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ORIGINAL RESEARCH ARTICLE

Analysis on the vacancy of mangrove ecosystem protection in China

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ABSTRACT

As an important ecosystem type in the coastal zone, mangroves have important ecological functions, such as maintaining coastal biodiversity, preventing wind and consolidating the coast, promoting silt and building land. It is of great significance to understand the protected status of mangroves in the context of climate change and rapid urbanization. Based on the mangrove classification data from remote sensing interpretation, through vacancy analysis, the in-situ protection status of mangroves in China is analyzed. The results show that the total area of mangroves distributed in China is 264 km^2 (excluding the statistical data of Hong Kong, Macao and Taiwan), of which 61.4% are protected in natural reserves. In terms of the main provinces where mangroves are distributed, the mangrove area distributed in Hainan Province is small but the protection proportion is high, while the mangrove area distributed in Guangxi and Guangdong Province is large but the proportion of protected areas is relatively low. Among the three mangrove types, *Rhizophora apiculate-Xylocarpus granatum* and *Rhizophora stylosa-Bruguiera gymnorrhiza* had high proportions (>90%) covered by reserves, but relatively small areas. In contrast, *Kandelia candel-Aegiceras corniculatum-Avicennia marina* had relatively low reserve coverage (52.6%), but a large area. The study puts forward the key areas of mangrove distribution outside the nature reserve, and suggests that they should be protected by delimiting ecological protection red lines.

Keywords: Mangrove; Ecosystem; Nature Reserve; Coastal Zone

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1. Introduction

The establishment of nature reserves is the most effective and important measure to protect typical ecosystems and rare and endangered species[1-3]. at present, the network system of nature reserves established in China covers about 15% of the land area of the country, but the spatial layout is not reasonable, which is consistent with the spatial distribution of important protected mammals, but with important areas of plants, amphibians and reptiles, and the important areas of ecosystem service function are not highly consistent in space[4]. There are few studies on the protection and coverage of ecosystems and vegetation in nature reserves. At present, they mainly focus on terrestrial ecosystems[5,6], the overall status of vegetation[7] and the overall status of wetland ecosystems[8]. There are few reports on the protection status of a specific type of ecosystem, especially the ecosystem under the stress of human activities.

Mangrove is an important temperate ecosystem type mainly composed of woody plants distributed on tropical or subtropical coasts, which has important ecological functions such as maintaining biodiversity in the coastal zone, preventing wind and consolidating the bank, promoting

siltation and land building[9-12]. In recent centuries, mangroves have undergone severe degradation due to human activities such as excessive logging, aquaculture development and building expansion[13-16]. The degradation of mangroves has further led to the loss of coastal biodiversity, thus endangering the sustainable economic and social development of coastal cities, so the protection of mangrove ecosystem is a topic of concern[17].

In recent years, the construction of mangrove reserves in China has developed rapidly. In 1980, the first National Mangrove Nature Reserve was established in Dongzhai port. So far, China has established more than 32 mangrove reserves, with the area of nature reserves reaching 975.61 km^2[18](**Figure 1**). However, at present, the overall protection status of mangroves in nature reserves is not clear, and the research is more limited to the analysis and evaluation of the fragmentary nature of local protected areas, such as the protection effect of mangrove wetlands in Zhanjiang and Zhangjiangkou, Fujian[19,20]. The research results are difficult to be used to comprehensively understand the protection status of mangrove ecosystem, and also have an adverse impact on the later development of mangrove protection and management and other related work.

Based on the above deficiencies in the current mangrove protection research, this paper evaluates the protection status of mangroves in national nature reserves and identifies the key areas of mangrove distribution outside the reserves by collecting the relevant data of different levels of mangrove nature reserves across the country, combining with the data of National Mangrove distribution map, and through gap analysis. The research results can provide a basis for further boundary adjustment and protection decision-making of mangrove reserve.

