Asian Agricultural Research 2014, 6(8): 60 – 64

Research Advances on Marine Ecological Effect and Repairing Techniques of Coastal Mangrove Wetland

Na LI[1,2*], Pimao CHEN[1], Peipei QIAO[1,2], Chuanxin QIN[1]

1. South China Sea Fisheries Research Institute, Chinese Academy of Fishery Science/Scientific Observing and Experimental Station of South China Sea Fishery Resources and Environment, Ministry of Agriculture, Guangzhou 510300, China; 2. College of Marine Science, Shanghai Ocean University, Shanghai 201306, China

Abstract Coastal mangrove wetland is one of the areas whose global ecological environmental conditions have severely changed. Its ecosystem is vulnerable to damaged. The international community has paid attention to conservation and wisely use of mangrove wetland. This paper describes five parts of coastal mangrove wetland at home and abroad, including seawater's purification effect of nitrogen and phosphorus, seawater's adsorption of heavy metals, the functions of carbon sequestration and climate regulation, implant restoration techniques and the status of protection and management . And research trends of coastal mangrove wetland were proposed, in order to provide reference for the restoration and protection of China's coastal mangrove wetland.

Key words Coastal mangrove wetland, Implant restoration, Marine ecological effect, Protection and management

Coastal wetland is the middle land that links marine ecosystem and continental ecosystem where fishery resources such as fishes, shrimps, crabs and shellfishes reproduce, grow, feed and live and is the ideal place for marine plants including seaweed or sea grass and mangrove. Constaza *et al*[1] estimate that the gross revenue of global coastal tidal flat ecosystem is worth $\$1.55\times10^{13}$, accounting for 46% of the total revenue of the global ecosystem. The coastal mangrove wetland is an important part of the coastal tidal flat ecosystem and plays a key role in food supply, wild species germplasm conservation and the sustainable development, biodiversity conservation, regional marine environment purification as well as in keeping biological balance, carbon sequestration and implant restoration.

Over the past years, due to the increasing population in coastal areas and the rapid development of coastal economy and problems brought by the urbanization as well, coastal mangrove wetland has been severely polluted by coastal construction, over exploration and increased industrial wastewater, urban sewage and sewage from agricultural activities which result in sharp reduction of mangrove wetland, severe water eutrophication and a less diverse and integrated environment biologically and ecologically. Therefore, it is our top priority to restore the ecosystem of coastal mangrove wetland. This paper will discuss the marine ecological effect of coastal mangrove wetland at home and abroad and will also demonstrate the research advances on its restoration and protection in a bid to provide reference for China's coastal mangrove wetland ecosystem restoration and protection.

Received: May 28, 2014 Accepted: July 14, 2014

Supported by State Scientific and Technological Supporting Plan (2012BAD18B02); State Public Agricultural Scientific and Technological Research Fund (201003068); Basic Scientific and Technological Fund for Chinese Academy of Fishery Sciences (2012A0102).

* Corresponding author. E-mail: chenpm@ scsfri. ac. cn

1 Research advances on marine ecological effect of coastal mangrove wetland

Planting mangrove can function effectively in terms of environmental management and protection as well as mangrove forest conservation. Meanwhile, it is also of great significance for the healthy and sustainable development of coastal ecosystem and environment. Mangrove forest ecosystem can reduce COD, suspended solids, nitrogen, phosphorus and heavy metals as well as CO_2 by means of soil surface absorption, chemical precipitation, microbial metabolism and plant uptake through which dismissed pollutants and organic matter can be removed and water & air pollution can be relived – the most significant being seawater's purification of nitrogen and phosphorus and adsorption of heavy metals, carbon sequestration as well as climate regulation.

