Resource status and protection strategies of mangroves in China

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Received: 9 July 2019 / Revised: 3 January 2020 / Accepted: 1 January 2021 / Published online: 2 July 2021
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Abstract

Mangrove is a typical natural landscape with great ecological, social and economic functions and values, and should be highly valued and protected. However, in the past few decades, mangrove resources have suffered serious damage, and there are also many deficiencies in mangrove protection. Chinese mangroves, as an important part of the global mangroves, are of great research value. In the present study, the status and historical dynamic process of Chinese mangrove resources were investigated and discussed to illustrate the problems of resources from three aspects, including mangrove distribution, area and plant species. Based on field research, literature research and data analysis, it was revealed that Chinese mangroves are distributed in eight provinces and regions along the southeast coast with an area of 35,749.25 hm², 38 species and 40 nature reserves. The protection situation and deficiencies were analyzed from the establishment and management of nature reserves. Based on the resource status and problems, reasonable strategies were proposed to protect and manage mangroves mainly from four aspects, including publicity and education, resources restoration and protection technology, legal system establishment, and comprehensive protection and management.

Keywords Mangrove resources · Problems and challenges · Historical dynamic process · Protection and management

Introduction

Mangroves are woody plant communities that grow in the coastal intertidal zones or river estuary of the tropics and subtropics, which are considered as a special type of forest that adapt to the transition zone between land and ocean, with the title of “coast guardian”, “land-making pioneer” and “bio-purification sieve” (Jia 2014). As an important buffer between land and ocean, mangroves have great ecological, economic and social functions and values. In terms of ecological functions, mangroves attenuate wind and waves (Zhang et al.

2006; Ba et al. 2017; Guo 2018), purify water and air (Zhang et al. 2006; Ba et al. 2017), provide excellent habitats (Ba et al. 2017; Fang and Dan 2001; Lin and Lin 2001), maintain biodiversity (Zhang et al. 2006; Li 2007; Lan et al. 2018), and promote siltation and land-making (Ba et al. 2017; Fang and Dan 2001; Jiang 1980). From the view of economic values, mangroves provide people direct and indirect economic products. Mangrove plants can be used for brewing (Fang and Dan 2001; Jiang 1980), eating (Guo 2018; Lin and Lin 2001) and sugar making (Fang and Dan 2001), as well as extracting industrial chemicals (Fang and Dan 2001; Lin and

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Lin 2001), and making furniture (Jiang 1980; Lin 1981). In addition, mangroves also have social values of scientific research (Li 2007), education (Ba et al. 2017) and tourism (Ba et al. 2017; Fang and Dan 2001; Fan 1990). They are the priceless wealth that has been given to mankind by nature.

At present, the global mangroves are mainly distributed between the Tropic of Capricorn and Tropic of Cancer in 124 countries (Jia 2014; Spalding et al. 2010). Overall, the area of worldwide mangroves is declining year by year. It has a decrease of 20% in the last 25 years (Spalding et al. 2010; Giri et al. 2011; Heru et al. 2017) and is still decreasing at a rate of 1–2% per year globally (Duke et al. 1998; Liu et al. 2018). The unreasonable exploitation and urbanization construction, such as deforestation and industrialization, have resulted in the loss of mangrove area all over the world, causing serious ecological damage and economic losses (Heru et al. 2017; Liu et al. 2018; Joffre et al. 2015). Chinese mangroves, belonging to the East group in the world (Lin 1981; Chen 1980; Wang and Wang 2007), accounts for a little in the world mangroves but with unique characteristics and values (Jia 2014; Chen et al. 2009) playing important role in the global mangrove system. Due to the rapid population growth, urbanization, and unreasonable economic exploitation, the area of Chinese mangroves decreased by nearly 50% in the past 50 years, from the 1950s to the end of the twentieth century. The rate of reduction was much greater than the global average (Jia 2014), indicating that Chinese mangrove resources have been severely damaged. From the twenty-first century, China began to pay more attention to mangrove protection with corresponding measures leading to a little increase of areas. However, there are still many problems and threats in the protection and management of mangroves in China.

In order to better protect mangroves, it is necessary to conduct a comprehensive and systematic study. At present, the studies conducted by scholars on Chinese mangroves have mainly involved in five aspects: protection strategy, pest control, invasive plant prevention and control, heavy metal pollution, and resource research. Among these research activities, studies on resources are the greatest, but the studies in the field of protection strategy remain insufficient (Zhang 2017). In terms of specific content, several reports focused on the mangrove distribution (Zhang et al. 2006; Dan et al. 2016), habitat characteristics (Chen 1980; Dong 2001; He et al. 2007) and ecological functions (Fang and Dan 2001; Lan et al. 2018; Fan 1990; Dong 2001), indicating their unique growing environment and great ecological values. Studies also revealed the area change of Chinese mangroves in different periods to illustrate the importance of protection (Dan et al. 2016; Yang et al. 2017a). Mangrove species and groups have been investigated concerning their distribution and changes (Lin 1981; Fu et al. 2009; Liao and Zhang 2014). In addition, mangrove protection and management have been discussed from the

perspective of legislation (Ma 2004), international comparison (Wang 2013; Ding et al. 2018), and situation analysis (Lv 1998; Huang 2017; Fan and Wang 2017).

Although it has been studied for the distribution, area, community type, animal and plant resources, ecological functions and influencing factors of Chinese mangroves (Zhang 2017), there is still a space for further study because some aspects of research remain insufficient. For example, the exact area of Chinese mangroves has not been confirmed due to the differences in statistical equipment and investigation methods (Yang et al. 2017a), and the data used in the existing literature are relatively out-of-date which could not reflect present situation. There is a lack of research and analysis on the current state of mangrove resources in China, and a lack of discussion on the challenges of mangrove resources in the future. Most studies about the area of mangroves were performed at the period from the 1950s to the end of the twentieth century, while few scholars analyzed mangrove area in recent 20 years. Studies on the mangrove plants distribution and endangered conservation are less performed in the literature. More scholars conducted a study in a certain province or region in China, while fewer scholars conducted holistic analyses and systematic studies on resource status from a nationwide perspective. In addition, most suggestions were proposed for mangrove conservation and management from a single view with the lacking of a comprehensive perspective.

In the present study, we investigated and analyzed the status of Chinese mangroves by using the methods of field research, literature inductive analysis, and scientific statistics. We integrated and updated relevant data, striving to reflect the present condition of mangrove resources in China. The overall explanation and description were made for the status of mangrove resources in the last 20 years. The problems of mangrove resources during the historical dynamic process and the threats to the future were also analyzed. Moreover, the situation of mangrove nature reserves in China was analyzed and their existing problems were stated from the perspective of resource protection and management. Finally, the targeted strategies were proposed from a comprehensive perspective for effective protection and management of Chinese mangrove resources.

Resource status of mangroves in China

Mangroves are composed of evergreen shrubs or trees that are distributed in the intertidal zone of tropical and subtropical regions, and are flooded by periodic tides (Saintilan 1997; Chang and Ding 2013). Mangroves are the special ecosystems of the transition from land to ocean, and the preferred line of defense for the construction of coastal shelter forest systems. Mangrove ecosystem have outstanding economic, ecological

and social values. The growing areas of Chinese mangroves cover the southern and southeastern coasts of Chinese mainland, as well as Hainan and Taiwan islands, with a coastline length of 14,000 km approximately (Jia 2014). In this study, the status of mangroves in China was analyzed in three aspects: the distribution, area, and species of mangroves.

The distribution of mangrove resources in China

The Chinese mangroves are distributed in the shallow water areas of tropical and subtropical southeastern coasts, including bays, harbors and firths. Their latitudinal distribution is mainly controlled by air temperature, seawater surface temperature and frost frequency. Cold and warm currents regulate air and water temperature as well as the spread of mangrove reproduction, thereby influencing the distribution of mangroves (Zhang and Sui 2005). When it comes to administrative regions, Chinese mangroves are concentrated in eight provinces and regions, namely, Guangdong, Guangxi, Fujian, Hainan, Zhejiang, Taiwan, Hong Kong and Macau (Fig. 1). Among them, mangroves are naturally distributed in 7 provinces and regions except Zhejiang province, while mangroves are introduced in the south of Zhejiang province (Liao and Zhang 2014). The distribution of natural mangroves ranges from the north, which is Shachengwan (27°20'N) in Fuding county of Fujian province, to the south, which is Yulingang (18°09'N) in Sanya city of Hainan province (Zhang et al. 2006; Lin and Fu 1995). But the northern

limit of artificial introduction is Yueqing county in Zhejiang province (28°25'N) (Zhang and Sui 2005) (Fig. 1).