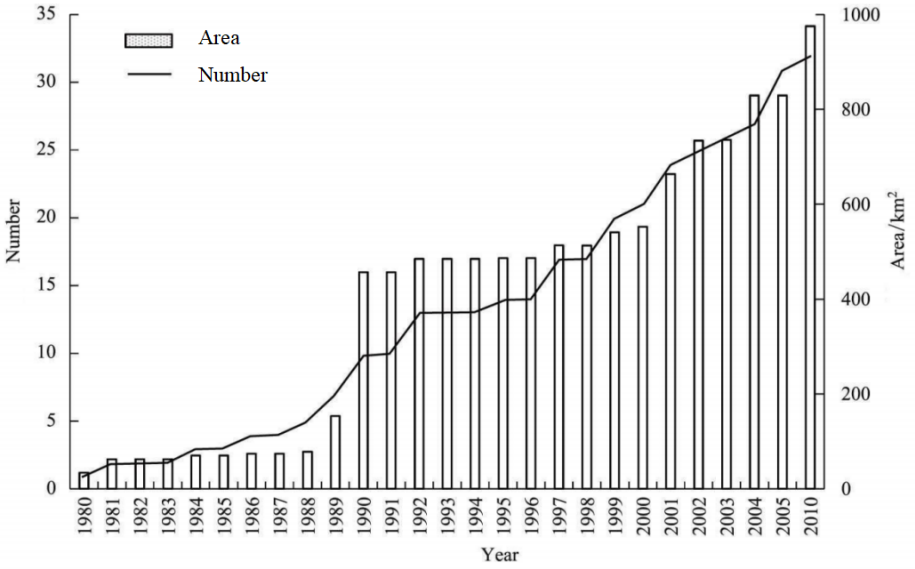

Figure 1. The number and area change both of mangrove protected area.

2. Research data and methods

2.1 Data source and processing

(1) Mangrove vegetation distribution map acquisition. Mangrove distribution map comes from the "2000–2010 survey and assessment of ecosystem changes in China"[21], which is obtained by using remote sensing data such as TM (30 m), CBERS-02B panchromatic image (resolution of 2.36 m) in 2010, environment 1 satellite multispectral data in 2010, image fusion and other preprocessing, and object-oriented classification technology interpretation. The accuracy of classification results is verified, with an accuracy of 89%[22]. In the GIS spatial analysis platform, the obtained mangrove distribution map is overlapped with the vegetation type map of China, and the mangroves in the country are divided into three vegetation types[23]: *Kandelia candel-Aegiceras corniculatum-Avicennia marina*, *Rhizophora stylosa-Bruguiera gymnorrhiza*, *Rhizophora apiculata-Xylocarpus granatum*, and the protection status

is analyzed.

(2) Natural reserves are obtained from countries where they are distributed. According to the list of China's natural reserves (2015) published on the official website of the Ministry of environmental protection, 32 national natural reserves for the protection of mangrove ecosystems are retrieved (6 of which are at the national level, 5 at the provincial level, 8 at the municipal level and 13 at the county level). The list of natural reserves is determined. The boundaries of natural reserves are from published literature[4].

2.2 Research methods

(1) Mangrove protection vacancy analysis. Using GIS software, the mangrove distribution map is spatially superimposed with the distribution map of natural reserves and the national administrative zoning map, and the index values of mangrove distribution area, protected area and protection vacancy of the country, provinces and vegetation types are obtained statistically, so as to analyze the protected status of mangrove ecosystem.

(2) Analysis of priority areas for mangrove protection outside the nature reserve. In landscape planning, ecosystem patches with relatively large area or high aggregation are often preferred for protection[24]. By applying the method provided by the IUCN (International Union for conservation of nature, IUCN) ecosystem red list evaluation standard, the area of occupancy (AOO)[25] of ecosystem is used to identify the priority protection area of mangrove, and the GIS software is used to draw 10 km × 10 km cell network, statistics the proportion of mangrove area not included in the natural reserve in the cell. The larger the value, the larger the mangrove patch area or the higher the aggregation in the region. In order to better understand the distribution of mangrove protection vacancy in space, this paper divides it into three levels according to the proportion of occupied area: <1%, 1%–5% and >5%, draws the spatial distribution map, and finally takes the distribution area with an area proportion of more than 1% as the priority protection area of mangrove.