1.1 Seawater's purification of nitrogen and phosphorus

Tam *et al*[2-3] found that mangrove forest ecosystem demonstrated a strong absorption capacity of heavy metals and nutrients such as nitrogen and phosphorus from the sewage water. With plants and microorganism absorbing nitrogen and phosphorus as well as soil filtering nitrogen and phosphorus, mangrove forest can remove eutrophic substances in water[4]. Chen[5] found that in the case of Nansha Wetland Park, after pollutants coming into the mangrove wetland, there was a sharp reduction of nitrogen, phosphorus, COD and BOD in the water body. In addition, by establishing mangrove – growing – and – farming coupled ecosystem, Li *et al*[6] have proved that mangrove can reduce nitrogen and phosphorus in the water body. In a research case of environmental effect of mangrove wetland restoration in Nansha, Guangzhou, Bai *et al*[7] concluded that the phosphate density in the river water of Nansha district showed an inverse relationship with the mangrove coverage along the watercourse to certain extent. It was also estimated that the reed and mangrove wetland could reduce 10 436 kg phosphorus and 105 789 kg nitrogen approximately in total per year. Meanwhile, Boto[8] and Clough[9] *et al* also pointed out that mangrove forest could absorb 1 020 kg phosphorus and 150 250 kg nitrogen per hectare annually. Chen *et al*[10] and Liao *et al*[11] found that in a simulated wetland ecosystem under a condition of warm house, mangrove forest demonstrated a significant effect on nitrogen and phosphorus purification from the sewage water. Also, Huang *et al*[12] pointed out that in the tidal planting – farming system, the mangrove forest could purify the water to II – III sea water quality standard.

In terms of mangrove wetland's nitrogen and phosphorus purification, most research were focusing on man – built mangrove forest ecosystem, while the purification of nitrogen and phosphorus of natural mangrove wetland in eutrophic seawater has been mostly applied to farming wastewater treatment. Future theoretical research should prioritize overall environment and ecosystem improvement of natural mangrove wetland. There are two points that need special attention: first, mangrove's ecosystem improvement capacity under different planting density through which mangrove coverage rate can be calculated for future reference; second, the possible synergistic effect and antagonistic effect among different plant species, and between mangrove and benthos, mangrove and other environmental factors during the purification process should be further investigated.

1.2 Seawater's adsorption of heavy metals Based on simulating lab tests and analyzing field samplings, scientists from home and abroad have conducted a great deal of research regarding heavy metal absorption of coastal mangrove wetland. Compared to mangroves themselves, their sediments in the mangrove wetland demonstrated a better absorption capacity of heavy metals. In terms of mangrove, the heavy metal content varied in line with different parts of the plant or plant species. To be more specific, regarding to heavy metal content, fine root > middle root > stem > leaf and flower. Heavy metal absorption of the upper layer of the sediment was more than that of the lower layer. The simulating tests proved that the absorption rate of Cr, Cd and Cu in the sediment was 4% higher than that of Ni and Zn. In the case of Aegiceras corniculatus forest of Jiulong River Estuary, Fujian, its sediment absorbed 5 heavy metals including Cu, Pb, Zn, Mn and Cd, accounting for 95% of the total amount[13]. In addition, the absorption rate of different heavy metals of the Avicennia marina forest of Futian, Shenzhen increased stepwise: Cd < Cr < Pb < Ni < Cu < Zn < Mn[14]. Qu *et al*[15] sampled in the typical mangrove wetland in Hainan and found that compared to research at home and abroad, the heavy metal content in this region was lower than the average level; in the core sediment, as content demonstrated a trend that surface layer had higher content, upper and middle layer lower content and lower layer less higher content. Among the world's largest mangrove forests, the contents of several heavy metals in the sediment decrease in an order of Mn, Zn, Cu, Pb, Ni, Cr, Cd and Hg[16–18]. The research result of Shriadah[19] and He *et al*[20] showed that the heavy metal contents in mangrove sediment demonstrated a significant positive correlation with organic matter content. He *et al*[21] found that heavy metal contents of mangrove plant tissues were low, with Pb and Zn content being lower than that of rhizosphere sediments and heavy metal contents of mangrove rhizosphere sediments being higher than that of mudflats.

Major research on seawater's absorption of heavy metals of mangrove wetland focused on the same mangrove species, the heavy metal contents and characteristics of its sediments, while there has been few research conducted on different mangrove species' heavy metal absorption capacity. Therefore, future research should be pay more attention to the comparison of heavy metal absorption capacity of one species in different areas and one area's different species.

