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Effects of Ecological Restoration of Mangrove Wetlands Using Native Mangrove Species to Replace *Spartina alterniflora*: A Case Study in Southern China

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Abstract

Within the expanse of China's coastline, the invasive alien cordgrass species *Spartina alterniflora* has caused profound nationwide damage and has emerged as a critical factor contributing to the degradation of mangrove wetlands, especially in the study area in Beihai, Guangxi. However, current treatments for *S. alterniflora* remain less effective and limited research focuses on the preliminary changes after artificial plantation. A comprehensive approach combining physical interventions with biological control measures has been employed to eradicate smooth cordgrass and facilitate the restoration of native mangrove wetlands. The study involved the periodic monitoring of the growth conditions of mangroves and the biodiversity of avian and benthic organisms, conducted at three to four-month intervals following the artificial plantation with one-year-old seedlings and propagules of native mangrove species *Rhizophora stylosa*. Results indicated that through the allometric equation, the above-ground biomass of planted seedlings had a ~20 g increase in average but the growth conditions were not significant over an eight-month period. High percentage of important avian species underlined the potential of the study site to serve as a worthwhile habitat and notable seasonal variations were observed in the biodiversity of bird species. Biodiversity indices of bird and benthos species also followed a similar fluctuation and reached a peak in April 2023. This research underscores the initial lack of distinct improvements during the early stages of the ecological restoration project, thorough maintenance, long-term monitoring, holistic considerations on a larger scale would be imperative for ongoing projects in the future.

Keywords

Mangrove, *Spartina alterniflora*, Invasive Species, Ecological Restoration, Ecological Monitoring

1. Introduction

Coastal ecosystems play a crucial role in upholding fundamental ecological functions, offering essential habitats for a diverse range of flora and fauna, and providing invaluable ecosystem services to local communities [1] [2]. Among these ecosystems, mangrove wetlands have demonstrated superior capabilities in terms of carbon sequestration, coastal protection, and biodiversity conservation [3] [4] [5]. Meanwhile, coastal wetlands, including mangrove forests, display a high degree of vulnerability and sensitivity to environmental changes [6] [7]. Studies have reported that, along with external transformations, mangroves in China have been undergoing a process of degradation over the past 2 - 3 decades, leading to the disappearance of two-thirds of the original mangrove forests [8] [9] [10]. Coastal reclamations for harbors, seawalls and aquacultural ponds have become the major factor for the loss of intertidal wetlands, altered the hydrology and the interaction between terrestrial ecosystems and marine ecosystems, leading to profound detriments to ecological succession and resilience [11] [12] [13]. As of 2014, the area reclaimed for maritime activities has accounted for more than 30% of the entire coastline area [1]. Additionally, biological invasion, specifically invaded by smooth cordgrass *Spartina alterniflora*, has been recognized as one of the most critical problems and priorities to be solved on a national scale [14] [15].

S. alterniflora originally thrived along the Atlantic Ocean coast of North America and has been discovered on the western coast of North America, Europe, and southern Africa since the 1990s [16] [17] [18]. Since its introduction to China in 1979, *S. alterniflora* rapidly took control in the intertidal zones of most administrative regions with a total area of 54,580 hectares in 2015 owing to its strong competency to reproduce and spread [19] [20]. Its unpredictable inbreak had resulted in adverse impacts on the local biodiversity and traditional maritime activities, making the urgent need for corresponding control measures [21] [22] [23]. Up to date, however, most approaches aimed at controlling and preventing the spread of *S. alterniflora* in China have not demonstrated both effectiveness and cost-efficiency [24] [25]. Foreign research mainly focused on chemical approaches, which utilized herbicides including glyphosate and imazapyr for treatments [26] [27]. Nevertheless, the usage of chemicals still remains controversial because of the potential for environmental contamination in surrounding maritime activities [24]. Such treatments are solely implemented on a small scale and have not been officially documented [28]. Physical methods, such as mowing, shading, and waterlogging, require higher expenditures and extensive manpower [24] [29].

Apart from the traditional methods, biological control has captured the attention of researchers. In the long term, invasive species can be influenced and gradually diminished by introduced species due to competition [30]. However, introducing exotic species is also a subject of controversy and needs to be carefully examined to prevent another round of adverse impacts on local ecosystems [31] [32]. To replace *S. alterniflora*, Wang *et al.* employed exotic mangrove species *Kandelia obovata* in Zhejiang Province [33], while Zhou *et al.* examined the effects of replacement control with two alien mangrove species *Sonneratia caseolaris* and *Sonneratia apetala* in Guangdong Province [34]. Notably, biological control for *S. alterniflora* treatment is primarily concentrated in China and there is limited research using native mangrove species for ecological control of invasive species [25].