The area of mangrove resources in China

Historical dynamic changes of mangrove area in China

Different from mangrove wetland area, mangrove area accounts for approximately one-third of the former (Zhang et al. 1995), referring to the area of tidal flats covered by mangroves, excluding the area of light beach and the harbor seabed with a water depth not exceeding 6 m at low tide (Wang and Wang 2007; Yang et al. 2017a). There is not an exact and consistent record on the area of mangrove resources in China due to different investigation equipment and methods, and now the specific figure is still controversial. Scholars have given different figures after investigation and research, which also increases the difficulty of statistics and use. In this case, with the comprehensive utilization of relevant literature, government reports and materials, the area of Chinese mangroves in different periods were collated and summarized as shown in Table 1.

According to recorded data, the change of mangrove area has roughly gone through six stages in China (Table 1). In the first stage, Chinese mangrove area had reached up to 25×10^4 hm² in history (Zhang et al. 2006; Yang et al. 2017a; China Ocean 21st Century agenda action plan 1996). In the second

Fig. 1 Sketch map of mangroves distribution in China. ●
Note: mangroves

Table 1 The area of Chinese mangrove resources in different history periods

Stage	Source and Year	Guangdong	Guangxi	Fujian	Hainan	Zhejiang	Taiwan	Hong kong	Macau	Total (hm ²)
1	History (Zhang et al. 2006; Yang et al. 2017a; China Ocean 21st Century agenda action plan 1996)									25 × 10 ⁴
2	Survey of the source 1956 (China Ocean 21st Century agenda action plan 1996)	21,289	10,000	720	9992					4 × 10 ⁴
3	Forest resources survey 1956 (China Ocean 21st Century agenda action plan 1996)	4000	8000	368	4667					4.2 × 10 ⁴
3	Coastal vegetation survey 1986 (China Ocean 21st Century agenda action plan 1996)	8053	8014	416	4800					17,035
3	Coastal forest survey 1986 (China Ocean 21st Century agenda action plan 1996)	8200	4667	2000	4800		3333			21,283
4	Coastal topography survey 1988 (Chen and Huang 1995)	4667	6170	416	4836		120			23,000
4	Liao 1992 (Liao et al. 1992)	3813	5654	250	4836		300			16,209
4	Fan 1993 (Fan 1993)	3813	4523	260	4836	8	120	85	1	14,853
4	Lin 1995 (Lin and Fu 1995)	3526	5654	360	4836	8	120	85	1	13,646
4	He 1995 (He and Fan 1995)	3813	5654	360	4836	8	120	85	1	14,590
4	Zhang 1997 (Zhang et al. 1997)	3526	5654	360	4836	8	120	85	1	14,877
4	Lv 1998 (Lv 1998)	4000	5654	360	4836					15,000
5	Fang 2001 (Fang and Dan 2001)	9084.0	8374.9	615.1	3930.3	20.6	278	510	60	14,426.3
5	State Forestry Bureau 2001 (National mangrove resources survey report 2002)	4667	6170	416	4836		120			22,872.9
5	Shi 2002 (Shi 2002)	3813	5654	260	4836	8	120	263	1	15,000
5	Zhang 2006 (Zhang et al. 2006)	9414	8374.9	911.6	3930.3		21.5			22,652.3
5	Lv 2008 (Lv 2008)	9084	7066.4	615.1	4300	3.4			2.3	21,071.2
5	Fu 2009 (Fu et al. 2009)	9084	8375	615	3930	21	287	380	60	22,752
6	Chen 2009 (Chen et al. 2009)	10,616.8	9428.4	1399.7	4885.9	79.2				26,410
6	Lu 2010 (Lu et al. 2019)	12,130.9	6594.5	941.9	4891.2	19.9				24,578
6	Wu 2012 (Wu 2012)									34,472.14
6	Second National Resource Wetland Survey 2013 (Dan et al. 2016)	16,348	8425	3437	4033	268	485			32,996
6	Jia 2014 (Jia 2014)	19,751.23	8780.73	1184.02	4736.05	20.11				34,472.14
6	Dan 2016 (Dan et al. 2016)									

stage (the 1950s), the national resource survey confirmed that the area of mangroves was 4×10^4 or 4.2×10^4 hm^2 (China Ocean 21st Century agenda action plan 1996). In the third stage, the mangrove area sharply decreased in the 1980s, shrinking to the range of $1.7\text{--}2.3 \times 10^4$ hm^2 (China Ocean 21st Century agenda action plan 1996; Chen and Huang 1995). During the fourth stage, the area fluctuated from 13,646 to 16,209 hm^2 according to the publications in the 1990s (Zhang and Sui 2001). In the fifth stage, the survey carried out by the State Forestry Administration in 2001 revealed that the mangrove area was 22,872.9 hm^2 in China (National mangrove resources survey report 2002), which had been maintained at approximately 20,000 hm^2 in the following years. In the sixth stage, thanks to strict protection policies and positive artificial activities, the mangrove area has significantly increased since 2009, fluctuating between 24,578 and 34,472.14 hm^2 (Jia 2014; Dan et al. 2016; Wu 2012). The second national survey conducted by the State Forestry Administration from 2009 to 2013, revealed that the mangrove area in China was 34,472.14 hm^2 (Dan et al. 2016). As one of the participants, Dan (Dan et al. 2016) conducted a comprehensive analysis through this survey and provided a detailed description on the mangrove area in 2016. This offered several specific figures of several provinces and the total mangrove area in China, which are credible and of important reference value.

Current state of mangrove area in China

After the second national wetland resource survey in 2013, which determined the area of mangroves in China, there has not been any authoritative data update in the past years. The available data are relatively obsolete, which mostly stayed in 2014. The data showed in the latest published literature have large deviations. Few scholars have studied and judged the present area of mangroves in China. In the present study, we collected and sorted out relevant literature materials, filtered and determined the specific figures of mangrove area in each province and region, and calculated the total area in China. The area of mangroves in each province and region was determined by the latest, authoritative and credible data. First, the area data were determined by the latest reports, documents, and materials released by local governments, state agencies, and other authorities. Second, in the absence of authoritative

information, we searched the data by the latest publications. The data from the latest publications were required not to be far from the data given by Dan (Dan et al. 2016), since the latter was considered to be authoritative and credible. If there was a large deviation, the data offered by the latest publications would be discarded. At last, when neither of the above was satisfied, the data given by Dan (Dan et al. 2016) were accepted (Table 2).

According to the methods in Table 2, the mangrove area in eight provinces and regions was successively determined, and the total mangrove area in China was finally calculated. In more detail, the mangrove area in Guangdong province is the largest, accounting for more than half of the nation. Two published papers in 2018 provided new data of mangrove area in Guangdong province (Lan et al. 2018; Yang et al. 2018), but the deviation of several data was extremely large with low credibility. Therefore, it was considered that the mangrove area in Guangdong province should be 19,751.23 hm^2 proposed by Dan (Dan et al. 2016). Guangxi province is an important distribution of mangroves with an area of 8780.7 hm^2 according to Fan (Fan et al. 2018). Relevant studies and materials on the area of mangroves in Fujian province was relatively scarce, thus it was considered to be 1184.02 hm^2 proposed by Dan (Dan et al. 2016). Hainan province is the center of mangrove distribution in China where there is a rich variety of mangrove plants. According to the second survey report of wetland resources in Hainan province, the mangrove area is 4710 hm^2 (Yang et al. 2017a; Ding et al. 2015). The area of mangroves in Zhejiang and Taiwan provinces were considered to be 268 hm^2 and 485 hm^2 proposed by Jia (Jia 2014). The mangrove area in Hong Kong was deemed to be 510 hm^2 based on the latest data of the Agriculture, Fisheries and Conservation Department (AFCD) in 2014 (Yang et al. 2017a; Liao and Zhang 2014). Few materials mentioned the mangrove area in Macao, but it has been generally considered to be 60 hm^2 (Chen et al. 2009). In this way, the data of the eight provinces and regions were updated. Finally, the total mangrove area in China was calculated to be 35,749.25 hm^2 summed from each province and region (Table 3), which meets the fluctuating trend of mangrove area in recent years. Since the total mangrove area is the sum of each province and region, the data obtained by this method should be feasible with less error, and could reflect the current total area of mangroves in China.