1.3 Carbon sequestration and climate regulation functions There are 1.81×10^5 km^2 mangrove wetlands globally, which have become world's major source that can absorb CO_2. With high deposition rate and low decomposition rate, mangrove wetland possesses a strong capacity of carbon sequestration. By means of photosynthesis, mangrove plants can capture CO_2 from the atmosphere, meanwhile release O_2 in the process of respiration. As a result, they keep the dynamic balance of CO_2 and O_2 in the atmosphere, relieve greenhouse effect and provide the most essential elements for human's survival[4]. In the wetland ecosystem, the majority of the carbon storage of the entire ecosystem is from the soil layer of the wetland. Soil carbon storage with plant covered on tidal wetlands is larger than that of bare tidal wetlands[22]. Presently, many are focusing on the research on carbon cycle of terrestrial forest ecosystem, while little attention has been paid to carbon storage and carbon cycle of coastal mangrove wetland. Through investigation and analysis, Duan *et al*[23] estimated the carbon sequestration rate and carbon sequestration potential of wetlands in China. It has been concluded that mangrove wetland and coastal salt marsh enjoy the highest carbon sequestration rate. Mangrove ecosystem is a carbon sequestration source. In a global context, plants' carbon storage is 403Gt, with 7/10 being in the tropic zone. And globally, the carbon sequestration capacity of mangrove ecosystem is 0.18 Gt per year within which soil carbon pool produces 0.02Gt per year and plants 0.16Gt per year[24]. By adopting whole plant harvesting method and constant drying method, Kang *et al*[25] calculated and concluded the biomass of four dominant mangrove species in Guangzhou and therefore calculated the gross productivity of the mangrove; using Potassium dichromate – hydration heating method, they determined each sample's carbon content from the four species' plant tissues and therefore calculated the plants' carbon content by which determined the annual gross productivity of carbon sequestration of mangrove plants; the calculation method of carbon sequestration potential was also provided. Sampling soil profiles from 3 natural mangrove forests in Gaoqiao, Zhanjiang Mangrove National Nature Reserve, Guangdong, Xu *et* al[26] determined organic carbon content of the soil by using isotope measurement method. It turned out that among the 3 plant communities (Aegiceras corniculatum, Kandelia Candel and Bruguiera Gymnorrhiza, Avicennia marina), Aegiceras corniculatum possess the largest carbon stock and Avicennia marina the least.

Presently, many research have calculated the carbon content of mangrove plants and soil layer and their carbon sequestration potential as well, whist there has been few focusing on the relationship of mangrove carbon content and other environmental factors, which should be given priority in the future research.

2 Research advances on coastal mangrove wetland restoration techniques

Mangrove, growing in the tropics and subtropics, are woody plants, often form green broadleaf forest. They can be found at intertidal areas such as marine shorelines and estuaries. On a global scale, there are 24 families, 20 genus and 86 species (including variations) being considered as mangrove. Mangrove and its surrounding environment consist of a special ecosystem – mangrove ecosystem, including 3 subsystems: mangrove plants, soil and water body. Mangrove ecosystem is one of the most important ecosystem of the coastal wetland ecosystem in China.

Research on mangrove restoration techniques started late, and the international community has taken measures to relieve and prevent the problem of mangrove forest degradation. Bangladesh is the first country that started the mangrove afforestation with the largest artificial mangrove forest. The country's first small – scale afforestation project started from 1996, lasting 7 years; over the period of 1974 – 1990, with the financial support from the World Bank, the country had built 1.15×105 hm^2 mangrove forests[27]. China's mangrove restoration and development research began in 1991. Lu *et al*[28] have researched the introduction of mangrove in Jiulong river estuary, Fujian. Lin *et al*[29] systematically analyzed some critical techniques of Kandelia candel afforestation based on field experience of mangrove afforestation and suggested that hypocotyl implant technique should be adopted due to its effectiveness. They also provided suggestions of hypocotyl implant depth, density and standards as well, which have become technique reference for China's large – scale mangrove afforestation. Liao *et al*[30] who researched on afforestation techniques of Kandelia candel found that when using hypocotyl implant, the survive rate of the first 6 months would decrease as the seedling growed and therefore concluded the initial implant density.

