Evaluation of mangrove ecosystem service functions of Ximen Island Marine Specially Protected Areas in Yueqing Bay, China

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Abstract. Taking the mangrove ecosystem of Ximen Island National Marine Specially Protected Areas as the research object, the ecological service value of the mangrove forest was evaluated and analyzed using a market value method, an ecological value method and a carbon tax method. The results showed that the ecosystem service value of the mangrove forest on Ximen Island is worth a total of 16,104,000 CNY/a. Among the value of individual ecosystem services, the direct value of material production function and leisure function reached 1,385,000 CNY/a, with a ratio of 8.6%. The indirect value of disturbance regulation, gas regulation, water purification, habitat function and culture research reached 14,719,000 CNY/a, with a ratio of 91.4%. Among the above sub-items, the proportion of disturbance regulation value, habitat function value and cultural research function value reached 78.8%, which reflects the important scientific value and ecological value of the Ximen Island mangrove ecosystem, especially its vital importance in providing a habitat for birds and playing a role in disaster prevention and mitigation.

1. Introduction

Mangrove ecosystems refer to systems consisting of producers (mangroves, semi-mangroves, etc.), consumers (fish, benthic animals, birds, etc.), decomposers and inorganic elements [1]. Mangroves are mainly distributed in river estuaries and bays. They are important ecological systems in regions where land to ocean transition occurs. These systems have high primary productivity, which supports land or sea ecosystems. In addition, these systems have high ecological value and aesthetic value, as well as research and education value [2]. Due to the important ecological function and high economic value of mangrove forests, mangrove ecosystem services have received increasing attention in recent years, and the evaluation of mangrove ecological service value has gradually increased.

Since the publication of the global ecosystem services paper by Constanz in 1997 [3], the United Nations implemented the Millennium Ecosystem Assessment in 2003 [4], national ecologists have established a multi-level assessment system of ecosystem service value which strongly contributed to the scientific assessment of ecosystem services.

Studies investigating the value of mangrove ecosystem services have advanced in method and theory after the long-term accumulation of scientific information. The research results are mainly

reflected in the definition and quantification of mangrove ecosystem values, the identification of mangrove production and maintenance of biodiversity, and the accumulation of mangrove nutrients [5-8]. China's mangrove ecosystem services research area is mainly located in the south of Fujian, including Fujian province, Guangdong province, Guangxi province and Hainan province, where is in the south latitude area of Ximen Island.

Zhejiang Ximen Island mangrove forest is the most northern end of the mangrove forest, composed of only Kandelia candel, whose height is approximately 2-3 m. The Ximen mangrove forest has adapted to the local climate and environment and has natural reproductive capacity. The introduction of the mangrove forest to Ximen Island has broken through the traditional growth of the Chinese mangrove forest. It not only has high ecological and tourism value but also has high scientific research value and needs to be protected and cultivated. In Ximen Island, the China-Italy climate change cooperation project "ecosystem capacity building adapt to climate change in the coastal areas" get implemented. At the same time, the United Nations Development Program (UNDP)/Global Environment Facility (GEF)/Small Grants Program Project (SGP)" Environmental Protection and Integrated Management of Mangroves Ecosystems in Ximen Island, Zhejiang Province" get implemented. Therefore, the study of the ecological value of the mangrove forest on Ximen Island can supplement the research results of high-latitude mangroves in China to a certain extent. Due to the importance of the Ximen Island mangrove, we put forward the hypothesis of "There are ecological service value difference between the natural growth mangrove at low latitude and artificial introduction mangrove at high latitude".

