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Study on the Evolutionary Characteristics of Coastal Mangrove Forests in China from 1990 to 2020

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Abstract. Mangroves are vital ecosystem for carbon sequestration and shoreline protection. However, the invasive Spartina alterniflora has caused mangrove degradation in China. From 1990 to 2020 , China saw significant changes in both coastal development and ecological conservation. This study focuses on the spatiotemporal dynamics of mangroves and Spartina alterniflora over three decades. By statistically processing remote sensing time-series datasets and systematically analyzing existing literature, it identifies natural and anthropogenic drivers of mangrove area changes. Consequently, it proposes conservation measures, providing core evidence for precise invasive species control and mangrove ecosystem restoration. Findings reveal that In 1990, China's mangrove area was 22,790.25 ha. By 2010, 4.37% disappeared. From 2010 to 2020, it increased by 26.96%, with a growth rate of 2.6%. Distributions decreased in Guangdong, Hainan, and Fujian from 1990 to 2010, but increased in Guangxi, Guangdong, and Hainan from 2010 to 2020. Mangrove connectivity improved. The shift in mangrove forest gravity centers reflects human disturbance and conservation efforts. In 1990, Spartina alterniflora area was 4,376.52 ha. It grew at a CAGR of 19.5% by 2000. From 2000 to 2015, its coverage decreased by 551.34 ha annually, while mangroves expanded by 847.78 ha annually. The correlation coefficient was -0.9447.

Keywords: China's coastal mangrove forests, spatio-temporal analysis, Spartina alterniflora, reclamation

1. Introduction

Mangrove forests, located in the intertidal zones of tropical and subtropical regions, are composed of evergreen shrubs or trees. Known as the "guardians of the coast," they resist flooding, coastal erosion, purify air and water, and sequester carbon, providing abundant social, economic, and ecological benefits. Since 1970, global mangrove areas have declined sharply due to climate change, water pollution, and exploitation. By 2010, China's mangrove coverage had dropped to approximately 55% of its 1970 total [1]. As a critical component of the four major marine ecosystems, mangroves have been the subject of multifaceted international research. Studies have focused on extreme events and climate oscillations, degradation and restoration, blue carbon, and ecology. Findings reveal that climate oscillations like ENSO and IOD drive a "see-saw" phenomenon in global mangrove growth, while hurricanes have caused Florida's mangroves to

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decline by approximately 547.3 km² over the past four decades [2]. Domestic research has achieved breakthroughs in seedling propagation, invasive species control, and remote sensing monitoring. Hainan's mangrove carbon storage ranks first nationally, and China has completed its 14th Five-Year Plan afforestation targets ahead of schedule. However, studies analyzing the spatiotemporal distribution of China's coastal mangroves and Spartina alterniflora from 1990 to 2020 remain scarce.

This study statistically processes remote sensing dynamic datasets of China's coastal mangroves and Spartina alterniflora from 1990 to 2020, analyzing their spatiotemporal distribution characteristics and interrelationship. It also reviews existing literature to explore influencing factors and regulatory measures for changes in mangrove abundance. This study offers critical references and decision support for achieving harmonious coexistence between humans and nature.

2. Temporal and spatial distribution characteristics of China's coastal mangroves

2.1. Temporal distribution characteristics

This dataset is constructed using remote sensing big data, including Landsat series imagery covering China's coastal mangrove growth zones from 1990 to 2020. It presents the total mangrove at five key temporal nodes: 1990, 2000, 2010, 2015, and 2020. Research indicates that China's mangrove area initially declined and then recovered over the past three decades (Figure 1). From 1990 to 2010, the area decreased from 22,790.25 ha to 22,076.46 ha and then to 21,793.59 ha. This represents a total loss of 996.66 ha, equivalent to approximately 4.37% of the mangrove area. However, from 2010 to 2020, it increased by 5,896.26 ha (26.96%), surpassing the 1990 level by 2015. Furthermore, the net change rate from 2010 to 2020 was 2.6%, exceeding the 0.21% rate from 1990 to 2010, indicating that the scale of restoration efforts have significantly surpassed degradation.