Peng *et al*[31] believed that failing in improving the survive rate had resulted in the failure of coastal mangrove afforestation, whilst the survive rate was closely connected with the applying of implant techniques. Hence, they concluded 4 mangrove implant methods on the basis of domestic and foreign research advances on coastal mangrove wetland restoration and pointed out that hypocotyl implant should be widely adopted in the future's afforestation. Hypocotyl implant means to collect wild brood body for implant and then plant the 1/3 – 1/2 depth of seedling into the mud. The row spacing is very important because it will determine the effect of wind – and – wave resistance and the quality of juvenile wood. The usual row spacing out of China is 0.4 – 1.5 m. In terms of China, the row spacing varies according to the species of mangrove: sonneratia apetala $2\ m\times1\ m$, Kandelia candel $0.5\ m\times1\ m$, $1\ m\times1$ or $0.2\ m\times0.4\ m$, aegiceras corniculatum $0.2\ m\times0.4\ m$, Bruguiear gymnorrhiza and rhizophora stylosa $0.4\ m\times0.4\ m$, $1\ m\times2\ m$ correspondingly[32–33]. Mo *et al*[34] who conducted research on mangrove planting at tidal flats in Guangxi found that there were 5 mangrove species that could be popularized for large – scale afforestation at tidal flats in Guangxi, including Kandelia candel, Avicennia marina, Rhizophora stylosa, Bruguiear gymnorrhiza and Aegiceras corniculatum thanks to their good adaptability and the abundance of provenance.

The mangrove implant techniques has been applied and the results have turned out to be excellent. Some fishermen from Zhejiang introduced 122 Kandelia candels from Fujian in 1957. With high survive rate and preservation rate, the area of mangrove had enlarged to 10 hm^2 after natural reproducing[35]. In 2001, Mexico planted Avicennia marina using group planting technique (2 – 5 seedlings per group), and it turned out that their survive rate was sustained at 74% approximately[36]. In 2001, more advanced implant techniques were adopted in Huizhou, Guangdong, and sonneratia apetala introduced from out of the region had proved to be afforested successfully with survive rate of over 90%[37]. China's mangrove forests restored and covered 22 024.9 hm^2 in 2001.

Most domestic and foreign research on coastal mangrove wetland restoration still focus on revegetation, with priority on seedling raising techniques and choosing forestation – suitable land, but fail to regard restoration of ecosystem function as research objectives, which is why they cannot be considered as ecological restoration. Lewis[38] set goals for coastal mangrove wetland restoration of the state of Florida. There are two sections of the goal of mangrove restoration: sustainable vegetation cover and mangrove function restoration or the restoration of its ecosystem functions. Hence, after researching on restoration techniques of coastal mangrove wetland, we should put our priority on restoring its ecosystem functions and conducting research on the protection and restoration of the structure and functions of coastal mangrove wetland.

3 Status of coastal mangrove wetland protection and management at home and abroad

On a global scale, mangrove forests had been severely damaged in the process of economic development and had not drawn enough attention of the international community until 1970s. FAO had not taken actions until 1950s since when it had conducted over 60 related projects in 35 countries and offered technique supports for these countries in terms of the mangrove protection, restoration, management and its sustainable development as well. Since 1980s, large amount of research and investigations have been conducted globally. And after 1982, the UNDP of UNESCO had started mangrove projects in 8 countries over the period of 8 years and achieved fruitful results. The UNDP established International Society for Mangrove Ecosystem (ISME) and pass the Mangrove Chapter in 1990. In addition, MAB and WWF have also joined their efforts with the United Nations in protecting mangrove forests.

There are 121 known countries and regions that have mangrove forests, 42 in America, 33 in Africa, 25 in Asia and 21 in the Pacific islands, whose major efforts in mangrove protection and management have been making legislations and founding conservation areas. Countries and regions out of China started early in terms of the coastal mangrove wetland protection and management. Major legislations and regulation around the world for mangrove protection and management are: Ramsar Convention, Convention on Biological Diversity, Coastal Mangrove Protection Plan of Thailand, West African Mangrove Protection Regulations of West Africa as well as National Mangrove Regionalization Strategy of Ecuador. More mangrove conservation zones in the world see Table 1.

Mangrove are protected in China. Chinese authorities have established over 36 mangrove conservation zones in national, provincial and county – level terms (see Table 2), and made related legislations and regulations in a bid to protect mangrove. China's legislation of modern mangrove protection law started in 1980s. Currently, China's mangrove protection laws and regulations include *Criminal Law*, *Forest Law*, *Marine Environmental Protection Law*, *Nature Reserve Ordinance*, *Agricultural Law*, *Land Administration Law* and *Mangrove Ecosystem Protection Measures* for the administration of the PRC. In addition to national laws, many local authorities have set up local regulations for mangrove protection, including: *Hainan Nature Reserve Management Ordinance and Notice on Strengthening the Protection of Mangroves and Coral Reefs in Hainan*, *Mangrove Ecosystem Nature Reserve Management Ordinance of Beilun Estuary of Zhuang Autonomous Region*, *Guangxi*, and *Marine Nature Reserve Management Ordinance of Beilun Estuary of Zhuang Autonomous Region*, *Guangxi*.