2. Study area

2.1. The location of Ximen Island

Ximen Island is located in the south of Zhejiang, China (figure 1). The area of this island is approximately 7 km^2, with a coastal wetland area of 19.2 km^2. In 2005, Ximen Island Marine Specially Protected Areas were established, including Ximen Island and its coastal wetlands, which mainly protected the mangrove communities in the northern latitudes of China, as well as benthic organisms and wetland birds. The total protected area is 30.80 km^2. There are 37 rocky reef organisms and 92 muddy beach organisms in the protected areas. This is an area of high biological value along the Zhejiang coastal area that has considerable biological diversity.
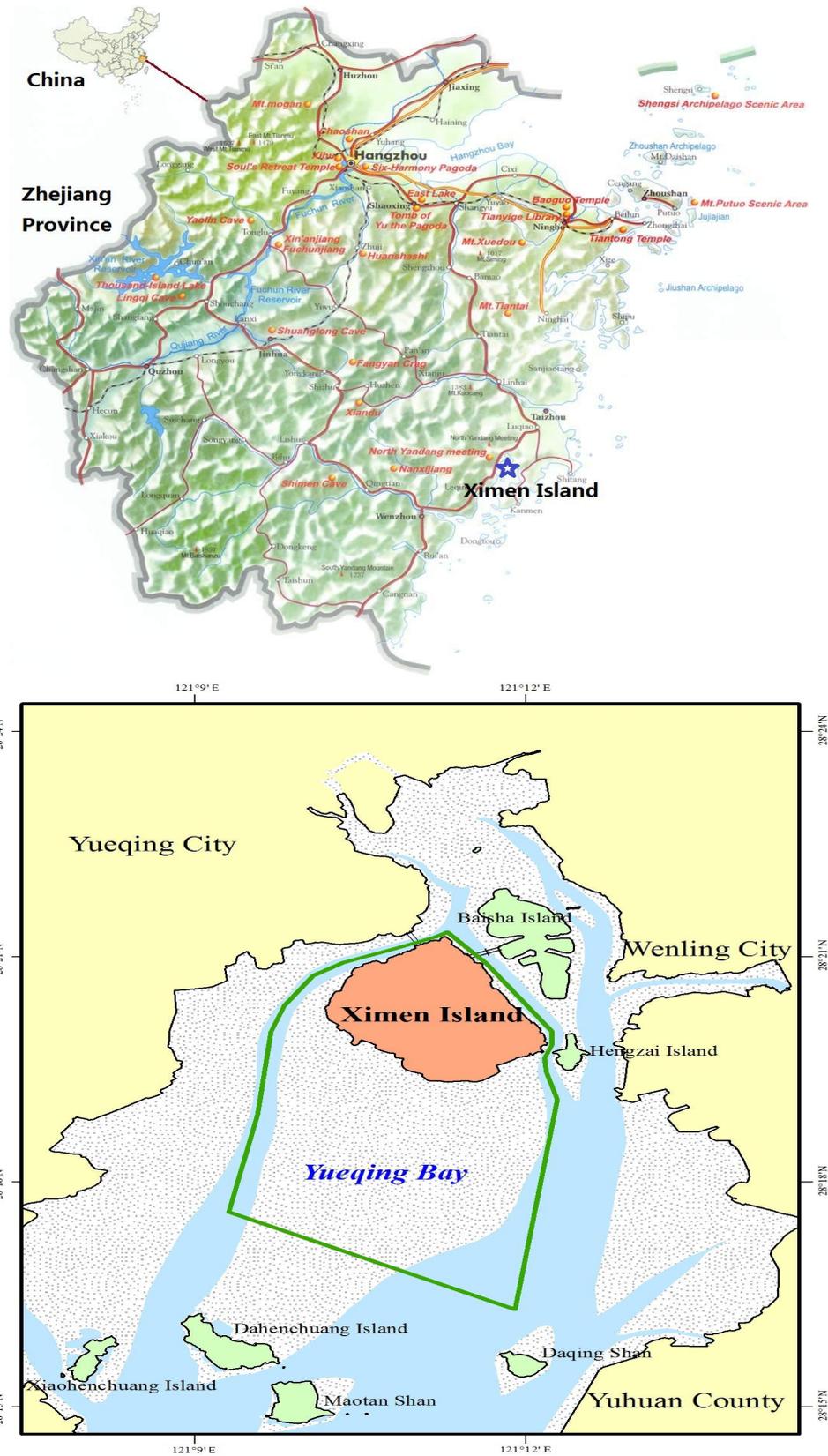
Figure 1. The location of Ximen Island Marine Specially Protected Areas.