Table 2 The methods for determining the present area of Chinese mangroves in each province and region

Order	Deterministic principle	Remarks
*1	Latest data released by the authorities	
*2	Data identified in the latest publications	Not far from *3
*3	Dan (Dan et al. 2016)	Have great reference value in the data of Guangdong, Guangxi, Hainan and Fujian.

Table 3 The area of mangrove resources in eight provinces and regions

Province	Mangrove Area (hm ²)	(LAT-LONG)	Basis (Table 2)
Hainan (Yang et al. 2017a; Ding et al. 2015)	4710.00	(20.03°N, 110.32°E)	*1
Guangxi (Fan et al. 2018)	8780.70	(22.82°N, 108.37°E)	*2
Guangdong (Dan et al. 2016)	19,751.23	(23.13°N, 113.27°E)	*3
Fujian (Dan et al. 2016)	1184.02	(26.08°N, 119.3°E)	*3
Zhejiang (Jia 2014)	268	(30.28°N, 120.15°E)	*2
Macau (Chen et al. 2009)	60.3	(22°14'N, 113°35'E)	*2
Hong Kong (Yang et al. 2017a; Liao and Zhang 2014)	510	(22.9°N, 113.52°E)	*1
Taiwan (Jia 2014)	485	(20.45°N, 119.18°E)	*1
Total	35,749.25		

The plants species of mangroves in China

Woody plants that grow in mangrove forests are deemed to be mangrove plants. Other herbaceous plants or lianas have been considered as mangrove companion plants (Fu et al. 2009). Mangrove plants can be divided into two types: exclusive mangroves that grow exclusively in intertidal zones, and non-exclusive mangroves that can grow in wetlands or on land, with amphibious characteristics (Lin and Fu 1995). There are 86 species (including varieties) of 30 genera in 24 families of mangrove plants in the world (Fu et al. 2009), divided into two central groups of the Western group and Eastern group (Lin 1981; Yang et al. 2017a). Chinese mangrove plants belong to the Eastern group in the district (Lin 1981), accounting for 43% of the global species and 50% of the Eastern group (Fu et al. 2009). At present, there are 38 species of 26 genera in the 22 families of Chinese mangrove species, including 27 species of exclusive mangrove species belonging to 15 genera in 13 families, and 11 species of non-exclusive mangrove species belonging to 11 genera in 9 families (Yang et al. 2017a; Fu et al. 2009; Liao and Zhang 2014) (Table 4).

The distribution and species of mangrove plants in each region are not uniform. Hainan province has the highest abundance of mangrove species, with up to 38 species in 21 families (Fu et al. 2009). There are 25 species in 15 families along the Guangdong coast (Liao and Zhang 2014; Xia 2014). Guangxi coastal area is located in the south of the tropic of Cancer and close to the Beibuwan Gulf, with 19 mangrove species in 14 families (Fu et al. 2009). In Fujian province, 18 species in 12 families of mangrove plants are distributed, growing mainly in the estuary of the Jiulongjiang River (Liao and Zhang 2014; Wu 2012). In Zhejiang province, mangrove species is mainly distributed in the south of Yueqing Bay (Qian 2010), in which only one exclusive mangrove plant, an artificially introduced species *K. obovata*, is growing (Liao and Zhang 2014; Du et al. 2004). There are 16 species of

mangrove plants in Taiwan, 15 species in Hong Kong, and 8 species in Macau (Yang et al. 2017a; Fu et al. 2009) (Table 4, Fig. 2).

Problems and challenges of mangrove resources

Problems and challenges in the historical dynamic process

Problems and challenges of mangrove area

The area of Chinese mangroves changed dramatically throughout the historical dynamic process (Fig. 3). The area once reached up to 25×10^4 hm² in history (Zhang et al. 2006; Yang et al. 2017a; China Ocean 21st Century agenda action plan 1996). In 1956, the mangroves covered 4.2×10^4 hm² (China Ocean 21st Century agenda action plan 1996) but sharply decreased since then. By 1986, the area reduced to 21,283 hm² (China Ocean 21st Century agenda action plan 1996), at a decreasing rate of 49.3%. And merely 14,877 hm² mangroves remained in 1997 (Zhang et al. 1997), with a decreasing rate of 30.1%. In the past 50 years, nearly two-thirds of Chinese mangroves have disappeared due to the over exploitation and improper human activities, such as urbanization and deforestation. Until the end of the twentieth century, the protection of mangrove resources was taken seriously, and the government began to take measures. As a consequence, the area of mangroves began to gradually increase, reaching 22,872 hm² in 2001 (National mangrove resources survey report 2002). After 2009, the government attached greater importance to mangrove protection and restoration. A series of mangrove ecological restoration projects were implemented (Dan et al. 2016), nature reserves were set up, and public protection awareness was also enhanced, resulting in a steady increase of mangrove area in China. By 2013, Chinese mangroves was significantly recovered and improved, with an area

Table 4 Species and distribution of mangrove plants in China

Family	Species	Hainan	Guangdong	Guangxi	Taiwan	HongKong	Macau	Fujian	Zhejiang
Exclusive mangroves									
Rhizophoraceae	<i>Bruguiera gymnoihiiza</i>	+	+	+	–	+		+	
	<i>Bruguiera sexangula</i>	+	Δ					Δ	
	<i>B. s. var. rhynchopetala</i>	+	Δ					Δ	
	<i>Ceriops tagal</i>	+	–	–	–				
	<i>Kandelia candel</i>	+	+	+	+	+	+	+	Δ
	<i>Rhizophora apiculata</i>	+							
	<i>Rhizophora stylosa</i>	+	+	+	+	–		Δ	
Acrostichaceae	<i>Acrostichum aureum</i>	+	+	+	+	+	+	–	
	<i>Acrostichum speciosum</i>	+							
Acanthaceae	<i>Acanthus ebracteatus</i>	+	+	+					
	<i>Acanthus ilicifolius</i>	+	+	+		+	+	+	
Combretaceae	<i>Lumnitzera littorea</i>	+							
	<i>Lumnitzera racemosa</i>	+	+	+	+	+	+	Δ	
	<i>Laguncularia racemosa</i>	Δ	Δ					Δ	
Euphorbiaceae	<i>Excoecaria agallocha</i>	+	+	+	+	+		–	
Meliaceae	<i>Xylocarpus granatum</i>	+							
Myrsinaceae	<i>Aegiceras corniculatum</i>	+	+	+		+	+	+	
Palmae	<i>Nypa fruticans</i>	+							
Rubiaceae	<i>Scyphiphora</i>	+							
Sonneratiaceae	<i>Sonneratia alba</i>	+							
	<i>Sonneratia caseolaris</i>	+	Δ						
	<i>Sonneratia hainanensis</i>	+							
	<i>Sonneratia ovata</i>	+							
	<i>Sonneratia paracaseolaris</i>	+							
	<i>Sonneratia apetala</i>	Δ	Δ	Δ				Δ	
Verbenaceae	<i>Avicennia marina</i>	+	+	+	+	+	+	+	
Sterculiaceae	<i>Heritiera littoralis</i>	+	+	+	+	+		Δ	
Non-exclusive mangroves									
Barringtoniaceae	<i>Barringtonia racemosa</i>	+			+			Δ	
Apocynaceae	<i>Cerbera manghas</i>	+	+	+	+	+	+	Δ	
Bignoniaceae	<i>Dolichandrone spathacea</i>	+	+						
Compositae	<i>Pluchea indica</i>	+	+	+	+	+	+	+	
Hernandiaceae	<i>Hernandia sonora</i>	+							
Leguminosae	<i>Pongamia pinnata</i>	+	+	+	+	+			
Lythraceae	<i>Pemphis acidula</i>	+			+				
Malvaceae	<i>Hibiscus tiliaceus</i>	+	+	+	+	+		+	
	<i>Thespesia populnea</i>	+	+	+	+	+		Δ	
Verbenaceae	<i>Premna obtusifolia</i>	+	+	+	+				
	<i>Clerodendrum inerme</i>	+	+	+	+	+	+	+	

+ natural distribution; Δ introduction; – extinction

of 34,472.14 hm² (Dan et al. 2016). Unfortunately, although consequences of mangrove destruction have been prevented and some measures have been taken, the destruction driven by local interests and short-term benefits still occurs from time to time with the difficulty in stopping (Dan et al. 2016). This

situation places a severe test and arouses great attention on the protection of mangrove resources. Hence, the historical dynamic process of the mangrove area may play a warning role, reminding people should take it seriously and conduct mangrove protection approach urgently.