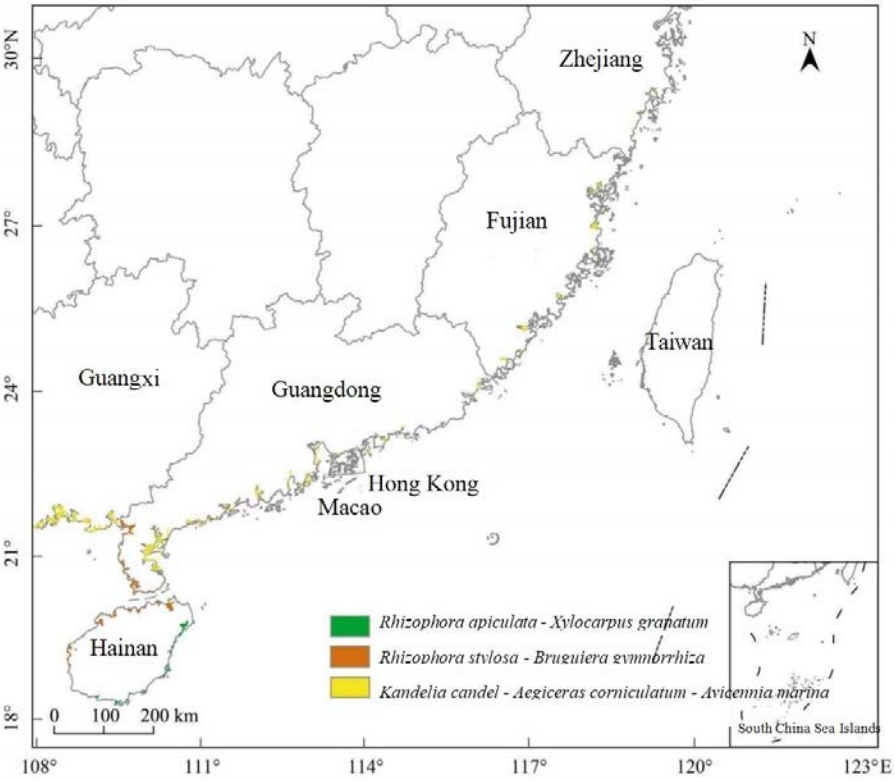

Figure 2. The spatial distribution of mangrove in China, 2010.

3. Results and analysis

3.1 Mangrove distribution and protection in China

In 2010, the total area of mangroves distributed nationwide was 264.1 km^2. Mangroves are mainly distributed in the coastal zone of Guangxi, Guangdong, Hainan and other provinces. The proportion of mangrove area distributed in the three provinces accounts for 40% of the total mangrove area of the country respectively 2%, 35.79% and 18.5%. The mangrove areas distributed in Fujian and Zhejiang are relatively small, accounting for 5% of the total mangrove area respectively 5.3% and 0.3% (**Figures 2** and **3**).

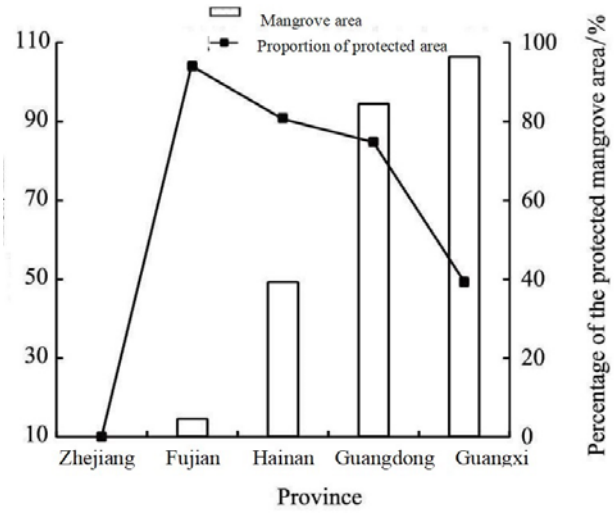

Figure 3. The status of the mangrove protected area in provinces.

At present, the mangrove area in the National Nature Reserve is 162.1 km^2, accounting for 61.40% of the total mangrove area, and 38.6% of the mangrove are distributed outside the boundary of the reserve, which is not strictly protected.

3.2 Current situation of mangrove protection in different provinces

Figure 3 shows that among the main provinces with mangrove distribution, the provinces with smaller mangrove area have a higher proportion of mangrove area covered in the nature reserve. In Fujian Province and Hainan Province, the proportion of protected mangrove areas in nature reserves is 94.0% and 80.9% respectively, and that in Guangdong Province is 74.8%. Guangxi Province, which has the largest mangrove area, has the lowest proportion of mangrove protection, which is only 39.5% of the total mangrove area of the province.