2.2. Distribution of mangroves

Using the WorldView-2 high-resolution satellite image interpretation, the distribution of mangrove communities in the Xasmen Island Marine Specially Protected Areas was obtained in 2016. The mangrove communities in the protected areas are mainly distributed in the northern part of the island (Area B) and the northwestern (Area A) and western part of the island (Area C) which can be seen in figure 2. As of 2016, the total area of the mangrove community in the Ximen Island Marine Specially Protected Areas was approximately 26.68 Ha.
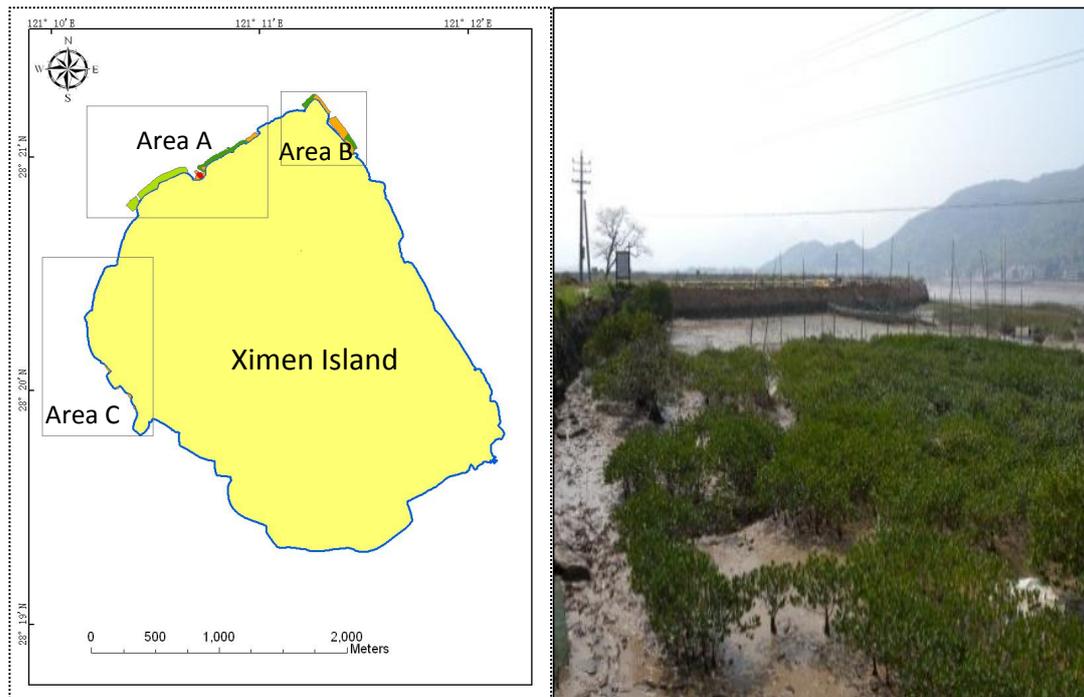
Figure 2. Distribution and live photo of mangrove communities in Ximen Island in 2016.
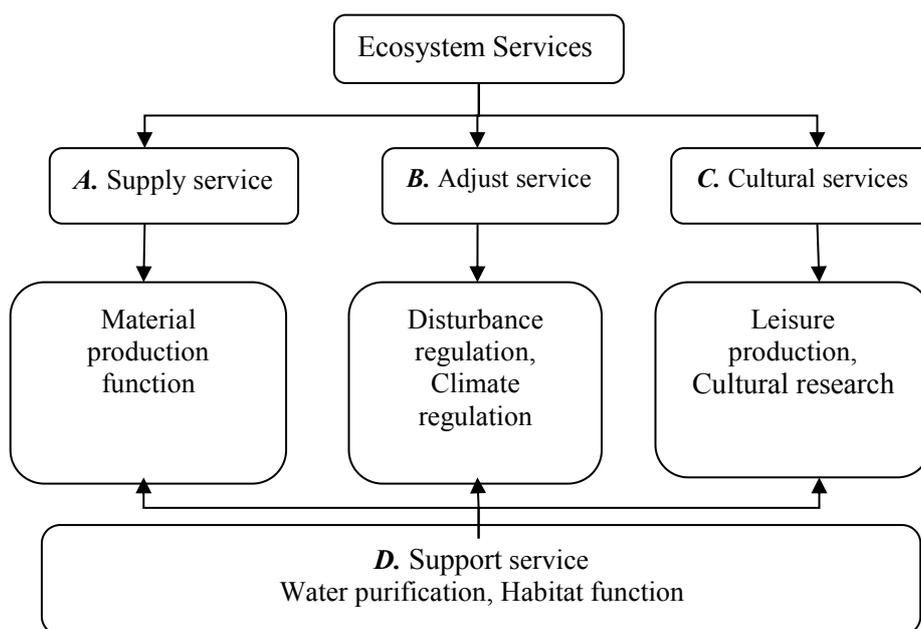
Figure 3. The function classification system of mangrove ecosystem in Ximen Island.