Fig. 2 Species number of mangrove plants in each region

Problems and challenges of mangrove plants

By analyzing the species and distribution of mangrove plants in China (Table 5), it could be inferred that five species of mangrove plants show signs of extinction in certain regions, which should be given great attention. In Guangdong, Guangxi and Taiwan, *Ceriops tagal* displays the signs of extinction. Several species have been extinct in some regions, for example, *Rhizophora stylosa* has been extinct in Hong Kong, *Bruguiera gymnohiza* extinct in Taiwan, and *Acrostichum aureum* and *Excoecaria agallocha* extinct in Fujian. Although the extinction of species in a certain region may be caused by a variety of reasons, some enlightenment could still be gained by analyzing the extinction trajectory. For example, we should avoid irrational development and utilization of the economic species, reinforce the protection of resources in the vicinal region, and strengthen the monitoring and management of a certain mangrove plant. These lessons

may play a positive role in the protection of mangrove resources.

In addition, some mangrove species have gradually declined into endangered species because the rapid economic development, huge environmental changes and excessive interference from human activities have seriously affected the living environment of mangrove plants (Zhong et al. 2011). According to the 2001 IUCN Red Book Rating and Standard System published by the International Union for Conservation of Nature and Natural Resources (IUCN), a species is considered endangered when it has fewer than 250 mature individuals within its population. Endangered species are classified into different endangered grades according to the degree of endangerment. At present, 14 mangrove plant species are classified as endangered into different grades in China (Table 6), of which *Lumnitzera littorea* and *Xylocarpus granatum* have been classified as national secondary protected plants. The extinction of a species means the loss of genetic diversity

Fig. 3 The historical dynamic changes of the area of Chinese mangroves

Table 5 Extinction of Chinese mangrove plants in some regions

Mangrove plant species	Extinct regions	Number
<i>Ceriops tagal</i>	Guangdong, Guangxi, Taiwan	3
<i>Rhizophora stylosa</i>	Hong Kong	1
<i>Bruguiera gymnohiza</i>	Taiwan	1
<i>Acrostichum aureum</i>	Fujian	1
<i>Excoecaria agallocha</i>	Fujian	1

and biodiversity, which will directly lead to an irreparable loss such as the destruction of ecological balance. It is of great theoretical and practical significance to recognize the endangered species of mangrove plants and implement special management to protect them. For the protection of biodiversity and the maintenance of ecological balance, it is also important to propose efficient restoration measures (Zhong et al. 2011).

Threats and challenges in the future

Chinese mangroves are distributed in 8 provinces and regions along the seacoast with abundant mangrove resources and great natural advantages. In recent years, due to the enhancement of protection awareness and the implementation of protection measures, the development of mangrove resources has showed a positive trend. However, with the development of society and the improvement of R&D technology, new functions and values of mangroves have been continuously exploited such as the discovery and application of medicinal values, which may bring new challenges. In addition, great development potential with inestimable economic benefits has placed demands on resource reserves, which are likely to lead to the re-destruction of resources. For example, the development of international tourism islands has led to the

deforestation of mangroves. Dongzhaigang Mangrove Nature Reserve in Hainan province has suffered severe damage in tourism development. What's more, the existing mode of management and protection remains incomplete and the deficiencies will pose a severe test for it in the future. Mangrove conservation is a long-term benign operation rather than a fragmented one. Therefore, the existing mode should be constantly improved, and the effective protection and management should not be ignored.

Protection status and problems of Chinese mangroves

Mangrove resources have great ecological, economic and social values, but there are still some problems and threats in the future. The protection of mangrove resources is particularly important, and it is necessary to actively take relevant actions. In fact, as early as the Qing dynasty, China, the idea of mangrove protection has already existed. However, it was not until the reform and opening up, a series of measures have been taken by the Chinese government, such as strengthening ecosystem research, establishing nature reserves, and requiring mangrove protection in national key ecological and economic development plans (Fang and Dan 2001). Mangrove nature reserves are established to protect mangrove wetland including the area of tidal flats covered by mangroves, light beach and the harbor seabed with a water depth not exceeding 6 m at low tide. At present, China has established 37 nature reserves, including 7 national, 6 provincial, and 24 local nature reserves (Table 7). The area of mangrove nature reserves has reached to 99,972.82 hm².

Although mangroves have been protected through the establishment of nature reserves, destruction and inappropriate

Table 6 Endangered species of mangrove plants in China

Family	Species	IUCN	Protection grade
Rhizophoraceae	<i>Ceriops tagal</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	NT	
Acrostichaceae	<i>Acrostichum speciosum</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	CR	
Acanthaceae	<i>Acanthus ebracteatus</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	NT	
Combretaceae	<i>Lumnitzera littorea</i> (China Red List of Biodiversity (Higher Plant Volume) n.d. ; List of China's Rare and Endangered Plants (summary) n.d.)	VU	National II
Meliaceae	<i>Xylocarpus granatum</i> (List of China's Rare and Endangered Plants (summary) n.d.)	LC	National II
Palmae	<i>Nypa fructicans</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	VU	Provincial-Hainan
Sonneratiaceae	<i>Sonneratia alba</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	VU	
	<i>Sonneratia caseolaris</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	NT	
	<i>Sonneratia hainanensis</i> (China Red List of Biodiversity (Higher Plant Volume) n.d. ; List of China's Rare and Endangered Plants (summary) n.d.)	CR	
	<i>Sonneratia paracaseolaris</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	NT	
Lecythidaceae	<i>Barringtonia racemosa</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	EN	
Sterculiaceae	<i>Heritiera littoralis</i> (China Red List of Biodiversity (Higher Plant Volume) n.d.)	VU	Provincial-Hainan, Guangxi

CR Critically Endangered, EN Endangered, VU Vulnerable, NT Near Threatened, LC Least Concern

Table 7 Mangrove nature reserves in China

Name of reserve	Administrative regions	Founding time	Area (hm ²)	Grade
Dongzhaigang	Haokou, Hainan	1980 (B)	3337	A
		1986 (A)		
Qinglan	Wenchang, Hainan	1981	2904.5	B
Yalongwan Qingmeigang	Sanya, Hainan	1989	156	C
Sanyahe	Sanya, Hainan	1992	343.83	C
Xinying	Danzhou, Hainan	1992	115.4	D
Huangchangwan	Chengmai, Hainan	1995	150	D
Caiqiao	Lingao, Hainan	1986	350	D
Tielugang	Sanya, Hainan	1999	292	C
Zhanjiang	Zhanjiang, Guangdong	1990 (B)	19,300	A
		1997 (A)		
Futian	Shenzhen, Guangdong	1984 (B)	815	A
		1988 (A)		
Qi'ao	Zhuhai, Guangdong	1989	7373.77	B
Taishan	Taishan, Guangdong	2000	119.33	D
Dianbai	Dianbai, Guangdong	1999	1950	C
Huidong	Huidong, Guangdong	1999	533.33	C
Chengcunhaoguang	Yangxi, Guangdong	2000	1000	D
Enping	Enping, Guangdong	2005	700	D
Shantou	Shantou, Guangdong	2001	10,333.33	C
Dapengbandao	Shenzhen, Guangdong	2010	14,622	C
Wulinanshan	Xuwen, Guangdong	1997	7	D
Xinliaoluntou	Xuwen, Guangdong	1997	309	D
Maogang	Maoming, Guangdong	2001	800	D
Nanduhekou	Leizhou, Guangdong	2003	200	D
Ganglie	Yangjiang, Guangdong	2005	40	D
Pinggang	Yangjiang, Guangdong	2005	800	D
Shankou	Hepu, Guangxi	1990	8000	A
Beilunhekou	Fangchenggang, Guangxi	1990 (B)	3000	A
		2000 (A)		
Maowei hai	Qinzhou, Guangxi	2005	3454	B
Zhangjiangkou	Yunxiao, Fujian	1992 (B)	2360	A
		1998 (A)		
Jiulongjiangkou	Longhai, Fujian	1988	420.2	B
Quanzhouwanhekou	Quanzhou, Fujian	2002	7008.84	B
Huansandao	Ningde, Fujian	1997	2406.29	C
Ximendao	Wenzhou, Zhejiang	2005	3080	A
Danshuihekou	Taipei, Taiwan	1986	50	B
Guandu	Taipei, Taiwan	1988	19	C
Beimen	Tainan, Taiwan	1986	3188	D
Maipo	Maipo, Hongkong	1975	380	E
Cotai	Macau	2003	55	F
Total: 37	A: 7 B: 6 C: 9 D: 13 E: 1 F: 1		99,972.82	