Rhizophora stylosa, commonly known as the red mangrove, represents a prominent pioneer species of the Rhizophoraceae family [35]. This species exhibits a widespread distribution across the tropical and subtropical regions of the Indo-Pacific, with extensive populations found along the coasts of Southeast Asia, northern Australia, and numerous Pacific islands [36]. *R. stylosa* has the remarkable ability to colonize bare mudflats with its distinctive aerial roots, and provide nursery grounds and foods for benthic and avian species [37] [38]. Such species are mainly distributed in Hainan, Guangxi, and Guangdong, China and have been proven to be recommended species with high-stress resistance for afforestation [39] [40] [41].

Survival rate was frequently considered as the primary indicator for assessing mangrove restoration projects in the last 20 years [42] [43]. Under such circumstances, large amounts of artificial planting projects emerged, where the emphasis was placed on plantation while neglecting the suitability of the actual environmental conditions [1]. For example, Guangxi has conducted cumulative artificial afforestation operations covering 3984.5 hectares between 2002 and 2015. Nevertheless, the preserved mangrove area amounted to only 1338.9 hectares, resulting in a preservation rate of 33.6% [44]. Restoration initiatives have evolved to prioritize the holistic restoration of mangrove ecosystems in the contemporary context, with metrics like avian and benthic data serving as parameters of project effectiveness [9] [45].

In assessing the effectiveness of the biological control and mangrove restoration projects, the biodiversity of the macrobenthos and bird community has been adopted as pivotal indicators [46]. Macrobenthic organisms have the capability of shaping the structure of coastal habitats by engineering activities and exhibit high sensitivity to environmental changes [47] [48] [49]. Consequently, macrobenthos are acknowledged as reliable indicators for assessing alterations in the functionality and ecological conditions of coastal wetlands [11]. Bird conservation has attracted greater attention in intertidal wetlands as China's coastline serves as a crucial stop along the East Asian-Australasian Flyway (EAAF) [50] [51]. Smooth cordgrass has been proven to have detrimental effects on bird biodiversity since it limits the availability of space and food resources for bird species [52]. In Yancheng, the invasion of *Spartina alterniflora* resulted in an 80% loss of *Suaeda salsa* from 2003 to 2018, such drastic shrinkage of suitable habitat for migratory birds has led to a significant decline in their population abundance [53]. Therefore, the presence of avian species could be used as an indicator to ascertain whether the ecosystem services have been enhanced.

In the current study, a comprehensive approach was employed to manage *S. alterniflora* and initiate the restoration of mangrove habitats. This comprehensive strategy encompassed the utilization of engineering methods to clear smooth cordgrass and stilt sediments, alongside the selective replantation of a higher density of native *R. stylosa* one-year-old seedlings and propagules. The primary objective of this research is to assess the alterations in mangrove ecosystems during the initial phases of the comprehensive treatments, which incorporate biological control and mangrove restoration. More specifically, the present study aims to: 1) determine whether the growth conditions of planted mangroves have shown significant improvements; 2) investigate the changes in biodiversity among avian species and benthic organisms. We predict that after eradication, newly planted *R. stylosa* would exhibit significant growth in the early stage of settlement and biodiversity would also have remarkable improvements.

2. Materials and Methods

2.1. Study Site

This study was carried out in the north side of Shatian Harbor, Beihai, Guangxi Zhuang Autonomous Region, China (21˚31'59"N, 109˚39'54"E). The study area is administered as the buffer zone of Guangxi Shankou Mangrove Ecological National Nature Reserve (Shankou Nature Reserve) under a subtropical marine monsoon which is a vital component of the Beibu Gulf's mangrove wetlands, possessing approximately 37% of China's total mangrove species. Smooth cordgrass was initially introduced to Shankou Nature Reserve in 1979 and the total area was recorded as approximately 336.35 ha in 2016 [54] [55]. Research indicated a density of 346 shoots/m^2 with an average height of 43.31 cm in Xicungang Estuary, located ~40 km to the west of the research site [56]. Within this area, the mean annual precipitation is 1600 - 2800 mm and the mean annual temperature is 23.4˚C. The region experiences a clear demarcation between dry and rainy seasons, with precipitation from April to September accounting for 84% of the annual total. The annual evaporation ranges from 1000 mm to 1400 mm, with an average relative humidity of 80% [57]. The annual average sea water temperature is 23.5˚C, salinity is 20‰ - 23‰, and the pH level falls within the range of 7.6 to 7.8. The tide is an irregular diurnal tide with a mean annual tide range of 2.31 - 2.59 m. (**Figure 1**)