3. Evaluation of ecological service value of the mangrove forest

3.1. The function and value of the mangrove ecosystem

The classification system of the United Nations' Millennium Ecosystem Assessment divides ecosystem services into four categories: supply services, regulatory services, cultural services and support services [9].

On the basis of MA (Millennium Ecosystem Assessment) general classification system, we selected the main ecological service value of mangrove forest system in Ximen Island. According to the characteristics of the Ximen Island Marine Specially Protected Areas, the mangrove ecosystem function is divided into material production function (MP), disturbance regulation (DR), climate regulation (GR), water purification (WP), habitat function (HF), leisure production (LP) and cultural research (CR) which can be seen in figure 3.

3.2. Ecological value assessment method

Mangrove wetlands have many functions that are important to human beings. The ecosystem service function is multidimensional and therefore has widespread value, which brings considerable social and economic benefits to mankind. According to the benefits, the economic value can be divided into direct use value, indirect use value, non-use value, presence value and genetic value. The value of ecosystem services is different, and the corresponding assessment methods are different (table 1). The selection of the assessment method should be based on feasibility and maneuverability, and the most appropriate method should be selected. Because genetic values are often difficult to assess, they are not evaluated in the paper. And the presence value is reflected in the indirect value and non-indirect value, in order to avoid duplication of calculation, so in the paper has not been assessed. According to the actual situation of the Ximen Island Marine Specially Protected Areas, the evaluation method of the mangrove ecosystem service function value was selected.

Table 1. Evaluation methods of ecosystem value.

Value type	Ecosystem service value	Assessment method
Direct use value	Material production value	Market value method
	Leisure production value	Travel fee method
Indirect use value	Disturbance regulation value	Shadow engineering method
	Climate regulation value	Carbon tax law
	Water purification value	Fuzzy mathematics
	Habitat function value	Ecological value method
	Cultural research value	Travel fee method
Non-use value	Presence value	Willingness to pay
	Genetic value	Willingness to pay

3.3. Calculation of ecological service value of mangrove forests

3.3.1. Material production value (MP). Mangrove ecosystems are among the most productive ecosystems in the world, and their material production function is mainly embodied in living trees and fallen material (e.g., leaves and twigs). According to the results presented by Han Weidong (2009) [10], Chinese mangrove forest production volume is 4.4 m^3/(ha *a), and the log market price is 1,200 CNY/m^3. In the current study, the market value method was used to estimate the value (MP_1) of the mangrove forest on Ximen Island.

$$MP_1 = S*Y_1*P_1 = 26.68*4.4*1200 = 14.1*10^4 \text{ CNY/a} \tag{1}$$

Where S is the mangrove area; Y_1 is the annual mangrove growth of Chinese mangroves; and P_1 is the price of Chinese logs.