(1) A: National; B: Provincial; C: Civic; D: County level; E: Hong Kong F: Macau (2) Data compiled from the "2015 Nature Reserves List of the Ministry of Environmental Protection of People's Republic of China"

exploitation still occur from time to time (Li 2007), and there are deficiencies in the mangrove protection and management in China. (1) The approach of mangrove protection is one-sided and isolated, resulting in the weak capacity of integrated

protection and management. All the time, mangrove protection and management involve many subjects such as the Forestry Department, the Marine Department and the Agricultural Department (Ding et al. 2018). Each department

Table 8 Proposed strategies for Chinese mangroves protection with advantages and disadvantages

Strategy		Advantages	Disadvantages
Strengthen the publicity and education of mangrove ecological functions for better protection		<ul style="list-style-type: none"> ▪ Various, flexible and operable methods ▪ Wide influence, easy to be accepted ▪ Lasting and long-term influence 	<ul style="list-style-type: none"> ▪ Long time, work slowly
Strengthen protection technology research and accelerate the process of ecological restoration	Protection Technology	<ul style="list-style-type: none"> ▪ Direct effects on mangroves ▪ Guidance for further study 	<ul style="list-style-type: none"> ▪ Certain degree of difficulty ▪ Long time ▪ High input costs
	Ecological Restoration	<ul style="list-style-type: none"> ▪ Practical and effective results 	<ul style="list-style-type: none"> ▪ Many variable factors ▪ Many requirements for material and manpower resources.
Formulate and improve relevant laws and regulations to form a sound legal system		<ul style="list-style-type: none"> ▪ Make the protection more targeted and effective ▪ Alerts and penalties work better ▪ Guide people to participate in mangrove protection 	<ul style="list-style-type: none"> ▪ Take some time ▪ Involve many departments ▪ May be disputable over the scope of the violations and the intensity of the punishments.
Establish a mangrove protection network for comprehensive protection and management		<ul style="list-style-type: none"> ▪ Comprehensive, systematic and dynamic monitoring for better protection ▪ Strong support for future study ▪ Upgraded and improved sub-network and technologies 	<ul style="list-style-type: none"> ▪ Complicated in technology, wide in scope, and various in requirements ▪ Long way to go

independently and separately protects and manages mangroves depending on its own responsibility. With many drawbacks, the fragmented approach cannot meet the characteristics of mangrove ecosystem, resulting in inefficiency. In 2018, the Forestry and Grassland Bureau of the Ministry of Natural Resources was established to integrate the management departments of natural factors, and subsequently, mangroves began to be integrally managed (Ding et al. 2018). Since this institution has just been established, the capability of comprehensive protection and management remains to be observed. In a word, a scientific and effective system still needs work. (2) The laws and regulations on mangrove protection and management are unsound, and a clear and complete legal mechanism has not been formed yet. China has not carried out special legislation on mangrove protection and management at the national level instead of relying on the scattered clauses mentioned in the relevant laws about forests and mangroves, which are rather disordered (Ding et al. 2018). Hence, these unsound laws and regulations have affected the further protection of mangrove resources. (3) It is still a long way to go for mangrove protection and management in nature reserves, such as scientific research, reserve construction, technical improvement, and manager education. There is a lack of scientific research in a nature reserve on mangrove species, ecological environment, and reserve management. The construction capacity of nature reserves remains insufficient and the supervision and management are lagging behind. What's more, the technical and educational level of managers working in mangrove nature reserves needs to be improved. Managers are generally lacking in technological skills, which has become one of the bottlenecks that restrict the

development of mangrove protection in China. It is necessary to cultivate a team that is good at science, technology, management and publicity (Wang 2013). (4) The awareness of mangrove protection in China is relatively insufficient, which is one of the important reasons for the destruction of mangrove resources. Thought could guide behavior, therefore publicity and education need to be strengthened to enhance the awareness of mangrove protection. All of the above factors are hindrances to the protection and management of mangrove resources.

Protection strategies for Chinese mangroves

The threats to mangrove resources and challenges to resources protection have seriously impacted Chinese mangroves. Therefore, it is of great practical significance to execute targeted, efficient and long-lasting protection strategies for mangroves. Based on the resource status and problems of Chinese mangroves, we proposed reasonable strategies to protect mangrove resources (Table 8). The advantages and possible obstacles of each strategy were also analyzed correspondingly.

Strengthen the publicity and education of mangrove ecological functions for better protection

Mangrove resources have many functions with great values, playing a crucial role in the maintenance of coastal ecosystems. Protecting mangroves are not only necessary for the survival of our generation, but also meet the demands of future

generations in a sustainable way. Mangroves had been extensively logged before people realized their importance (Gan 2019), therefore, the enhancement of protection awareness is the key to resource protection. Publicity and education activities (Table 8) should be actively carried out to raise public protection awareness. For example, personnel training (Pei 2010), community preaching (Huang 2017), mangrove tourism and media publicity (Gan 2019; Chen et al. 2017; Huang et al. 2018) may help people better understand the great ecological functions and values of mangrove resources (Ba et al. 2017; Gan 2019; Chen et al. 2017; Jin et al. 2005) contributing to mangrove protection.

There are many advantages in the way of strengthening publicity and education of mangrove ecological functions (Table 8). Methods used for publicity and education are various, flexible and operable. The goal of publicity and education could be achieved by the ways of media propaganda, community outreach, and tourism activities. Publicity and education could bring a strong and wide influence in the masses. The activities are easy to be organized at any time, place or crowd and easy to be accepted by the masses. For example, mangrove tourism could introduce more people the ecological functions, ecological benefits, and landscape benefits of mangroves (Li et al. 2019). What's more, compared with a specific measure, publicity and education could enhance the public protection awareness, bringing a lasting and long-term influence. Of course, there is a probable obstacle in the implementation of this strategy (Table 8). In view of the difficult process to change or establish a standpoint, it may take a long time to achieve the actual effect through publicity and education. What's the matter, this strategy could help people more appreciate the ecological value of mangrove resources (Ba et al. 2017), increase the awareness of mangrove protection, and spontaneously carry out protection action (Yao et al. 2010; Yu et al. 2019). The change in the perception of ecological protection and the enhancement of protection awareness could bring a long-term and sustainable impact, which is the fundamental way to protect mangroves.

Strengthen protection technology research and accelerate the process of ecological restoration

The mangrove is a unique land-ocean ecosystem. It is therefore necessary to thoroughly investigate the present status of mangrove resources, succession processes, degeneration mechanisms, and restoration technology (Huang 2017; Govindan and Kathiresan 2015). It is also essential to strengthen the research of technologies for mangrove resources conservation (Ba et al. 2017; Saenger et al. 1983). The technologies for mangrove wetland conservation include high-throughput sequencing technologies, mangrove restoration engineering, embryonic implantation methods, and nursery-reared seedlings techniques (Basel et al. 2013; Li

et al. 2013). In further works, tissue culture technology and molecular biotechnology should be applied for the breeding and seedling cultivation of mangrove plants (Duan and Xu 2004). It will also be important to explore strategies for preventing and mitigating ecological invasions (Yang et al. 2017a; Duan and Xu 2004; Feng et al. 2018; Qiu et al. 2019). The goal of resource protection may be achieved by mastering the characteristics of mangrove resources, strengthening protection techniques, and adopting correct protection methods (Huang et al. 2010).