Based on historical satellite images and face-to-face interviews with local communities, it was determined that the research site previously served as aquacultural

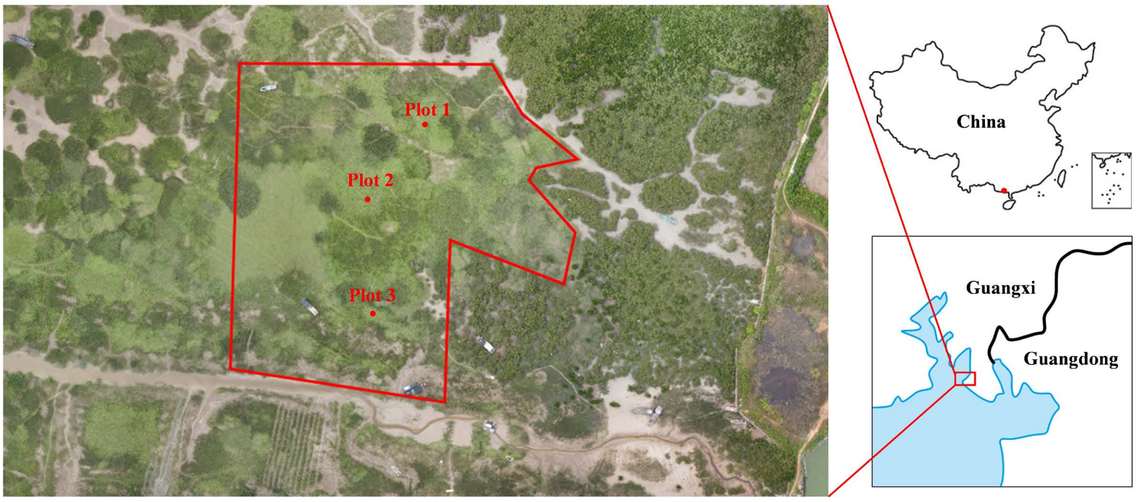


Figure 1. Location of the research site and sampling sites. The study area is situated within an inland bay with the ocean to the west and north. Native mangrove species *Rhizophora stylosa* (dark green on the right side of the research site) and *Avicennia marina* (light green on the right side of the research site) are dominant along the closest coastal area while the smooth cordgrass has largely invaded among the mudflats. The map of China and base image composites of middle scale were acquired from the official website of the Ministry of Natural Resources of China (http://bzdt.ch.mnr.gov.cn/). The remote sensing image (1:1500) was taken by an unmanned aerial vehicle (UAV) during low tide to avoid submersion by seawater. This image was captured on Oct.26th, 2022, right before the engineering activities started. Sampling sites for growth condition monitoring were selected considering randomness, accessibility, and diversity. Bare mudflat of the study site after engineering treatments is depicted in photograph (c) in **Figure 2**.

ponds, which were subsequently abandoned in 2006. Over the following three years, native mangroves naturally regenerated in the area, with *Spartina alterniflora* extending its growth 200 meters seaward. In 2010, the construction of Shatian Harbor commenced, resulting in the clearance of extensive areas of mangrove forests, including the study site. Subsequently, smooth cordgrass engaged in competition with native mangroves for the available bare mudflats until its full control was established in 2019. The selected site encompassed an area of approximately 2.07 ha with full coverage of *S. alterniflora* before the project started. The region southeast of the research site where native mangroves and cordgrass coexisted was not considered for treatment since any potential damages to current mangrove individuals would result in strict legal consequences. Due to the extensive growth of cordgrass in the inshore intertidal region, accessibility to the area was severely limited, and biodiversity was significantly reduced. As a result, local villagers typically ventured further seaward to collect seafood for economic gains, using this area primarily as a parking space for boats because the presence of such plants would also serve a practical purpose by preventing small ships from drifting.