The Mangrove fallen leaves in the Ximen Island Protected Area are an important source of food for winter migratory birds. The mangrove annual dislocations are approximately 9.4t / (ha *a), and the market price of various types of waterfowl feed is 2,800 CNY/t. The paper uses the market value method to estimate the dislocation value (MP₂) in the protected area of Ximen Island.

$$MP_2 = S*Y_2*P_2 = 26.68*9.4*2800 = 70.2*10^4 \text{ CNY/a} \tag{2}$$

Where S is the mangrove area; Y_2 is the mangrove annual dislocation; and P_2 is the waterfowl feed price.

Thus, the total value (MP) of the mangrove material production for Ximen Island is obtained by the sum of the above two values.

$$MP = MP1 + MP2 = 84.3*10^4 \text{ CNY/a} \tag{3}$$

3.3.2. Leisure production value (LP). The Ximen Island Marine Specially Protected Areas do not charge for entry tickets and have not released the statistics pertaining to annual traffic. Due to proximity to the national 5A-level Yandang Mountain Scenic Area, Ximen Island has many tourists. With reference to the Leizhou mangrove wetland tourism value assessment conducted by Han Weidong [11], the unit area annual tourism value of the Ximen Island mangrove is $2.03 * 10^4$ CNY/(ha*a). By multiplying the per unit area annual tourism value by the mangrove area, the mangrove leisure travel value (LP) of Ximen Island can be obtained.

$$LP = L*S = 2.03*26.68*10^4 = 54.2*10^4 \text{ CNY/a} \tag{4}$$

Where S is the mangrove area, and L is the mangrove area per annual tourism value.

3.3.3. Disturbance regulation value (DR). Mangroves adapt to the tide and flood impacts, forming a unique ventilation organization, canopy and other morphological features that have a strong anti-wind and anti-wave function. In addition, the mangrove-dense roots function as berms by slowing the velocity of the water, settling the suspended particles in the water, and promoting the formation of soil. Therefore, the disturbance regulation value of the mangroves on Ximen Island mainly includes the function of the coastal flood control and berms.

The mangrove belt on Ximen Island is approximately 3 km long. According to research results presented by Lu Changyi, the mangrove coastline can provide typhoon disaster protection benefits of approximately $8.0*10^4$ CNY/(km*a) [12], and the ecological conservation benefits of the embankment are $64.7 * 10^4$ CNY (km*a) [13]. Combined with the length of the mangrove forest, the value of the Ximen Island protected area (DR₁) is $24 * 10^4$ CNY/a, and the embankment value (DR₂) is $194.1 * 10^4$ CNY/a.

The total disturbance regulation value of the mangroves on Ximen Island is the sum of the wave value and the berm value.

$$DR = DR_1 + DR_2 = 218.1*10^4 \text{ CNY/a} \tag{5}$$

3.3.4. Climate regulation value (GR). According to Kang Wenxing *et al* [14], the mangrove ecosystem absorbs 21.48 t/ha of CO_2 per year. The total amount of CO_2 in the mangrove forest was estimated by calculation.

$$C = GP*S = 21.48*26.68 = 573.1 (t/a) \tag{6}$$

Where C is the amount of CO_2 absorbed; GP is the amount of CO_2 absorbed per unit area of mangroves per year; and S is the mangrove area.

The amount of CO_2 absorbed and the amount of O_2 released can be obtained through the photosynthesis equation, that is, the absorption of 1 g CO_2 by plants can result in the release of 0.75 g O_2. Therefore, the CO_2 absorbed by the mangrove forest on Ximen Island is 573.1 t/a, and the amount of O_2 released is 429.8 t/a.