3.3 Protection status of different types of mangroves

Figure 4 shows that the most important type of mangrove is *Kandelia candel-Aegiceras corniculatum-Avicennia marina*, which distribution area of 71.6% of the total area of mangrove, followed by the type of *Rhizophora stylosa-Bruguiera gymnorrhiza*, which is 37.2% of the total area of mangrove, and the distribution area of *Rhizophora apiculata-Xylocarpus granatum* is the least, which is only 5.2% of the total area of mangroveThe analysis of protection status shows that mangroves with small area have a higher protection proportion in the nature reserve. At present, the nature reserve covers 95.4% of *Rhizophora apiculata-Xylocarpus granatum*, 90.4% of *Rhizophora stylosa-Bruguiera gymnorrhiza*, and the larger *Kandelia candel-Aegiceras corniculatum-Avicennia marina* has a relatively low proportion of protected area, only 52.6%.

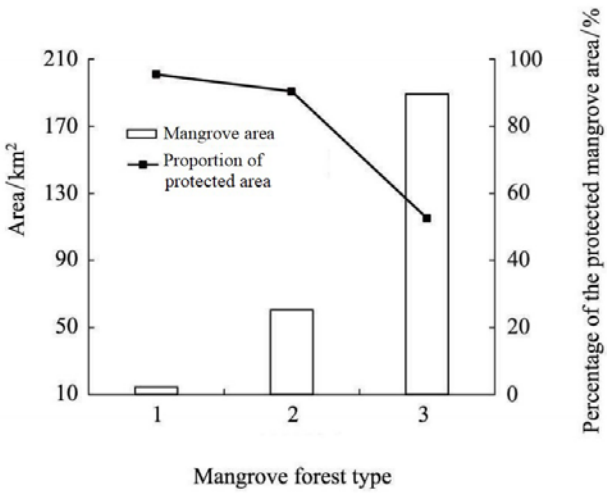

Figure 4. The status of three kinds of mangroves protection. 1: *Rhizophora apiculata-Xylocarpus granatum*; 2: *Rhizophora stylosa-Bruguiera gymnorrhiza*; 3: *Kandelia candel-Aegiceras corniculatum-Avicennia marina*

3.4 Analysis of priority protection of mangroves outside the protection area

Although 61.4% of mangroves in the country have been protected, there are still large areas of mangrove vacancies. Mangroves with a high degree of protection vacancy are mainly distributed in the

middle of Guangxi coast, the west coast of Hainan Province and some areas of Guangdong Province. These areas can be taken as priority protection areas in future protection planning (**Figure 5**).

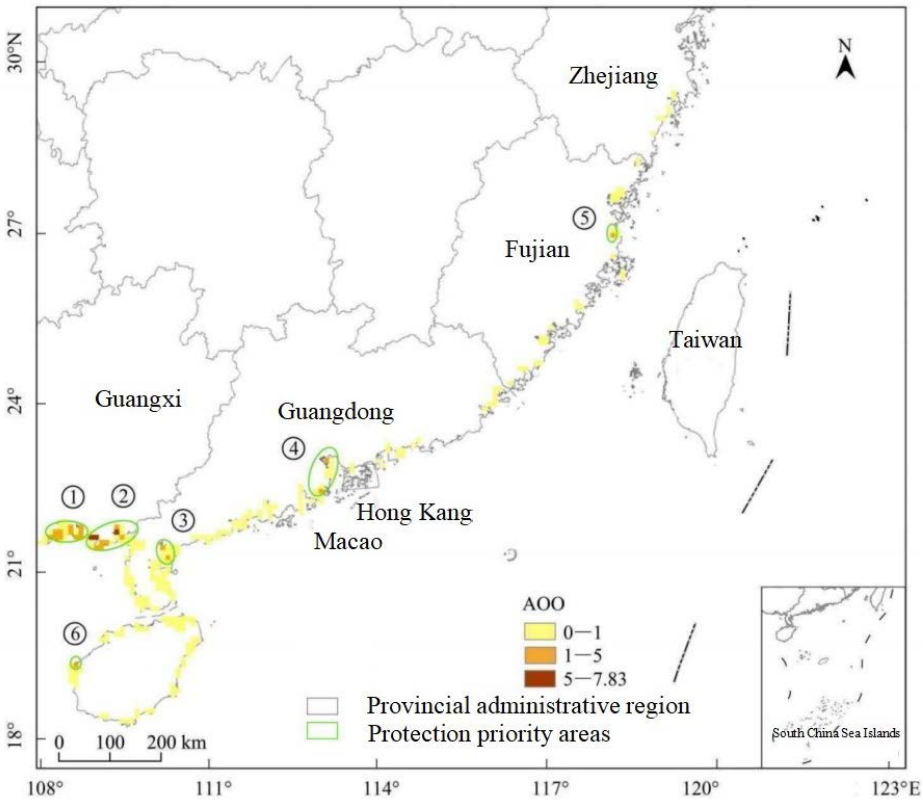

Figure 5. The area of occupancy map of the unprotected mangrove area.
Priority protection areas: ① Fangchenggang, Qinzhou Bay Mangrove; ② North seas mangroves; ③ mangroves in Potou area of Zhanjiang; ④ mangroves in Pearl River port; ⑤ mangroves in Minjiang Estuary; ⑥ mangroves in Xiantian port of Changjiang River.