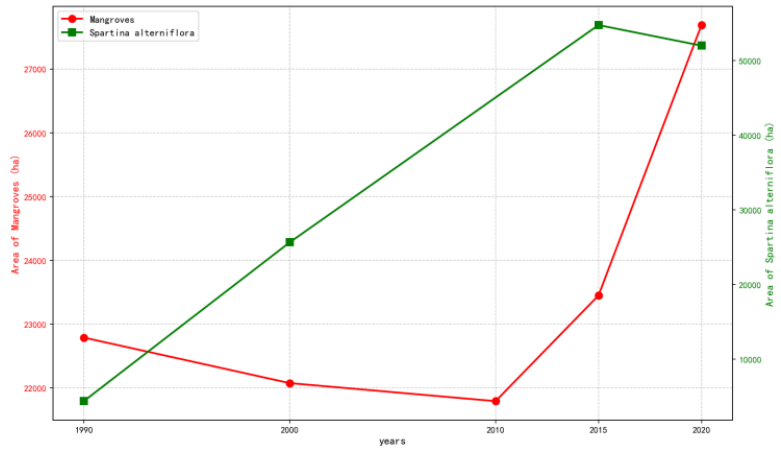


Figure 1. Total area changes in China's coastal mangroves and Spartina alterniflora from 1990 to 2020

2.2. Spatial distribution characteristics

China's coastal mangrove forests primarily grow along the southern and southeastern coasts of mainland China, the entire coastline of Hainan Island, and the western coast of Taiwan Island, spanning approximately 14,000 kilometers of shoreline [3]. Over the past three decades, China's coastal mangrove forests have consistently exhibited a spatial distribution pattern characterized by “abundance in the south and scarcity in the north.” Their presence is particularly prominent in the

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coastal regions of Guangdong, Guangxi, and Hainan. The mangrove forests along the northern coast of Fujian have been greatly reduced . From 1990 to 2010, coastal mangrove areas declined across all regions of China, with the most pronounced reductions occurring in Guangdong, Hainan, and Fujian. Guangdong Province lost 1,608 hectares (approximately 14% of its total mangrove area), Hainan Province lost 1,233 hectares (approximately 25% of its total), and Fujian Province lost 193 ha, representing about 15% of its total mangrove area [1]. The primary cause was the rapid advancement of industrialization and urbanization in China during this period, which fueled rising demand for coastal land. Taking 2010 as a turning point, after a decade of conservation and restoration efforts, China's coastal mangrove areas saw substantial growth by 2020. The most notable increases occurred in Guangxi, Guangdong, and Hainan, with respective gains of 3,517 ha, 4,322 ha, and 2,957 ha, representing increases of 60%, 44%, and 82%, respectively(Figure 2) [1]. Additionally, 28 wetland nature reserves and 6 internationally important wetlands were established, playing an indelible role in the rapid conservation of mangroves .

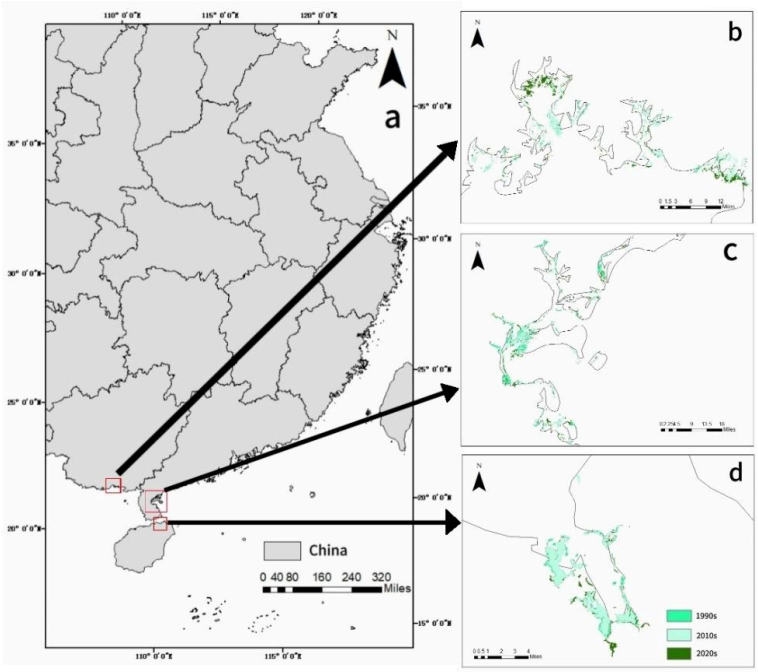


Figure 2. Spatial distribution changes of core mangrove areas along China's coastline (1990-2020).a.Qinzhou (Guangxi), b.Eastern Leizhou Peninsula (Guangdong), c.Beigang Island (Hainan)