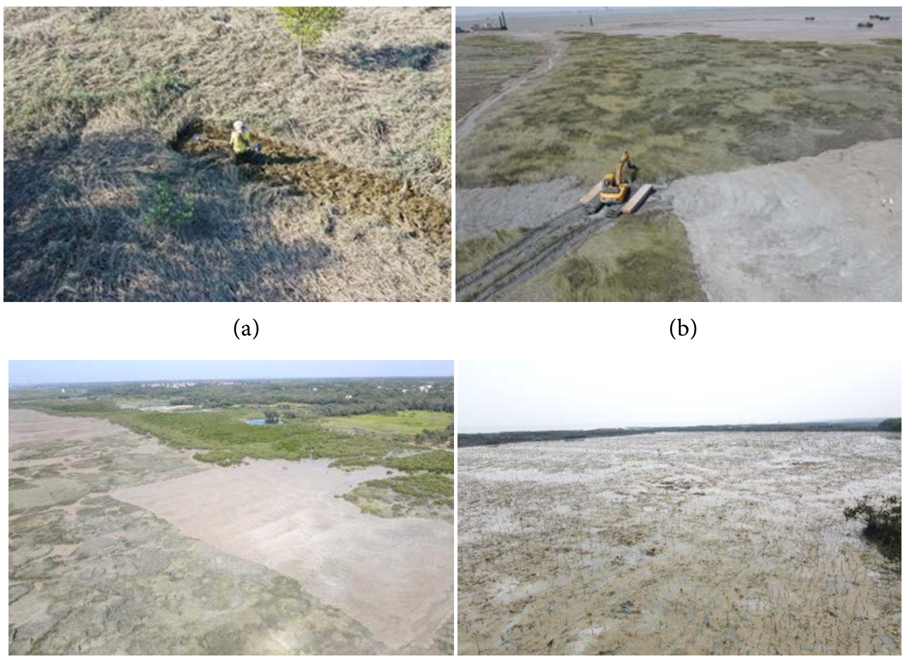
Through communication with engineers of Shankou Nature Reserve and experts in artificial plantation, investigations of the hydrological conditions within the study site were primarily conducted by on-site observations instead of comprehensive laboratory analysis based on the following two key reasons. Firstly, the selected mangrove species *R. stylosa*, is officially suggested for plantation with high, middle and low salinity in this specific research area, highlighting its capacity for environmental resilience [40]. Secondly, the study area was situated in the middle intertidal zone, and mature mangroves grew in healthy condition approximately 10 - 20 meters to the east and north, indicating the holistic conditions were relatively preferable once the control of smooth cordgrass was achieved.

2.2. Treatments of *S. alterniflora*

The above-ground parts of *S. alterniflora* were mechanically mowed and cleared up timely to ensure the residual stubbles of cordgrass were no higher than 5 cm. Furthermore, plowing was undertaken, with a requirement for the depth of the turningover to be at least 50 cm [40] [58]. Following these physical treatments, the study area was left undisturbed for at least 15 days to allow for the eradication of any remaining plants through the combined effects of waterlogging and suffocation. (**Figure 2**)

2.3. Artificial Plantation

Native *R. stylosa* propagules and one-year-old seedlings from nursery within 5



(a) (b) (c) (d)

Figure 2. Treatments of *S. alterniflora*. (a) Above-ground parts of smooth cordgrass were manually cut and removed to mitigate the risk of potential pollution (late Sept. 2022); (b) Small amphibious excavator was utilized to till the mudflat and eliminate the below-ground part of *S. alterniflora* (mid-Oct. 2022); (c) Remaining plants were kept in mudflat for at least 15 days to establish an anaerobic environment and prevent respiration. (till early Nov. 2022); (d) One-year-old seedlings and propagules of *Rhizophora stylosa* were planted in mid-November 2022. The final picture was captured during cloudy weather, making the seedlings and propagules harder to recognize and distinguish.

km were carefully selected. Healthy *R. stylosa* propagules without obvious damage were collected from surrounding mangrove wetlands, washed and preserved in shaded, moist and ventilated places. The one-year stands were cultivated in similar pH, salinity and tidal conditions, sterilized and transplanted to coastal regions of the study site one week in advance for preliminary adjustment [41]. Seedlings were transplanted using soil balls exceeding 10 cm in diameter enclosed in biodegradable materials, while propagules were planted at a depth equal to one-third of their own length and positioned at an angle of 30 - 40 degrees facing sunlight. The plantation densities were 1 m × 1 m for one-year seedlings and 0.5 m × 1 m for propagules [40] [58]. Artificial planting diagram was illustrated in **Figure 3**.