4. Discussion

This study found that the protected area of mangroves in China is more than 60%, of which the proportion of *Rhizophora apiculata-Xylocarpus granatum*, *Rhizophora stylosa-Bruguiera gymnorrhiza* has exceeded 90%, indicating that the protection proportion of mangroves is significantly higher than that of domestic land vegetation. For example, the research of Chen et al shows that there are 47 types of terrestrial natural vegetation in China, of which 42 are less than 40%. There are five types protected by more than 40%: *Alpine cushion dwarf semi-hrubby desert*, *Alpine grass-Carex steppe*, *Alpine swamp*, *Alpine tundra* and *Alpine cushion vegetation*. Wu *et al*.[5] showed that the proportion of protected land natural vegetation communities in China is basically below 40%, so mangrove ecosystem has become one of the natural ecosystems with the highest protection proportion in China.

The reason for the high proportion of mangroves in nature reserves may be related to the rapid loss of mangroves in the past few decades. According to the statistics of the State Oceanic Administration (2002)[26], the mangrove area in China was about 550 km^2 in the 1950s. By 2002, the mangrove area had been reduced to 150 km^2. In the past 50 years, the mangrove area in China has decreased by 73%, of which the mangrove distribution areas in Guangdong, Hainan and Guangxi have decreased by 82%, 52% and 43%, respectively. The reduction of mangrove area leads to the loss of coastal bird habitat and fishery resources, and also intensifies coastal red tide disasters, coastal erosion and other disasters, which has become one of the important reasons for the degradation of coastal ecosystem system[27,28]. Therefore, mangrove protection has been widely concerned by the society, and the investment in mangrove protection has been increased. At present, 32 mangrove nature reserves have been established in China, and many mangrove temperate lands such as Dongzhai port in Hainan and

Zhanjiang Hong in Guangdong have been listed in the list of internationally important protected wetlands, which plays an important role in promoting mangrove protection[29].

The study also found that Guangxi, Guangdong and Hainan, the three provinces with mangrove distribution, showed a large difference in the proportion of mangrove protected. Hainan Province has the least mangrove distribution area among the three provinces, but the highest degree of protection, which may be related to the high richness of mangrove plant species distributed in the region. Hainan Province is the province with the most abundant mangrove species in China. There are 26 species of true mangrove plants, accounting for 37.1% of the true mangrove plants in the world, more than 90% of the true mangrove plants in the country[30], including Chinese endemic and IUCN extremely dangerous plant species such as *Sonneratia x hainanensis*, national secondary protected plant species such as *Lumnitzera littorea* and *Xylocarpus granatum*, as well as *Nypa fruticans, Sonneratia x gulngai*, *Rhizophora apiculata*, *Bruguiera sexangula* have been listed in the list of provincial key protected wild plants in Hainan Province and are under important protection, so mangroves are protected in a high proportion. On the contrary, mangroves in Guangxi Province have a large area but a low degree of protection, which may be related to people's insufficient understanding of the protection value of mangroves. Mangrove species distributed in these areas are mainly *Kandelia candel*, *Aegiceras corniculatum*, *avicennia marina*, etc.[31], which are not threatened species, so the degree of protection is low. However, mangroves in Guangxi provide important ecological functions in reducing waves, promoting siltation and protecting beaches, protecting embankments, and play an irreplaceable role in maintaining the diversity of coastal wetlands[32,33], and their protection value should be paid attention to.

At present, 61.4% of the total area of mangroves in China is protected within the scope of the reserve, and 38.6% of the area is still not strictly protected. In view of the important functions of mangroves in windbreak and shore consolidation, habitat provision and so on, it is suggested that mangroves in the main distribution areas be included in the nature reserve through the construction or expansion of nature reserves, including the Guangxi coast, the west coast of Hainan Province, the Pearl River port area in Guangdong Province and the mangrove forest in Fujian Minjiang port. In addition, it is suggested that the main distribution areas of mangroves and mangrove patches with relatively scattered distribution and small area should be included in the ecological protection mangrove line to realize the strict protection and management of mangroves.