Table 1 Mangrove Conservation Zones in the world

Country	Conservation Zone Name
Brazil	Reentrancias Maranhenses State Protected Area
Malaysia	Tanjung Piai National Park
Malaysia	Pulau Kukup National Park
Republic of Senegal	Saloum Delta Biosphere Reserve
The Malay Peninsula	Matang Mangrove Forest Reserve
The Republic of Ghana	Songor Ramsar Wetland Reserve

Table 2 China's Provincial and National Mangrove Nature Reserves

Level	Name	Location
National	Hainan Dongjiazhai National Nature Reserve	Haikou, Hainan
	Guangxi Shankou National Mangrove Ecosystem Nature Reserve	Hepu, Guangxi
	Futian National Nature Reserve of mangroves and birds	Shenzhen, Guangdong
	Guangdong Zhanjiang Mangrove National Nature Reserve	Zhanjiang, Guangdong
	Guangxi Beilun Estuary National Nature Reserve	Fangcheng Port, Guangxi
	Fujian Zhangjiang Estuary National Mangrove Wetland Nature Reserve	Yunxiao, Fujian
Provincial	Hainan Qinglan Provincial Nature Reserve	Wenchang, Hainan
	Fujian Jiulong Estuary Provincial Mangrove Nature Reserve	Longhai, Fujian
	Quanzhou Estuarine Wetland Nature Reserve	Quanzhou, Fujian
	Guangdong Zhuhai Qi'ao – Dangan Island Nature Reserve	Zhuhai, Guangdong
	Guangxi Qinzhou Maowei Sea Mangrove Reserve	Qinzhou, Guangxi
	Hong Kong Mai Po Nature Reserve Restricted Area	Yuen Long, Hong Kong
	Taiwan Zhuwei Mangrove Nature Reserve	Zhuwei, Taipei

China's mangrove forests have not been well protected although there are over 10 national laws and local regulations. 40 years ago, China has 4.2×10^4 hm^2 mangrove forests, but nowadays the area has decreased to only 1.46×10^4 hm^2 which is less than 1/1000 of the world's total mangrove forests resulting from deforestation and sea land reclamation for landing and aquaculture. Therefore, only have we had stricter enforcement on these laws and regulations, can we make the current mangrove exploration (lawless, guiltless and disordered) under control for the sake of more effective marine and tidal resource protection including mangrove forests.

4 Outlook

Since coastal mangrove wetland is most damaged during the world's ecosystem environment changes and the most vulnerable areas regarding its ecosystem, it has drawn many attentions from the international community in terms of the protection and reasonable exploration of mangrove wetlands.

There have been few conflicts between people and natural resource in countries like the United States, UK, France and Germany. Therefore, there is little need in developing marine engineering and other technology that can improve the ecological functions of shorelines in these regions. Regarding this, their urgent research demands fall in the ecological structure, carbon sequestration, environmental effects, dynamic monitoring and protective legislations of coastal and tidal areas.

China's widespread coastal mangrove wetlands can filter and purify surface water that comes from surrounding lands and rivers, relieve sea water deterioration and red tide issues, and is of great importance in terms of global carbon sequestration. Moreover, it plays a significant role in protecting seedling resource of local marine species and its biodiversity as well as adjusting and maintaining local climate. Nevertheless, China's coastal mangrove wetlands have been severely damaged with 1/3 of the natural mangrove wetlands being threaten.

China's coastal mangrove wetland research have not started until recent years. Regarding the research on biological restoration and carbon sequestration function of China's mangrove wetland ecosystem as well as suggestions to counter measures and management, there are several fields needing our extra attentions: (1) current situation of coastal mangrove environment; (2) most reasonable restoration methods according to regions and mangrove species; (3) mangrove's purification effect on eutrophicating matters; (4) dynamic recycle mechanism of mangrove wetland's carbon sequestration; (5) the interactions between mangrove and microorganism and soil, and the sustainable development of mangrove wetland ecosystem; (6) measures for protecting and managing mangrove wetland ecosystem.