2.4. Plant Growth Measurement

Three 3 m × 3 m fixed plots were selected randomly with different locations (**Figure 1**). Height (H), trunk diameter at 30 cm above the ground ($D_{0.3}$), and the number of both seedlings and propagules were recorded every 3 - 4 months. Since most one-year stands of *R. stylosa* in Beibu Gulf are within one-meter height, most allometric equations using the diameter at breast height (DBH) are not applicable in the present study. As a result, the above-ground biomass (AGB) of *R. stylosa* was calculated using an empirical formula with the help of $D_{0.3}$ [59] [60], where the wood density of *R. stylosa* is recorded as 0.91 g/m^3 [61]:

$$W = 0.251 \times \rho \times D_{0.3}^{2.46}. \quad (1)$$

where W = above-ground biomass (kg), ρ = wood density of *R. stylosa* (g/m^3), $D_{0.3}$ = trunk diameter at 30 cm above the ground (cm).

Besides, the growth conditions of propagules are not included in current study for two main reasons. Firstly, the extremely soft sediments made movement difficult, resulting in propagule damage during fieldwork. Secondly, propagules generally need a longer time to adjust to new environments and may not exhibit distinct changes during the data collection period.

2.5. Bird Monitoring

The point count method was employed to monitor the bird species richness and

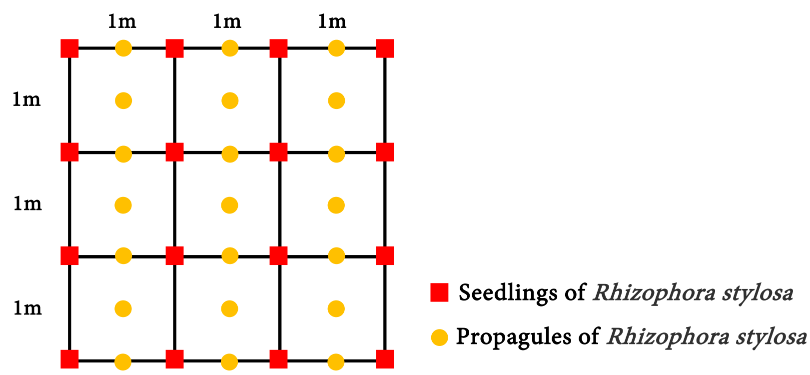


Figure 3. Artificial planting diagram.

abundance within the research site and surrounding area, as well as the inshore area. All the birds staying and utilizing certain regions will be recorded while the flying ones will not be counted. Fieldwork is conducted every 3 - 4 months, and the duration of each time will be one hour during low tide [62]. All the recorded birds will also be categorized as summer birds, winter birds or resident bird considering of the seasonal characteristics of the target region according to interviews with local bird conservation organizations.

2.6. Macrobenthos Sampling

Triplicate samples of 30 cm × 30 cm were selected randomly each time. Sediment samples with the depth of 30 cm were collected and sieved by 0.5 mm mesh to collect macrobenthos. All the specimens were taken back to laboratory and preserved by 5% formalin. Samples would be identified, counted, and weighed on precision electronic laboratory balance afterwards. Fieldwork is conducted every 3 - 4 months [62].

2.7. Data Analysis

Data analysis was conducted using comprehensive statistical approaches. In the case of plant growth measurement, above-ground biomass was calculated by an allometric equation, and one-way ANOVA was performed to analyze the differences between samples at different times. For bird monitoring, various metrics including total abundance, the Simpson index, the Shannon-Wiener diversity index, and Pielou's evenness index were calculated. Likewise, for macrobenthic samples, key metrics such as total abundance, total biomass, the Simpson index, the Shannon-Wiener diversity index, and Pielou's evenness index were computed.