From 1990 to 2010, mangrove patches exhibited significant fragmentation. Influenced by both human and natural factors, China's coastal mangroves underwent cycles of decline, fragmentation, disappearance, stabilization, expansion, and new growth between 1990 and 2020. Today, the largest patch index has increased while the number of patches has decreased, reflecting the effectiveness of restoration efforts and improved connectivity [4].

Since 1990, the spatial centers of mangrove ecosystems in Fujian, Guangdong, Guangxi, and Hainan have diverged markedly, driven primarily by the cyclical interplay between human disturbance and ecological conservation measures. Fujian exhibits a “hook-shaped” migration pattern: from 1990 to 2000, land reclamation and pond construction in southeastern Fujian fragmented communities, shifting the center westward; after 2000, artificial restoration in northeastern Fujian pulled the center eastward [5, 6]. Guangdong shows a “linear” migration: industrialization pushed the center northward before 2005; thereafter, the implementation of the

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Guangdong Mangrove Protection Regulations and restoration efforts in western Guangdong shifted the center southward [5, 7]. Guangxi exhibits relatively stable “7-shaped” evolution: early port construction forced eastward shift, while later “ecology-first” planning spurred western recovery, shifting the center westward [5, 8]. Hainan shows “scissor-shaped” migration: early aquaculture expansion in the east pushed the center westward, while later northeastern conservation efforts drove it eastward [5, 9]. The centers in all four provinces migrate along administrative boundaries toward calmer harbors and estuaries.

3. Factors influencing mangrove changes

3.1. Natural influencing factors

Mangroves thrive within the 25°C isotherm in both hemispheres and rank among the most climate-sensitive marine ecosystems. With global warming, their growth zones will expand toward the poles, indicating increased suitable habitats. However, rising temperatures will cause polar ice caps to melt, leading to sea level rise and reduced intertidal zones. This will submerge large swathes of mangrove forests,. The destructive impact of extreme weather events on mangroves cannot be underestimated. Tsunamis, typhoons, storm surges, and extreme cold temperatures pose significant threats. The first three can directly cause mangroves to collapse and die, while the latter inhibits their growth. Additionally, invasive species like Spartina alterniflora compete for ecological niches, leading to a trend where grasses advance while forests decline.. Pests and diseases are direct causes of mangrove degradation.

3.2. Human activity factors

Mangrove ecosystems located in coastal areas, they are profoundly affected by human interference. Sewage discharge and waste dumping into the ocean cause severe water pollution. Investigations reveal that Class IV seawater has been detected in water quality monitoring across multiple regions [10]. Mangroves, valued for their hardness and rot resistance, also serve as chemical raw materials, leading to excessive harvesting and exploitation. Furthermore, the most damaging human activities include land reclamation and enclosed aquaculture ponds. These projects not only block mangroves' migration inland but also disrupt their ecological structure. A 2001 investigation revealed that 10 hectares of natural secondary mangrove forests in Aotou Xiwang, Shantou City, Guangdong Province, were converted into aquaculture ponds. Reclamation activities east of the Hailing Sea Dike in Guangdong were assessed as posing a “severe” threat to wetlands [10].

