosive-deposit, fluid-plastic and heterogeneous hazardous geology types, including active fault, earthquake, coastal erosion, coastal accumulation, sand wave, tidal sand ridge, and so on (Sun et al., 2010).

Alien species invasion was one ecological disaster declining the biodiversity in CSSC. *Spartina* sp. was transplanted into CSSC in the beginning of 1980s for the protection of the tidal flat and mainly distributed in the coast of Zhuhai, Shenzhen and Beihai. 90% tidal flats in Zhuhai were covered by *Spartina* sp. in 1990s. The area of *Spartina* sp. was 25 ha and reduced the area of the mangrove in Hepu coast of Beihai. It threatened the ecosystem in CSSC by altering the sediment characters, affecting water body exchange, choking sea channel and competing for the nutrients with other macroflora (Deng et al., 2006). *Sonneratia apetala*, *Water Hyacinth* and *Mikania micrantha*, as invasion species, had a negative effect on the ecosystem of CSSC (Zhou et al., 2003; Liao et al., 2004; Han et al., 2005). *Mikania micrantha* endangered 3000 ha of forests and made 243 ha of forests die out in Shenzhen (Zhou et al., 2003) and was seriously harmful to Pearl River Estuary (Han et al., 2006). Alien red tide species, such as *Alexandrium catenella*, *Amphidinium carterae Hulburt*, *Chaetoceros concavicor*, *Cyclindrotheca closterium*, *Prorocentrum lima* and *Skeletonema costatum* can also reduce biodiversity and lower the stability of the marine ecosystem, even induce the collapse of the ecosystem (Liu et al., 2007). *Phaeocystis pouchetis*, one of the alien invasion species, led to red tides in 1997 to

Table 1. Laws and regulations related to the coastal areas in south China.

Name of laws/regulations	Date of promulgation (d/m/y)
Marine environmental protection law of the People's Republic of China	23-08-1982
Regulations concerning environmental protection in offshore oil exploration and exploitation	29-12-1983
Regulations concerning the prevention of pollution of sea areas by vessels	29-12-1983
Law on Fishery Resources (Amended on 21-10-2000)	20-01-1986
Regulations concerning the dumping of wastes at sea	06-03-1985
Measures for management of fishery in Guangdong Province	28-2-1990
Regulations concerning prevention of pollution damage to the marine environment	25-05-1990
Measures for implementation of the regulations concerning the dumping of wastes at sea	25-09-1992
Regulations for the protection and management of marine aquaculture in the coastal tidal flats of Guangdong Province	1-02-1994
Measures for management of mangrove natural reserve in Shankou in Guangxi Zhuang Antonomous Region (Amended on 25-12-1997 and 29-6-2004)	1-07-1994
Measures of management of marine natural reserves	29-05-1995
Provisions on the procedure for investigation and handling of accidents of pollution in fishing areas	26-03-1997
Regulations of coral reef protection in Hainan Province	24-09-1998
Measures of management on utilization of sea areas	27-10-2001
Marine functional zonation scheme	22-10-2002
Measures for management of natural reserve in Beilun River estuary in Guangxi Zhuang Antonomous Region	29-06-2004
Marine economy development scheme in Hainan Province	17-07-2005
Law on prevention of marine pollution and damage from marine construction projects	19-09-2006
Regulations of marine environmental protection in Hainan Province	31-07-2008
Measures for implementation of the Law on the Fishery Resources in Hainan Province	1-08-2008
Measures of management on utilization of sea areas in Guangxi Zhuang Antonomous Region	29-08-2008
Measures for implementation of Marine environmental protection law of the People's Republic of China in Guangdong Province	31-03-2009
Law on the Island Protection	26-12-2009

1999 in CSSC (Liu et al., 2007). *Mytilop sis sallei* originally located in the tropical water areas in Central America, invaded in CSSC through shipping and distributed in Shenzhen mangrove areas (Zhou et al., 2006), and negatively affected phytoplankton and marine aquaculture (Lin and Yang, 2006).

Current efforts and problems

Over the last few decades, Chinese government has made a significant effort in developing a better management scheme in CSSC. China has improved its legislation concerning CSSC, and a series of laws and regulations at national or local level for the protection of marine ecology and environment have been formulated (Table 1). Chinese government set up some natural reserves to protect coastal biological diversity and ecosystems. Until now, China had 9 natural reserves in CSSC, including a turtle natural reserve in Huidong of Guangdong, Neilingding Island—Futian natural reserve, mangrove natural reserve in Zhanjiang of Guangdong, mangrove natural reserve in Shankou, mangrove natural reserve in Beilun River Estuary, dugong natural reserve in Hepu, mangrove natural reserve in Dongzhai Port, marine natural reserve in Dazhou Island and coral reef natural reserve in Sanya. China has also supported some projects to research CSSC in recent years, mainly including the blue sea activity plan, Chinese 908 special item, 908 special item of Guangdong Province, 973 item of the Ministry of Science and Technology, prevention and cure of red tide in coastal China, Chinese 973 special item, and so on. From the 1980s to 1990s, a large-scale multidisciplinary investigation of resources in CSSC was carried out. The investigation aimed to establish an inventory of coastal resources including tideland, wetland, coastal hydrology, chemistry, climate, geology and biology and uniquely collected the baseline data and information in CSSC. The pollution-monitoring network has been significantly established, improved and strengthened by satellites, ships and offshore monitoring stations since 2002.

Although the Chinese government has taken a series of actions for protecting the environment in CSSC, there are many challenges in policy, management and science research, such as overlapping jurisdiction, lack of public participation, poor financial support and lack of pollution monitoring and evaluation.

Overlapping jurisdiction is a serious problem negatively affecting the environment management in CSSC. There are about twenty or so related ministries and agencies, such as the State Oceanic Administration, Ministry of Land Resources, State Environmental Protection Bureau and the Ministry of Transport, which are responsible for agriculture, construction, flood control, environmental protection, transport and natural resources exploitation in CSSC. Furthermore at provincial, city and county levels, there are similar horizontal sections having responsibilities for management and planning at the corresponding level. The rights and responsibilities of each section are usually confusing for the effective management of the environment in CSSC.

Integrated coastal management (ICM) is a continuous and dynamic process by which decisions are taken for the sustainable use, development, and protection of coastal and marine areas and resources (Cicin-Sain and Knecht, 1998). But ICM has not acted in CSSC. The protection of marine environment in CSSC was usually the action of the government, and public participation was very weak. Stakeholders usually obtained the economy value at the expense of the marine environment. Although marine research has increased in recent years, there are not abundant long-term projects for scientific research. The prediction and pre-warning of marine disasters needs improvement.

Recommendations and Conclusions

The planning of marine resource exploitation and use should be reinforced through integrated coastal zone management. Inter-agencies conflict and overlapping jurisdiction should be alleviated through coordination among the agencies of government with significant roles in management of CSSC. It is essential to consider the coastal zone as a whole continuum and take an integrated management approach to solve those multifaceted issues within a legislative framework. Marine environment protection during marine exploitation should be strengthened according to laws and regulations.

The marine environment and protection awareness and participation of the public should be strengthened, and it is worth it for the government taking actions to educate the public about the importance of protecting the marine environment.

It is necessary for the Chinese government to support more long-time scientific projects to study CSSC and managers should be trained. Marine staff in the government should provide service improving marine environment quality and promoting the sustainable development of marine economy according to the scientific assessment data. Marine scientists should further study the marine disasters and the technology of prevention and remediation in order to reduce their negative effects.

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