It is necessary to actively carry out the ecological restoration of mangrove wetlands, which is of vital significance for the recovery of mangrove ecosystems (Duan and Xu 2004). Before carrying out ecological restoration, a comprehensive and in-depth investigation should be conducted to understand the cause of the problem. Then, appropriate methods and measures should be selected based on the local conditions (Yang et al. 2017b). In reality, many mangrove areas have been usurped as ponds for aquaculture, and have been inappropriately divided or obstructed by reclamation projects, such as sea walls and coastal roads. Supporting measures should be adopted to restore the mangroves, such as conceding ponds to forests (Huang et al. 2018; Yang et al. 2017b; Zheng 2010), opening gates to irrigate (Huang 2017; Duan and Xu 2004), replanting (Yang et al. 2017b), and establishing biological corridors (Duan and Xu 2004; Zheng 2010). Mangrove plantation areas need to be identified in the exposed coastal beaches of tidal zones that are suitable for mangrove growth according to tidal levels, tidal velocity, tidal cycles, seawater salinity and basement properties (Duan and Xu 2004). Suitable seeds and seedlings also need to be selected and planted. Appropriate techniques should be adopted to enhance mangrove survival rates (Zheng 2010). If these measures are correctly applied, the regeneration of mangrove ecosystems could be successfully achieved.

Of course, the strategy to strengthen protection technology research and accelerate the process of ecological restoration has both advantages and disadvantages (Table 8). In terms of technology research, the research results could be directly applied to the protection of mangrove resources. For example, the researches on seedling optimization, disease control and other related technologies could improve the survival rate of mangrove seedlings. These technical studies may provide guidance for further protection and development. But it also has shortcomings from the perspective of technical research, such as the certain difficulty of the research work, the long time required, and high input costs. In terms of ecological restoration, it is a method to protect mangroves through practical actions. The advantages are that the repair behavior is practice-oriented, and the actual operation could lead to practical and effective results. But the shortcomings also exist. The actual restoration works may be cumbersome and complicated, which need to meet local conditions. So there are many

variable factors to conduct restoration work and there are also many requirements for manpower and material resources.

Formulate and improve relevant laws and regulations to form a sound legal system

In China, there is no a law specialized in mangrove protection and management at present (Ding et al. 2018; Zeng 2014) instead of relying on the scattered clauses mentioned in relevant laws (Ma 2004; Wang 2014). The existing laws and regulations concerning mangrove protection, such as the Forest Law, the Marine Environmental Protection Law, and the Regulation on Administration of Reserves Ordinance (Ma 2004; Ding et al. 2018; Mei and Xue 2011; Lu 2004), still have shortcomings and need to be improved. In a word, a comprehensive and sound legal system focusing on mangroves has not been established yet. In order to deal with these problems, the national administrative organizations for marine protection should speed up the formulation and improvement of corresponding laws and regulations. Therefore, several suggestions were proposed in present study. First of all, specialized national legislation for mangrove protection should be carried out (Ma 2004; Zeng 2014; Mei and Xue 2011). It is suggested that practical encouraging and guiding clauses should be added to the legislation, instead of merely using prohibitive clauses as the whole content of laws and regulations (Ma 2004). For some conflict legal provisions caused by non-standard legislation, it is proposed to amend and improve the relevant contents (Ma 2004). Each mangrove natural reserve should formulate its regulations based on its own features to effectively protect mangroves (Mei and Xue 2011). Subsequently, the public participation mechanism should be improved (Zeng 2014; Mei and Xue 2011). Subjects and procedures of public participation for mangrove protection should be clarified in relevant regulations and resolutions (Wang 2014). Finally, the comprehensive legislation for mangrove protection should be implemented with the combination of laws and regulations in economy, administration, and management.

With the effect of mandatory restraint, laws and regulations clarify the code of conduct in the form of legal provisions. There are irreplaceable meanings through formulating and improving relevant laws and regulations to protect mangroves (Table 8). The scope of mangroves could be clarified by specialized legislation to make resource protection more targeted and effective. The behavior of destroying mangroves will be punished according to relevant legal provisions. Alerts and penalties may work better to protect mangrove resources. The inclusion of encouraging clauses and the improvement of public participation mechanism will contribute to guiding the public to actively participate in mangrove protection. Inevitably, there are certain weaknesses for protecting mangrove resources through this strategy (Table 8). Involving a

range of departments, the legislation sometimes takes a long time and the procedure is usually complicated. As for the destruction of mangroves, it is likely to be disputable over the scope of the violations and the severity of the punishments. Although there are some difficulties in formulating and improving relevant laws and regulations, its importance is beyond doubt. It is still of great practical significance to form a comprehensive and efficient legal system as soon as possible.

Establish a mangrove protection network for comprehensive protection and management

Comprehensive protection and management is an effective means to protect mangroves. This is a special way for protecting mangroves. The action is implemented according to the objective features of resources, combined with the actual situation of resources, designed by drawing lessons from administrative, economic, legal and other means, and based on scientific decision-making. To achieve this goal, an integrated management plan should be designed with the concept of ecological economics and eco-economic management (Possingham et al. 2015). A mangrove resources protection network system is necessary to be established. Legal and economic means, including taxation, fines, funds, and financial aids, should also be used to adjust the economic relationships between various economic organizations in marine activities (Li 2007). The crucial link is the establishment of a multidimensional network system for mangrove protection, including mangrove natural reserves network (Pei 2010; Duan and Xu 2004; Lin and Liu 2003), coastal integrated management network (Duan and Xu 2004), and scientific and technological information network (Duan and Xu 2004). Some actions should be conducted, such as carrying out scientific research on mangrove species, ecological environment and management (Pei 2010), establishing and improving an ecological monitoring system (Wang 2013; Yu et al. 2019), and establishing an integrated protection information system for mangrove resources (Wang 2007). Comprehensive protection and management in this way will effectively protect mangrove resources (Duan and Xu 2004).

The establishment of protection network could be conducive to realize the effective protection of mangroves. Therefore, this strategy has some outstanding merits (Table 8). It is possible to conduct comprehensive, systematic and dynamic monitoring for better protection and management by multidimensional protection network. It is also feasible to collect a large number of data through the protection network, which could be used for both decision making and future study on mangrove resources. The establishment of such network system which is composed of multiple sub-networks may promote the improvement and upgrading of related technologies. Of course, the comprehensive protection network is required to integrate related sub-networks, which is

complicated in technology, wide in scope, and various in requirements. Currently, this network has not been established completely in China. Even though establishing a mangrove protection network for comprehensive protection and management is considered to be effective and positive, there is still a long way to go. What cannot be denied is that this strategy is of strategic significance, and is still an important method to protect mangroves in the future.

Acknowledgments The supports of fund projects are gratefully acknowledged. Thanks for the reviewers and editors who provided valuable comments and suggestions for revising this paper.

Funding This research was funded by the National Social Science Fund Major Project of China, grant number 16ZDA049; the National Natural Science Fund Major Project of China, grant number 41830535; and the Ocean Strategic Planning and Economic Research Project of China, grant number CAMA201817.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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References