References

[1] Costanza R, D'arg R, De Groot R, *et al*. The value of the world's ecosystem services and natural capital[J]. Nature, 1997(387): 253 – 260.

[2] Tam N F Y, Wong Y S. Nutrient and heavy metal retention in mangrove sediment receiving wastewater[J]. Water Science Technology, 1994(29): 193 – 200.

[3] Tam N F Y. Retention and distribution of heavy metals in mangrove soils receiving waste water[J]. Environmental Pollution, 1996(94): 291 – 293.

[4] CHEN Z. Guangdong Province mangrove forest ecosystem purification function and its value appraisal[D]. Guangzhou: South China Normal University, 2007. (in Chinese).

[5] CHEN ZL. Purification function of mangrove wetlands and it's respond to sewage[D]. Haikou: Hainan Normal University, 2012. (in Chinese).

[6] LI C, LIU Y, HUANG SF. Phytoplankton and N and P nutrients in the plantation aquaculture coupling system of mangrove in the Pearl River Estuary[J]. Acta Scientiarum Naturalium Universitatis Sunyatseni, 2010, 49 (5): 150 – 154. (in Chinese).

[7] BAI XY, ZHENG KZ, CHEN GZ, *et al*. The environmental effect of mangrove restoration in Guangzhou Nansha[J]. Guangdong Chemical Industry, 2011, 38(7): 220 – 221. (in Chinese).

[8] Boto K G. Nutrients and mangroves[A]. In: Connell D W, Hawker D W (ed.). Pollution in tropical aquatic systems[M]. Ann Arbor, London: CRC Press Inc., 1992: 16 – 22.

[9] Clough B F, Boto K G, Atiwill P M. Mangroves and sewage: A revaluation [A]. In: Teas H J (ed.). Biology and ecology of mangroves: Tasks for vegetation science series[M]. Boston: Kluwer Academic Publishers, 1981: 28 – 34.

[10] CHEN GZ, MIAO SY, HUANG YS, *et al*. Allocation, cycle and purged effects of nutrient pollutant N in artificial wastewater in simulated Kandelia candel wetland system[J]. Acta Scientiae Circumstantiae, 1996, 16(1): 44 – 50. (in Chinese).

[11] MIAO SY, CHEN GZ, HUANG YS, *et al*. Allocation and circulation of phosphorus in artificial wastewater within a simulated mangrove wetland system[J]. Acta Ecologica Sinica, 1999, 19(2): 236 – 241. (in Chinese).

[12] HUANG FL, XIA BC, DAI X, *et al*. Bacteria ecology in planting——culturing system[J]. Chinese Journal of Applied Ecology, 2004, 15(6): 1030 – 1034. (in Chinese).

[13] ZHENG WJ, ZHENG FZ. The accumulation and dynamic of Cu, Pb, Zn and Mn elements in *Kandelia candel* (L.) Druce mangrove forest in Jiulong river estuary of Fujian[J]. Acta Botanica Sinica, 1996, 38(3): 227 – 233. (in Chinese).

[14] ZHENG WJ, LIN P. Accumulation and distribution of Cr, Ni and Mn in Avicennia marina mangrove community at Futian of Shenzhen[J]. Chinese Journal of Applied Ecology, 1996, 7(2): 139 – 144. (in Chinese).

[15] QIU YW, YU KF. Accumulation of heavy metals in sediment of mangrove wetland from Hainan Island[J]. Journal of Tropical Oceanography, 2011, 30(2): 102 – 108. (in Chinese).

[16] Kehrigha, Pintofn, Moreirai, *et al*. Heavy metals and methyl mercury in a tropical coastal estuary and a mangrove in Brazil[J]. Organic Geochemistry, 2003(34): 661 – 669.

[17] Machadow, Moscatellim, Rezendelg, *et al*. Mercury, zinc and copper accumulation in mangrove sediments surrounding a large and fill in southeast Brazil[J]. Environmental Pollution, 2002(120): 455 – 461.

[18] Tam N F Y. Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps[J]. Environmental Pollution, 2000, 11(2): 195 – 205.

[19] Shriadah M M A. Heavy metal in mangrove sediments of the United ARBR Emirates Shoreline (Arabian Gulf)[J]. Water, Air, and Soil Pollution, 1999, 116(3/4): 523 – 534.