3.3. Correlation analysis between mangroves and Spartina alterniflora

Based on acquired remote sensing data, this study systematically analyzed and mapped the total area change curves of China's coastal mangroves and Spartina alterniflora from 1990 to 2020 (Figure 1). Over these three decades, mangrove area first declined then increased, while Spartina alterniflora area followed the opposite trend—rising initially before declining. Native to the southeastern coast of the United States, Spartina was introduced to Yuanwan, Fujian, China in 1979 and subsequently spread nationwide. By 1990, the total Spartina alterniflora area reached 4,376.52 ha, primarily distributed across Fujian, Shanghai, Guangdong, and Jiangsu, with subsequent reductions. Although China's coastal mangrove area had significantly decreased compared to the 1970s, it still exceeded the Spartina alterniflora area by 18,413.73 ha. Between 1990 and 2010, while mangrove areas continued to decline, Spartina alterniflora in China's coastal zones experienced rapid growth from

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1990 to 2000. Its area expanded from 4,377 ha to 25,600 ha, nearly sixfold, with a CAGR of 19.5%. During the subsequent 15-year period from 2000 to 2015, the CAGR slowed to 5.3%. Spartina alterniflora's total area roughly equaled that of mangroves by 1998 and continued to rise, reaching its peak in 2015 at 54,745.83 hectares, covering vast areas of China's coastal regions. From 2015 to 2020, Spartina alterniflora's area began to decline, decreasing by 2,756.7 hectares.

As an invasive alien species, Spartina impacts native flora and fauna. Prior to 2010, their growth trends were inversely correlated (correlation coefficient -0.9447), suggesting Spartina inhibits mangrove growth. However, due to limited data collection, the significance level was 0.2128, indicating low reliability. From 2010 to 2015, mangrove area began to increase, likely slowing Spartina's growth rate.. From 2015 to 2020, mangrove forests grew by an average of approximately 847.78 ha annually, while Spartina alterniflora decreased by an average of about 551.34 ha per year. This suggests that, excluding human intervention targeting Spartina alterniflora, the success of mangrove conservation and restoration efforts enhanced the ecological niche advantage of mangroves, thereby slowing the growth rate of Spartina alterniflora.

4. Conservation and management measures for mangrove forests

To conserve and manage mangrove forests effectively, several measures should be implemented. First,clear penalty standards should be established, rigorous monitoring should be enforced, and severe penalties should be imposed on individuals and enterprises engaged in illegal logging. Second, artificial afforestation should be scientifically planned. Before undertaking such projects, local natural conditions must be thoroughly considered. Tailored approaches should be adopted for specific environments. The intertidal and high-tide zones, which are ideal habitats for mangroves, are often occupied by human development. Therefore, a balance between economic growth and ecological conservation must be found to promote sustainable development. Additionally, multiple mangrove wetland nature reserves should be established to provide mangroves with a safer and more stable ecological environment to promote their natural recovery and growth. Addressing invasive species requires integrated strategies against non-native threats. Employing physical/mechanical barriers and biological control methods enhances eradication effectiveness. For instance, replacing ecologically inferior Spartina populations with native mangrove species can suppress invasive growth [11]. Finally, through educational campaigns, environmental consciousness should be strengthened, encouraging active societal participation in mangrove protection to foster a collective commitment to safeguarding these ecosystems.

5. Conclusion

China's coastal mangrove area was 22,790.25 ha in 1990, declining to 21,793.59 ha by 2010 (4.37% loss). However, from 2010 to 2020, it increased by 5,896.26 ha (26.96%), reflecting successful conservation efforts. Prominent regions included Guangdong, Guangxi, and Hainan. While Guangdong, Hainan, and Fujian lost areas, Guangxi, Guangdong, and Hainan saw significant gains by 2020. The maximum patch index increased and patch numbers decreased, indicating improved connectivity. In contrast, Spartina alterniflora expanded from 4,376.52 ha in 1990 to a peak of 54,745.83 ha in 2015 before declining to 51,989.13 ha by 2020. A strong negative correlation (-0.9447) between the two suggests that mangrove conservation may have limited Spartina's growth, particularly between 2015 and 2020, where mangroves expanded while Spartina decreased.

However, this study has several limitations. For instance, due to limited data availability, values for some regions are difficult to determine, and the lack of data accuracy verification reduces the

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study's reliability. Future research should focus on improving data precision and coverage. By incorporating more advanced remote sensing technologies and field monitoring methods, more detailed monitoring and analysis of mangrove and Spartina alterniflora distributions can be conducted to enhance the reliability and accuracy of research findings.

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