- Ba WY, Tian H, Geng L (2017) The ecological value of mangroves and its protection. *Agricultural Technology Service*: 34, 92. <https://dwz.cn/xOpQj8gl>
- Basel K, Ganesan P, Nina VF (2013) Identification and analysis of red sea mangrove (*Avicennia marina*) microRNAs by high-throughput sequencing and their association with stress responses. *PLoS One* 8: e60774. <https://doi.org/10.1371/journal.pone.0060774>
- Chang YZ, Ding SB (2013) The disappearance of mangroves: ecological pain. *Ecol Econ* 11:18–23. <https://doi.org/10.3969/j.issn.1671-4407.2013.11.003>
- Chen SP (1980) Chinese mangroves. *For Sci Technol*:21–24. <https://doi.org/10.13456/j.cnki.lykt.1980.11.010>
- Chen JY, Huang JS (1995) Chinese coastal landscape. Ocean Press, Beijing
- Chen L, Wang W, Zhang Y, Lin G (2009) Recent progresses in mangrove conservation, restoration and research in China. *J Plant Ecol* 2:45–54. <https://doi.org/10.1097/00019052-200502000-00004>
- Chen M, Chen SQ, Chen CH, Chen XH, Cai ZF, Wu ZJ, Zhang GX, Yao HJ (2017) Research on conservation and sustainable utilization of lagoon resources around Hainan Island. *Trans Oceanol Limnol*: 107–114. <https://doi.org/10.13984/j.cnki.cn37-1141.2017.04.013>
- China Ocean 21st Century agenda action plan (1996) China oceanic administration: Beijing, China
- China Red List of Biodiversity (Higher Plant Volume) (n.d.) Available online: <http://rep.iplant.cn/protlist/4>
- Dan XQ, Liao BW, Wu ZB, Wu HJ, Bao DM, Dan WN, Liu SH (2016) Resources, conservation status and main threats of mangrove wetlands in China. *Ecol Environ Sci* 25:1237–1243. <https://doi.org/10.16258/j.cnki.1674-5906.2016.07.021>
- Ding DJ, Li M, Liao BW, Dan XQ (2015) Evaluation of economic value of coastal natural wetland ecosystem services of Hainan province. *Ecol Environ Sci* 24:1472–1477. <https://doi.org/10.16258/j.cnki.1674-5906.2015.09.008>
- Ding XQ, Zhang JW, Ye HL (2018) Comparison and reference of mangrove conservation management in China and Vietnam. *Environ Sustain Dev* 43:73–76. <https://doi.org/10.19758/j.cnki.issn1673-288x.2018.03.021>
- Dong ZY (2001) Discussion on mangrove resources and protection countermeasures in China. *East China Forest Management* 15:37–39. <https://doi.org/10.3969/j.issn.1004-7743.2001.02.013>
- Du Q, Chen ZH, Sun MJ, Zhu GG, Ying BG (2004) Investigation on mangrove resource and development plan in Zhejiang province. *For Invent Plan* 29:9–12 <https://dwz.cn/Pzhedg2V>
- Duan SS, Xu JL (2004) Functions of mangrove wetlands in the conservation of the coastal ecosystems. *Ecologic Science* Nov 23:351–355. <https://doi.org/10.3969/j.issn.1008-8873.2004.04.016>
- Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K, Berger U, Cannicci S, Diele K, Ewelk C, Field CD et al (1998) A world without mangroves? *Science* 317:41–43 <http://hub.hku.hk/handle/10722/219542>
- Fan HQ (1990) The ecological economic value of mangroves and its crisis and countermeasures. *Resour Sci* 55-58:46 <https://dwz.cn/TMpRBMbt>
- Fan HQ (1993) The necessity of establishing the “China mangrove research center” and the task of the center. *Journal of Guangxi Academy of Sciences* 9:122–129. <https://doi.org/10.13657/j.cnki.gkxxyxb.1993.02.017>
- Fan HQ, Wang WQ (2017) Some thematic issues for mangrove conservation in China. *Journal of Xiamen University (Natural Science)* 56: 323–330. <https://doi.org/10.6043/j.issn.0438-0479.201612003>
- Fan HQ, Lu L, Yan B (2018) Evolution history and research processes of Guangxi mangroves *Guangxi Sci* 25: 343–351,449. <https://doi.org/10.13656/j.cnki.gkx.20180907.001>
- Fang BX, Dan XQ (2001) Chinese mangrove resources and protection. *Central South Forest Inventory and Planning* 20: 25–30,33. <https://doi.org/10.3969/j.issn.1003-6075.2001.03.009>
- Feng JX, Huang Q, Xu H, Shen QQ, Huang JR, Li ZF (2018) Effects of *Spartina alterniflora* invasion on benthic faunal community in saltmarsh and mangrove wetland. *Chinese Journal of Ecology* 37: 943–951. <https://doi.org/10.13292/j.1000-4890.201803.012>
- Fu XM, Wang CY, Shao CL, Han L, Wu YF, Wu HS, Qian SB, Guan HS (2009) Endangered and rare species of marine medicinal organisms and their protection in China. *Periodical of ocean university of China* 39: 719–728, 734. <https://doi.org/10.16441/j.cnki.hdx.2009.04.027>
- Gan JJ (2019) Discussion on the value and protection of mangrove wetland ecosystem. *J Green Sci Technol*:46–47. <https://doi.org/10.16663/j.cnki.lskj.2019.12.017>
- Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob Ecol Biogeogr* 20: 154–159. <https://doi.org/10.1111/j.1466-8238.2010.00584.x>
- Govindan T, Kathiresan K (2015) Vegetative propagation of salt excreting mangrove species *Aegiceras corniculatum*, *Avicennia marina* and *Avicennia officinalis*. *Int J Adv Res Biol Sci* 2:1–6 <https://dwz.cn/y4Hh47DI>