Using the internationally recognized carbon tax rate that is, 150 US dollars/t (in accordance with the exchange rate, which is 1,050 CNY/t), and the value of fixed CO_2 (GR_1) is $60.2*10^4$ CNY/a. Using the alternative market method, the release value of O_2 can be calculated. The industrial oxygen price is 1,000 CNY/t; therefore, the value (GR_2) of O_2 released is $43.0 * 10^4$ CNY/a.

The climate regulation value of the Ximen Island mangrove (GR) is the sum of the above two terms.

$$GR= GR_1+ GR_2=103.2*10^4 \text{ CNY/a} \tag{7}$$

3.3.5. Water purification value (WP). There are four villages on the island of Ximen, and considerable domestic sewage flows through the mangrove area into Yueqing Bay. According to the results presented by Zhang and Yu *et al*, the annual adsorption capacity of mangroves with respect to nitrogen, phosphorus and heavy metals is $3.77*10^4$ CNY/(ha*a) [15]. Combined with the area of Simmental mangroves, the value of purified water (WP) can be calculated.

$$WP=W*S=100.6*10^4 \text{ CNY/a} \tag{8}$$

Where W is the water purification value of the mangroves per unit area per year; S is the mangrove area.

3.3.6. Habitat function value (HF). The Ximen Island Marine Specially Protected Areas are an important habitat for migratory wetland waterfowl, which are included in the Agreement on the Conservation of Migratory Birds and Their Habitats in China and Japan and the Agreement on the Conservation of Migratory Birds and Their Habitats in China and Australia. The habitat function value of the protected area is the sum of the habitat value of important and ordinary birds. In the calculation, the conservation costs of important and ordinary birds can be multiplied by the number of birds, and then the results are added to obtain the habitat function value of the Ximen Island protected area.

According to the "Ximen Island Marine Specially Protected Areas General Plan", the number of world-class endangered Black Mouth Gulls along the Wenzhou coastal region is approximately 3,000 in winter, whereas Egrets and other ordinary birds account for approximately $2.5 * 10^4$. The number of birds in the mangrove area of Ximen Island was calculated as 1/50, that is, 60 important birds and 500 ordinary birds. Significant bird protection costs are $10 * 10^4$ CNY /a, and ordinary bird protection costs are 1,000 CNY/a [16]. The habitat function value of Ximen Island mangroves is the sum of these two amounts.

$$F=A_1*N_1+ A_2*N_2=650*10^4 \text{ CNY/a} \tag{9}$$

Where A_1 is the protection cost of important birds; N_1 is the number of important birds; A_2 is the protection cost of ordinary birds; and N_2 is the number of ordinary birds.

3.3.7. Cultural research value (CR). According to the work summary of the Ximen Island Marine Specially Protected Areas presented by the Yueqing Marine and Fishery Bureau in 2016, the investment cost of research and education in 2005-2015 was $8,000 * 10^4$ CNY, and the average annual investment was $800 * 10^4$ CNY. Research funding for the mangrove forest was calculated as 50% of the total funds, resulting in $400 * 10^4$ CNY/a, i.e., CR=$400 * 10^4$ CNY/ a.

3.3.8. Non-use value. Because non-use value depends on human subjectivity, it is relatively difficult to calculate this value; therefore, no quantitative assessment was performed.

4. Discussion and conclusion

4.1. Discussion

In this paper, mangroves in different latitudes in China were selected from the north to the south, which were mangrove forests in Ximen Island, Zhejiang Province, Zhangjiangkou mangrove forest in Fujian Province, Futian mangrove forest in Shenzhen Bay, Guangdong Province and Dongzhai port mangrove forest in Hainan Province. Based on the research of this paper, the research of mangrove forest in Zhangjiangkou of Fujian Province by Zhang [15], research of Futian mangrove forest in Shenzhen, Guangdong Province by Li [17] and research of mangrove forests in Dongzhai port, Hainan Province by Ding [6], the comparison of the mangrove species, height, category, latitude, the main ecological service value type and the ecological service value per unit area were analyzed (table 2).