[20] HE BY, DAI PJ, FAN HQ. A study on the contents of the heavy metals in the sediments and macrobenthos of Yingluo Mangrove Swamps, Guangxi [J]. Marine Environmental Science, 1996, 15(1): 35 – 41. (in Chinese).

[21] CHEN XY, ZENG BQ, CHEN LH. Heavy metals contents in sediments, mangroves and bivalves from Ting Kok, Hong Kong[J]. China Environmental Science, 2003, 23(5): 480 – 484. (in Chinese).

[22] HUANG WJ, PAN H, TAN FL. Study on carbon storage in Minjiang River Estuary[D]. Fuzhou: Fujian Agriculture and Forestry University, 2008. (in Chinese).

[23] DUAN XN, WANG XK, LU F, *et al*. Carbon sequestration and its potential by wetland ecosystems in China[J]. Acta Ecologica Sinica, 2008, 28 (2): 463 – 469. (in Chinese).

[24] Twileyrr, Chenrh, Hargis T. Carbon sinks in mangroves and their implications to carbon budget of tropical coastal ecosystems[J]. Water Air Soil Poll, 1992(64) (1/2): 265 – 288.

[25] KANG WX, ZHAO ZH, TIAN DL, *et al*. CO2 exchanges between mangrove – and shoal wetland ecosystems and atmosphere in Guangzhou[J]. Chinese Journal of Applied Ecology, 2008, 19(12): 2605 – 2610. (in Chinese).

[26] XU FH, ZHANG JP, ZHANG QM, *et al*. Carbon storage of three natural mangrove forests in Gaoqiao, Zhanjiang[J]. Value Engineering, 2012, 31 (15): 5 – 6. (in Chinese).

[27] Forest Resources Development Branch, Forest Resources Division, FAO Forestry Department. Mangrove forest management guidelines[R]. Rome: FAO, UN, 1994: 7 – 11.

[28] LU CY, LIN P, WANG GL, *et al*. Study on mangrove introduction technology from Hainan Island to Jiulongjiang Estuary, Fujian[M]. Xiamen: Xiamen University Press, 1993: 122 – 129. (in Chinese).

[29] LU CY, LIN P. The forestation techniques of Kandelia candel mangrove and its ecological principle[J]. Journal of Xiamen University(Natural Science), 1990, 29(6): 694 – 698. (in Chinese).

[30] LIAO BW, ZHENG DZ, ZHENG SF, *et al*. Study on the forestation techniques of Kandelia candel mangrove[J]. Forest Research, 1996, 9(6): 586 – 592. (in Chinese).

[31] PENG YS, ZHOU YW, CHEN GZ. The restoration of mangrove wetland: a review[J]. Acta Ecologica Sinica, 2008, 28(2): 786 – 797. (in Chinese).

[32] Liao B W, Chen Y J, Zheng S F, *et al*. Early screening trials of provenance on *Bruguiera gymnorrhiza* in Shenzhen Bay of China[J]. Forest Research, 2002, 15(6): 660 – 665.

[33] Liao B W, Zheng D Z, Zheng S F, *et al*. Study on the affore station techniques of Kandelia cande mangrove[J]. Forest Research, 1996, 9(6): 586 – 592.

[34] MO ZC, FAN HQ. Comparison of mangrove planting methods[J]. Guangxi Forestry Science, 2001, 30(2): 73 – 75, 81. (in Chinese).

[35] GONG J, SONG YQ, CHEN SB. Effects of global climate change on mangrove in Zhejiang Coast[J]. Journal of Anhui Agricultural Sciences, 2009, 37(20): 9742 – 9744, 9784. (in Chinese).

[36] Toledo G, Rojas A, Bashan Y. Monitoring of black mangrove restoration with nursery-reared seedlings on an arid coastal lagoon[J]. Hydrobiologia, 2001, 444: 101 – 109.

[37] ZENG XG. On the current state and protective countermeasures of Huizhou mangrove land resources[J]. Journal of Huizhou University, 2008, 28(6): 55 – 57. (in Chinese).

[38] Lewis R. R. Ecologically based goal setting in mangrove forest and tidal marsh restoration in Florida[J]. Ecological Engineering, 2000, 15(324): 191 – 198.