3. Results

3.1. Plant Growth Conditions

Essential information, including height, $D_{0.3}$ and the counts of seedlings and propagules are summarized in **Table 1**. The heights of *R. stylosa* seedlings in research sites vary from 21 cm to 74 cm. Most one-year stands have similar $D_{0.3}$ values ranging from 0.90 cm to 1.10 cm. Three to five planted seedlings had shown potential degradation in winter, while the rest of the monitored mangrove stands were in good condition according to field observations. Apart from that, there were 11, 9, and 11 seedlings in three plots along with 40, 46, and 15 propagules respectively at the beginning of fieldwork. After eight months following the eradication of *S. alterniflora*, 2 out of 31 planted mangrove seedlings in plot 3 were missing after April 2023, leaving 29 *R. stylosa* seedlings. The total number of *R. stylosa* propagules was 101, which decreased to 75 in April and further to 65 in July 2023.

Figure 4 displays the above-ground biomass of three plots monitored in Dec. 2022, Apr. 2023, and July 2023. Average AGB of all three plots only increased by

Table 1. General plant growth conditions of three-time fieldwork.

Sampling Time	Plot	Range of Height (H, cm)	Average Height (cm)	Range of $D_{0.3}$ (cm)	Average of $D_{0.3}$ (cm)	No. of Individuals	No. of Propagules
Dec. 2022	1	38 - 74	57.00	0.86 - 1.20	0.98	11	40
	2	24 - 57	46.11	0.82 - 1.07	0.90	9	46
	3	22 - 67	55.64	0.67 - 1.19	1.00	11	15
Apr. 2023	1	38 - 74	56.82	0.86 - 1.20	0.98	11	32
	2	25 - 57	46.11	0.82 - 1.07	0.91	9	31
	3	21 - 67	55.45	0.68 - 1.20	1.00	11	12
July 2023	1	43 - 72	57.33	0.90 - 1.21	1.01	9	22
	2	30 - 60	46.33	0.85 - 1.07	0.95	9	31
	3	29 - 72	55.82	0.74 - 1.21	1.02	11	12

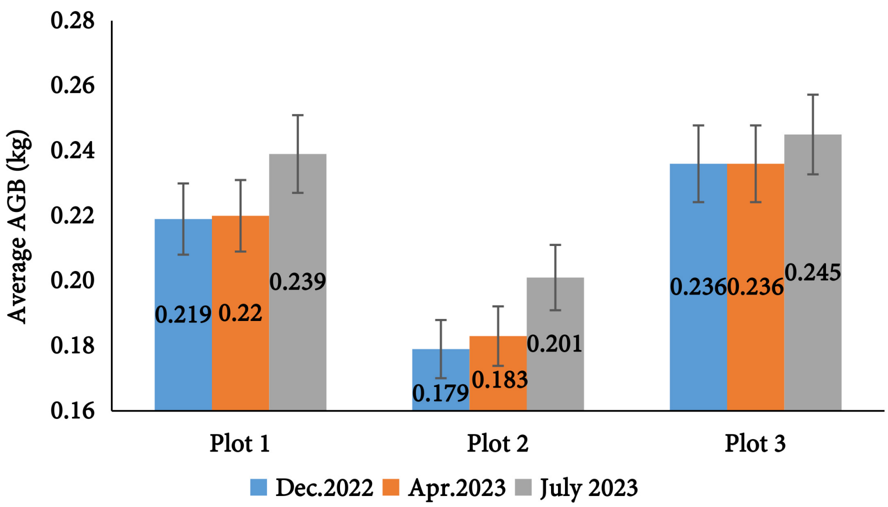


Figure 4. Average AGB changes of three plots in eight-month monitoring.

less than 10 g from Dec. 2022 to Apr. 2023, with *R. stylosa* stands showing an average growth of 15 - 20 grams in the rainy season starting in April. The implementation of one-way ANOVA revealed that above-ground biomass did not exhibit significant enhancement through sampling time (all $p > 0.05$).

3.2. Bird Monitoring

(Table 2) Based on the monitoring during three time periods, a total of 197 individuals from 29 avian species were recorded, among which 84 individuals from 12 species, 67 individuals from 20 species, and 46 individuals from 12 species were documented respectively. During the winter, the majority of recorded birds (77.4%) showed a preference for staying and foraging in mudflats with mangrove stands, especially for winter bird Kentish plover (*Charadrius alexandrinus*) and grey heron (*Ardea cinerea*). As spring arrived, more avian species tended to gather and stay around the inshore area in April (82.1%) and July (73.9%), and barn swallow (*Hirundo rustica*) became the dominant species in most cases. Simpson Index, Shannon-Wiener Index, and Pielou's Evenness Index were calculated and presented in **Table 3**. Indices all exhibited a pattern of initially increasing and then decreasing, reaching their peak values in April 2023.