There are also some deficiencies in this study, mainly including two aspects. First, the protection status of mangroves in the nature reserve is evaluated only from the distribution and area of mangroves, and the priority areas for protection outside the reserve are identified. In the future, a complete evaluation index system can be established from mangrove productivity, vegetation coverage, ecological function, distribution of animal and plant species, water environment and other aspects to comprehensively evaluate the protection effect of mangroves. Second, limited by data and technical conditions, the artificial forests in mangroves are not separated from natural forest areas, which makes it impossible to have an in-depth understanding of the protection status of natural mangroves. In the next step, we will further explore the classification methods of natural forests and artificial forests, focusing on the evaluation of the protection status of natural mangroves, so as to provide a scientific basis for the protection planning and management of mangroves.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix

Table 1. The existing mangrove nature reserves in China

No.	Province	Name	County	Area/km^2	Level
1	Fujian	Longhai jiulongjiangkou Mangrove Nature Reserve	Longhai	4.20	Provincial level
2	Fujian	Zhangjiangkou Mangrove Nature Reserve	Yunxiao County	23.60	National level
3	Fujian	Huansandu'ao Mangrove Nature Reserve	Ningde City	24.06	Municipal level
4	Fujian	Longhai Jiulong River Estuary Wetland mangrove natural protection	Longhai	43.60	County-level
5	Fujian	Quanzhou | Bay Estuary Wetland Nature Reserve	Quanzhou City	70.10	Provincial level
6	Guangdong	Dianbai Mangrove Nature Reserve	Dianbai County	19.50	Municipal level
7	Guangdong	Shantou Wetland Nature Reserve	Shantou City	103.33	Municipal level
8	Guangdong	Huidong Mangrove Nature Reserve	Huidong County	5.33	Municipal level
9	Guangdong	Taishan Town Bay Mangrove Nature Reserve	Taishan City	1.19	County-level
10	Guangdong	Chengcun Haoguang Mangrove Nature Reserve	Yangxi County	10.00	County-level
11	Guangdong	Hong'ao Dangan Island Mangrove Nature Reserve	Zhuhai	73.74	Provincial level
12	Guangdong	Wulinanshan Mangrove Nature Reserve	Xuwen County	0.07	County-level
13	Guangdong	Maogang Mangrove Nature Reserve	Maogang District, Maoming City	8.00	County-level
14	Guangdong	Enping Mangrove Nature Reserve	Enping	7.00	County-level
15	Guangdong	Zhanjiang Mangrove Nature Reserve	Zhanjiang City	193.00	National level
16	Guangdong	Neiling {Ding Dao Dou Lvtian	Shenzhen City	8.15	National level
17	Guangdong	Dapeng Peninsula	Longgang District, Shenzhen	146.22	Municipal level
18	Guangdong	Xinchaluntau mangrove forest	Xuwen County	3.09	County-level
19	Guangdong	Nandu Estuary	Leizhou City	2.00	County-level
20	Guangdong	Ganglie opposite Delta	Yangjiang City	0.40	County-level
21	Guangdong	Pinggang mangrove wetland	Yangjiang City	8.00	County-level
22	Guangxi	BEILUNHEKOU Mangrove Nature Reserve	Fangchenggang City	30.00	National level
23	Guangxi	Shankou Mangrove Nature Reserve	Hepu County	80.00	National level
24	Guangxi	Maoweihai Mangrove Nature Reserve	Qinzhou City	34.54	Provincial level
25	Hainan	Huachang Bay Coastal Mangrove Nature Reserve	Chengmai County	1.50	County-level
26	Hainan	J Qinglan port Mangrove Nature Reserve	Wenchang City	29.05	Provincial level
27	Hainan	Tielugang Mangrove Nature Reserve	The city of Sanya	2.92	Municipal level
28	Hainan	Dongzhaigang Mangrove Nature Reserve	Haikou City	33.37	National level
29	Hainan	Caiqiao Mangrove Nature Reserve	Lugao County	3.50	County-level
30	Hainan	LANYA River Mangrove Nature Reserve	The city of Sanya	3.44	Municipal level
31	Hainan	Yalong Bay Qingmei port	The city of Sanya	1.56	Municipal level
32	Hainan	Xinyingwan Mangrove Nature Reserve	Suzhou City	2.15	County-level
32	Hainan	Xinyingwan Mangrove Nature Reserve	Suzhou City	2.15	County-level