- Guo YX (2018) The eco-economic value of mangrove forests in the Beibuwan gulf, Guangxi. *Heilongjiang Science* 9:42–45,49 <https://dwz.cn/wPqPpy8S>
- He HM, Fan HQ (1995) Current status of mangrove protection and management in China. *Chinese mangrove research and management*. Science Press, Beijing
- He BY, Fan HQ, Wang M, Zhang LH, Wang WQ (2007) Species diversity in mangrove wetlands of China and its causation analyses. *Acta Ecol Sin* 27:4859–4870. <https://doi.org/10.3321/j.issn:1000-0933.2007.11.056>
- Heru S, Yoshifumi T, Mitsuyasu Y (2017) The opportunity cost of labor for valuing mangrove restoration in Mahakam Delta, Indonesia. *Sustainability* 9:2169. <https://doi.org/10.3390/su9122169>
- Huang YC (2017) Present situation and management countermeasures of mangrove wetland protection in Dongzhaigang. *Trop For* 45:49–52. <https://doi.org/10.3969/j.issn.1672-0938.2017.02.014>
- Huang L, Wang M, Wang WQ (2010) The definition of mangrove forest and protection of mangrove wetland. *Wetl Sci Manag* 6:45–48 <https://dwz.cn/RW1dYSMH>
- Huang XL, Zhang T, Tan RG (2018) The studies on current status and pre-warning mechanism of mangroves in Hainan. *Journal of Jiangxi Normal University (Natural Science)* 42:236–241. <https://doi.org/10.16357/j.cnki.issn1000-5862.2018.03.04>
- Jia MM (2014) Remote sensing analysis of China's mangrove forests dynamics during 1973 to 2013. Doctor, University of Chinese Academy of Sciences. <https://dwz.cn/OJS1pdrz>
- Jiang LL (1980) Unique aquatic ecosystem—mangroves. *Tropical Geography* 16. <https://doi.org/10.13284/j.cnki.rddl.001641>
- Jin BM, Chen SB, Ai WM (2005) Mangrove wetland resources and its protection and development in Wenzhou, Zhejiang. *J Hydroecol*: 61–63. <https://doi.org/10.15928/j.1674-3075.2005.02.026>
- Joffre OM, Bosma RH, Bregt AK, van Zwieten PAM, Bush SR, Verreth JAJ (2015) What drives the adoption of integrated shrimp mangrove aquaculture in Vietnam? *Ocean Coast Manag* 114:53–63. <https://doi.org/10.1016/j.ocecoaman.2015.06.015>
- Lan GZ, Luo XL, Lan SP (2018) Discussion on the status quo of mangroves in Guangdong and forestry ecological construction. *Rural Economy and Science-Technology* 29: 38–39. <https://dwz.cn/IvblbFm>
- Li J (2007) Protection and Management of mangrove wetland ecosystem in China. Proceedings of the 11th annual conference of the Chinese society of mineral rock and geochemistry, Chinese Society of Mineral Rock Geochemistry, Beijing, China. <https://dwz.cn/Qc40XMnT>
- Li N, Chen PM, Qiao PP, Qin CX (2013) Research advances on marine ecological effect and repair techniques of coastal mangrove wetland. *Guangdong Agric Sci* 157–160:167 <https://dwz.cn/hdtrOssg>
- Li HS, Dong HJ, Zhang CC, Deng ZK (2019) Current status and conservation of mangrove resources in Luzui, Shenzhen. *J Anhui Agric Sci* 47:110–112 <https://dwz.cn/DlbICFQc>
- Liao BW, Zhang QM (2014) Area, distribution and species composition of mangroves in China. *Wetl Sci* 12:435–43s. <https://doi.org/10.13248/j.cnki.wetlandsci.2014.04.005>
- Liao BW, Zheng DZ, Zheng SF (1992) A special type of shelter forest on the southeast coast in China—mangroves. *For Environ Sci* 9:30–33 <https://dwz.cn/TOvuoMOQ>
- Lin P (1981) The group and distribution of mangroves in the southeastern coast of China. *Acta Ecol Sin* 1: 283–290. <https://dwz.cn/58qgheLv>
- Lin P, Fu Q (1995) *Chinese mangrove environment ecology and economic utilization*. Higher Education Press, Beijing
- Lin YM, Lin P (2001) Species, diversities, functions and protections of plants in mangrove ecosystem in China. *Trans Oceanol Limnol*:8–16. <https://doi.org/10.13984/j.cnki.cn37-1141.2001.03.002>
- Lin ZD, Liu HM (2003) Protection and management countermeasures for mangrove resource in Guangdong Province. *Central South Forest Inventory and Planning*:35–38. <https://doi.org/10.3969/j.issn.1003-6075.2003.02.012>
- List of China's Rare and Endangered Plants (summary) (n.d.) Available online: <http://rep.iplant.cn/protlst>
- Liu MF, Zhang HS, Lin GH, Lin H, Tang DL (2018) Zonation and directional dynamics of mangrove forests derived from time-series satellite imagery in Mai Po, Hong Kong. *Sustainability* 10:1913. <https://doi.org/10.3390/su10061913>
- Lu ZL (2004) The discussion of the protection of the mangrove by local legislation. *J Guangxi Admin. Cadre Inst Polit Law* 19: 43
- Lu YP, Xu WH, Zhang ZM, Zhang L, Xie SL, Zhang JJ, Fan XY, Ouyang ZY (2019) Gap analysis of mangrove ecosystem conservation in China. *Acta Ecol Sin* 39:684–691. <https://doi.org/10.5846/stxb201804080794>
- Lv CX (1998) Current status, existing problems and countermeasures of mangrove ecosystem protection in China. *Ocean Dev Manag*:41–43 <https://dwz.cn/B8vIE4z6>
- Lv J (2008) Studies on distribution and management of Chinese mangrove forests. Master, Beijing Forestry University. <https://dwz.cn/H3tRpIJ1>
- Ma YJ (2004) Research on mangrove protection legislation in China. China Environmental Resources Law Seminar (annual meeting), Chongqing, China. <https://dwz.cn/IAJODrWQ>
- Mei H, Xue ZY (2011) On the management and legislation of mangroves natural reserves in China. *China Oceans Law Rev* 1:219–240 <https://dwz.cn/vJcacJEr>
- National mangrove resources survey report (2002) Forest resources management division of the state forestry administration: Beijing, China
- Pei KB (2010) Comprehensive conservation and development strategy of Dongzhaigang mangrove in Meilan District. Master, Tianjin University <https://doi.org/10.7666/d.y1873071>
- Possingham HP, Bode M, Klein CJ (2015) Optimal conservation outcomes require both restoration and protection. *PLoS Biol* 13: e1002052. <https://doi.org/10.1371/journal.pbio.1002052>
- Qian TZ (2010) Study on ecological investigation and exploitation of mangrove in Yueqing Bay. *Liberal Arts Navigation* 5:50–51
- Qiu ZG, Yang X, Yu LY, Shen XX (2019) Ecological problems and conservation strategies for mangrove forest under impacts of urbanization: a case study of Futian, Shenzhen. *Wetl Sci Manag* 15:31–34 <https://dwz.cn/NUJZzU3K>
- Saenger P, Hegerl EJ, Davie JDS (1983) Global status of mangrove ecosystems. *Environmentalist* 3:69–74. <https://doi.org/10.1007/BF02340516>
- Saintilan N (1997) Above-and below-ground biomasses of two species of mangrove on the Hawkesbury River estuary, New South Wales. *Mar Freshw Res* 48:147–152. <https://doi.org/10.1071/mf96079>
- Shi L (2002) Distribution, growth environment and environmental adaptability of mangroves in China. *Marine Information*:14–18. <https://doi.org/10.3969/j.issn.1005-1724.2002.04.005>
- Spalding M, Kainuma M, Collins L (2010) *World atlas of mangroves*; Earthscan, London, UK and Washington, DC, USA <https://doi.org/10.1007/s13157-011-0224-1>, 31, 1003, 1005
- Wang H (2007) Design of Special Information System of mangrove coast biodiversity. *Agricultural Library and Information*:175–178. <https://doi.org/10.13998/j.cnki.issn1002-1248.2007.08.004>
- Wang M (2013) Comparison of the management of mangrove nature reserves between China and Australia. *Wetl Sci Manag* 9:45–48. <https://doi.org/10.3969/j.issn.1673-3290.2013.02.12>
- Wang LX (2014) Laws and regulations study of Hainan mangrove protection. Master, Hainan University. <https://dwz.cn/N2Pv9BdM>
- Wang WQ, Wang M (2007) *Chinese mangroves*. Science Press, Beijing
- Wu PQ (2012) Remote sensing monitoring and analysis of the changes of mangrove forests resources in China in the past 20 years. Master, The First Institute of Oceanography (MNR), Qingdao. 10.3969/j.issn.1671-6647.2013.03.013

- Xia XF (2014) Discuss on the distribution and growth status of mangrove of coastal areas in Guangdong province, China. *For Econ* 2:54–60 <https://dwz.cn/xR7jGWdg>
- Yang SC, Lu WX, Zou Z, Li S (2017a) Mangrove wetlands: distribution, species composition and protection in China. *Subtrop Plant Sci* 46: 301–310. <https://doi.org/10.3969/j.issn.1009-7791.2017.04.001>
- Yang QQ, Chen XH, Du ZH (2017b) Present situation and protection countermeasures of mangrove community in Hainan Island. *Trop For* 45:22–24 <https://dwz.cn/DjiNla9U>
- Yang JZ, Hu YH, Luo Y, Xue CQ (2018) Study on the distribution and dynamic change of mangrove in Guangdong. *For Environ Sci* 34: 24–27 <https://dwz.cn/0soBYCUA>
- Yao YF, Liao WB, Song XY, Li CS (2010) Current status and conservation of mangrove resources in Tielu Harbor, Sanya, Hainan. *Mar Sci Bull* 29:150–155. <https://doi.org/10.3969/j.issn.1001-6392.2010.02.005>
- Yu LY, Lin SH, Jiao XR, Shen XX, Li RL (2019) Ecological problems and protection countermeasures of mangrove wetland in Guangdong-Hong Kong-Macao Greater Bay Area. *Acta Scientiarum Naturalium Universitatis Pekinensis* 55: 782–790. <https://doi.org/10.13209/j.0479-8023.2019.051>
- Zeng FC (2014) Study on the legislation of mangrove ecological environment protection in the southeast coast of China. *Legal Syst Soc*: 63–64. <https://doi.org/10.19387/j.cnki.1009-0592.2014.01.030>
- Zhang JS (2017) Present research status of mangrove conservation in China based on bibliometric analysis. *J For Environ* 37:102–106 <https://dwz.cn/ewVCEhPt>
- Zhang QM, Sui SZ (2001) The mangrove wetland resources and their conservation in China. *J Nat Resour* 16:28–36. <https://doi.org/10.3321/j.issn:1000-3037.2001.01.006>
- Zhang QM, Sui SZ (2005) Chinese mangrove wetland resources and their protection. *For China* 13 <https://dwz.cn/s8jNw7li>
- Zhang QM, Yu HB, Chen XS, Wen XS (1995) Preliminary study on tidal dynamics of mangrove coast, Chinese mangrove research and Managemen. Science Press, Beijing
- Zhang QM, Zhang YC, Sun SZ (1997) Status and management of mangrove and mangrove coasts in China. Tropical Ocean Research. Science Press, Beijing
- Zhang ZH, Hu G, Liang SC (2006) Distribution status, protection and ecological value of mangroves in China. *Bull Biol* 4:9–11,64. <https://doi.org/10.3969/j.issn.0006-3193.2006.04.005>
- Zheng KJ (2010) The comparative studies on heavy metals pollution and ecological risks between the kandelia candel natural forest and plantations in the north of Fujian. Master, Fujian Agriculture and Forestry University <https://doi.org/10.7666/d.y1748123>
- Zhong CR, Li SC, Guan W, Li HL, Lin XY, Liao BW (2011) Current distributions of three endangered species in China. *Ecol Sci* 30:431–435. <https://doi.org/10.3969/j.issn.1008-8873.2011.04.011>

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