Table 2. Comparison of mangrove in Ximen Island and other mangroves in different latitudes.

Area	The main species	Height (m)	Category	Latitude	Main ecological service value type and proportion	Ecological service value per unit area (CNY/ha*a)
Ximen Island, Zhejiang Province	Kandelia candel	2-3	Artificial cultivation	28°21′-28°16′	Habitat function value (40.4%), Cultural research value (24.8%)	23,078
Zhangjiangkou , Fujian Province	Avicennia marina, Bruguiera gymnorrhiza, Kandelia candel	2-5	Natural growth	23°53′-23°56′	Disturbance Regulation value (46.9%), Water purification value (20.9%)	59, 991
Futian, Shenzhen Bay, Guangdong Province	Kandelia candel, Aegiceras corniculata, Avicennia marina	2-6	Natural growth	22°30′-22°32′	Disturbance Regulation value (23.4%), Water purification value (14.2%)	107,400
Dongzhai port, Hainan Province	Sonneratia caseolaris, Avicennia marina	3-10	Natural growth	19°51′-20°01′	Climate regulation value (32.6%), Disturbance Regulation value (22.3%)	225,500

Through the comparison of the ecological services value per unit area, it can be concluded that, Hainan Province> Guangdong Province > Fujian Province > Zhejiang Province. This indicates that the

value of ecological services per unit area of mangrove forests is closely related to the latitude, that is, the growth of mangrove forests in the low latitudes is lusher and the value of ecological services is higher.

Secondly, it also has some differences between natural growth and artificial introduction mangroves in the ecological service value type composition. The main ecological service value of the natural growth mangrove forest is the value of disturbance Regulation, Water purification or climate regulation, while the artificial introduction forest of Ximen Island is mainly the value of habitat and cultural research. This conclusion provides a solid theoretical basis for the introduction project of China's high latitude mangrove forest by State Oceanic Administration.

4.2. Conclusion

4.2.1. Ecological value of the mangrove forest on Ximen Island. Through the evaluation of the mangrove ecosystem service value for the Ximen Island Marine Specially Protected Areas, the total service function value, each individual function value and their proportion were obtained.

The results in table 3 show that the total value of the mangrove ecosystem service for the Ximen Island Marine Specially Protected Areas is 16,104,000 CNY/a, the material production value is 843,000 CNY/a, the value of leisure is 542,000 CNY/a, the disturbance regulation value is 2,181,000 CNY/a, the value of climate regulation is 1,032,000 CNY/a, the value of water purification is 1,006,000 CNY/a, the habitat function value is 6,500,000 CNY/a, and the cultural research value is 4,000,000 CNY/a.

Table 3. Components of the ecosystem value of mangrove on Ximen Island.

Ecosystem Service Value	Value (CNY/a)	Proportion (%)
Material production value (MP)	843,000	5.2
Leisure production value (LP)	542,000	3.4
Disturbance Regulation value (DR)	2,181,000	13.6
Climate regulation value (GR)	1,032,000	6.4
Water purification value (WP)	1,006,000	6.2
Habitat function value (HF)	6,500,000	40.4
Cultural research value (CR)	4,000,000	24.8
Total	16,104,000	100

From the value composition analysis, HF> CR> DR> GR> WP> MP> LP. Among them, the habitat value, cultural research value and disturbance regulation value dominate, accounting for 78.8% of the total value. The composition of the value well reflects the practical role of the Ximen mangrove forest in the region, especially reflecting the significant scientific research value of this forest as the most northern latitude distribution of China. At the same time, it also reflects the importance of Yueqing Bay as an important international migratory habitat, as well as the important disaster prevention and mitigation effects of the mangrove forest in Wenzhou.