Birds are classified into different categories, including summer birds, winter birds, and residence birds based on the regional situation (**Figure 5**). In December 2022, winter birds (57.14%) were predominant, and no summer birds were observed in coastal areas. Residence birds became more popular in Apr. and July 2023, while summer birds were recorded with 21 individuals in April and 22 in July.

Table 2. General bird monitoring results of three-time fieldwork.

Sampling Time	Location	No. of Species	No. of Total Individuals	Most Common Species	
				Name	No.
Dec. 2022	Research site and surrounding area	8	65	*Charadrius alexandrinus*	21
				Ardea cinerea	13
				Egretta garzetta	12
				Charadrius mongolus	9
	Inshore area	7	19	*Egretta garzetta*	9
				Ardeola bacchus	3
	Total	**12**	**84**		
Apr. 2023	Research site and surrounding area	7	12	*Ardea cinerea*	4
	Inshore area	16	55	*Hirundo rustica*	15
				Cacomantis merulinus	6
				Pycnonotus sinensis	6
	Total	**20**	**67**		
July 2023	Research site and surrounding area	5	12	*Hirundo rustica*	7
	Inshore area	10	34	*Hirundo rustica*	15
				Egretta garzetta	4
				Francolinus pintadeanus	4
	Total	**12**	**46**		

Table 3. Biodiversity indices of three-time monitoring of bird species.

	Dec. 2022	Apr. 2023	July 2023
Simpson Index	0.827	0.900	0.734
Shannon-Wiener Index	1.979	2.607	1.834
Pielou's Evenness Index	0.796	0.870	0.738

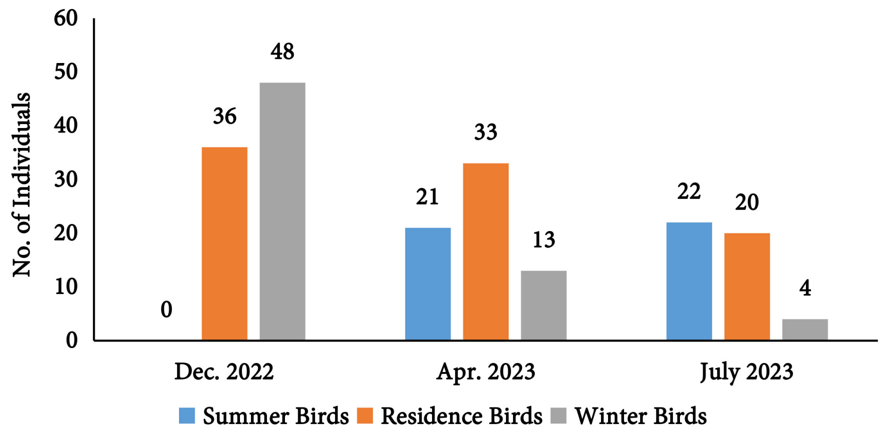


Figure 5. Number of different bird categories in three-time monitoring.

3.3. Macrobenthos Sampling

(Table 4) According to the monitoring results of three times' periods, 163 individuals from 14 macrobenthic species were recorded in total, among which 53 individuals of 7 species, 61 individuals of 12 species, and 49 individuals of 9 species were documented respectively. Among the macrobenthos, species are categorized in 6 classes, namely 4 species in Gastropoda, 4 species in Malacostraca, 3 species in Bivalvia, and 1 species in all Multicrustacea, Polychaeta, and Teleostei. Common species include *L. takii* (Gastropoda, 38.7% in population size), *P. tumidus* (Gastropoda, 9.8%), *C. dilatatum* (Malacostraca, 12.3%), *E. withersi* (Multicrustacea, 12.9%) and mudskipper (*P. cantonensis* in Teleostei, 8.6%). Biomass recorded in Dec. 2022 was 1457.89 g/m^2 in total, within which *P. cantonensis* accounts for 33.0% (481.48 g/m^2) and *P. tumidus* accounts for 28.5% (414.81 g/m^2) of the biomass. In April 2023, three Bivalvia species totally accounted for 43.7% (829.63 g/m^2) of the total biomass while *A. hoplocheles* has the largest proportion of 25.7% (248.15 g/m^2) in July 2023. Biodiversity indices of benthic organisms were calculated and illustrated in Table 5. These indices followed a pattern of initial increase followed by a decrease, with their peak values occurring in April 2023.