4.2.2. Analysis of the ecological service value of mangroves on Ximen Island. The value of mangrove ecosystem services for Ximen Island is mainly composed of direct use value (material production value and leisure value) and indirect use value (disturbance regulation value, climate regulation value, water purification value, habitat function value, cultural research value). The results show that the proportion of the direct use value relative to the total value is 8.6%, and the proportion of the indirect use value is 91.4%. This indicates that material production is not the main ecological service function of the mangrove forests on Ximen Island, and the invisible ecological service function strongly indicates its ecological value, such as the value of habitat, the value of cultural research and the value of disturbance regulation. At the same time, the results also show that the ecological value and scientific research value of the Ximen Island mangrove are extremely high.

Therefore, in the protection of mangroves on Ximen Island, we should pay special attention to the protection of ecological processes. At the same time, the management agency should strengthen the research investment in Ximen Island mangroves in order to enhance the cultural and scientific value of Chinese high-latitude mangrove forests. In the later construction of the Ximen Island Marine Specially Protected Areas, we should expand the mangroves associated with the "South Mangrove and North Chinese Tamarisk Twig" program of the State Oceanic Administration. The expansion plan will enhance the service value of the mangrove ecosystem and realize the sustainable development of the Ximen Island Marine Specially Protected Areas.

References
[1] Wang W Q 2007 *Chinese Mangrove Forest* (Beijing: Science Press)
[2] Jiang J and Hu B Q 2013 The services function and value of mangrove ecosystem *J. Anhui Agric. Sci.* **41** 3958-60
[3] Costanza R, Agre R and De G 1997 The value of the world's ecosystem and natural capital *Nature* **387** 253-60
[4] Zhao S-D and Zhang Y-M 2004 Concepts, contents and challenges of ecosystem assessment—Introduction to "ecosystems and human well-being: A framework for assessment" *Adv. Earth Sci.* **19** 42-6
[5] Li W H 2002 *Research on Ecosystem Service Function* (Beijing: Meteorological Press)
[6] Ding D J, Liao B W and Guan W 2016 Evaluation on service value of coastal wetland ecosystem in Dongzhai harbor mangrove nature reserve *Ecol. Sci.* **35** 182-90
[7] He H J, Wen J S and Zhang J W 2015 Ecological functions assessment of mangrove wetland in Hainan Province *Ecol. Econo.* **31** 145-9
[8] Zhao S, Hong H-S and Zhang L-P 2007 Emergy value of mangrove ecosystem services in China *Resour. Sci.* **29** 147-54
[9] Millennium Ecosystem Assessment (MA) 2003 *Ecosystems and Human Well-being: A Framework for Assessment* (Washington DC: Island Press)
[10] Han W-D, Gao X-M and Lu C-Y 2000 The ecological values of mangrove ecosystems in China *Ecol. Sci.* **19** 40-6
[11] Han W D 2009 *Mangrove Ecosystem of Leizhou Peninsula and Its Protection Strategy* (Guangzhou: South China University of Technology Press)
[12] Lu C Y 1991 The development of mangrove forest is an effective countermeasure to reduce the tide of typhoon *J. Nanjing Univ. (Nat. Sci.)* **1** 70-5
[13] Fan H Q 1995 An ecological pattern of sea dyke maintenance by mangroves and assessment of its benefits along Guangxi Coast *Guangxi Sci.* **2** 48-52
[14] Kang W X, Zhao Z H and Tian D L 2008 CO_2 exchanges between mangrove and shoal wetland ecosystems and atmosphere in Guangzhou *Chin. J. Appl. Ecol.* **19** 2605-10
[15] Zhang H-Y, Chen C-M and Zheng H-Y 2013 Evaluation of value of wetland ecosystem services of Zhangjiang estuary mangrove national nature reserve *Wetl. Sci.* **11** 108-13
[16] Dai Y B 2004 Preliminary exploration on forest ecological function and value estimate of Daxueshan nature reserve *Forest Invent. Plan.* **29** 83-7
[17] Li Y-L, Ning T-Z and Xu H-L 2011 Evaluation of mangrove ecosystem service functions for Futian Mangrove Reserve in Shenzhen Bay, Southern China *J. Cent. South Univ. For. Technol.* **31** 41-8