Species abundance was analyzed by categorizing benthic organisms into different classes (Figure 6). Gastropoda species (60.38%) dominated since the project started in December 2022, and Malacostraca and Teleostei held the same number of 9 individuals (16.98%). Species of Bivalvia (one *Meretrix lusoria*, one *Tegillarca granosa* and one *Ostrea glomerata*) and Multicrustacea (21 individuals of *E. withersi*) were only recorded in Apr. 2023 and accounted for 39.34% of the total species abundance. During the fieldwork in July 2023, the numbers of organisms within the Gastropoda, Malacostraca and Polychaeta classes remained similar to those observed during the initial monitoring.

4. Discussion

In general, the majority of planted seedlings and propagules have exhibited robust

Table 4. General benthic organism sampling results of fieldwork.

Sampling Time	Plot	No. of Species	No. of Total Ind.	Density (ind./m^2)	Weight (g)	Biomass (g/m^2)	Most Common Species	
							Name	No.
Dec. 2022	1	5	21	233.3	37.33	414.78	*Lactiforis takii*	13
	2	5	10	111.1	33.44	371.56		
	3	4	22	244.4	60.44	671.56	*Paromoionchis tumidus*	9
	Total	**7**	**53**	**588.9**	**131.21**	**1457.89**		
Apr. 2023	1	5	7	77.8	47.00	522.22		
	2	5	38	422.2	38.33	425.89	*Euraphia withersi* *Lactiforis takii*	21 9
	3	8	16	177.8	85.67	951.89	*Lactiforis takii*	6
	Total	**12**	**61**	**677.8**	**171.00**	**1900.00**		
July 2023	1	4	15	166.7	18.11	201.22	*Lactiforis takii*	11
	2	5	17	188.9	31.89	354.33	*Lactiforis takii*	9
	3	6	17	188.9	37.00	411.11	*Lactiforis takii*	7
	Total	**9**	**49**	**544.4**	**87.00**	**966.67**		

Table 5. Biodiversity indices of monitoring of benthic species.

	Dec. 2022	Apr. 2023	July 2023
Simpson Index	0.750	0.793	0.665
Shannon-Wiener Index	1.574	1.917	1.561
Pielou's Evenness Index	0.396	0.466	0.401

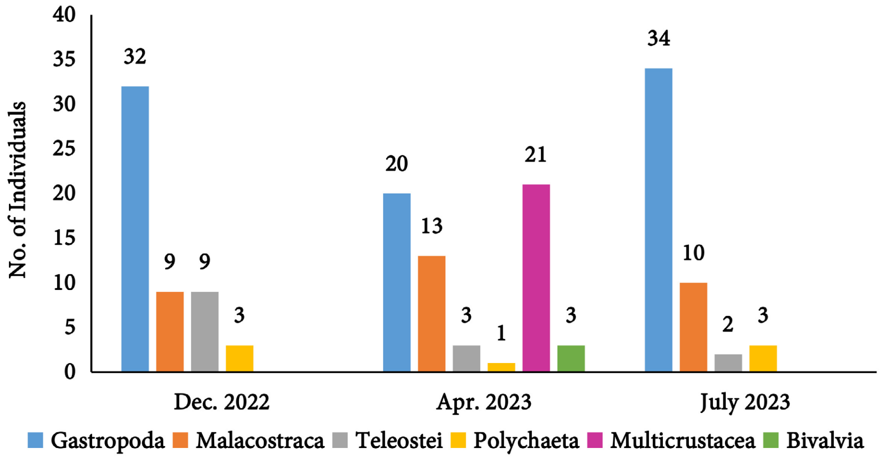


Figure 6. Number of different benthos categories in monitoring.

and healthy conditions. The survival rate of planted *R. stylosa* seedlings in three plots is 80.6% after eight months, with the exception of two missing seedlings and four uncertain planted individuals whose leaves had partly fallen off. Over 70% of the planted one-year-stands could survive based on general field observations, which is higher than the survival rates documented in guideline and acquired in other research [40]. Certain planted seedlings have either disappeared or retained only partial remnants of their stems. Approximately half of the propagules have already grown stems and leaves with 5 - 10 cm while the others remain dormant. The results indicate that the conditions are preferable for native mangroves to grow after eradicating threatened factors, namely the appearance of invasive species *S. alterniflora*. However, it's worth noting that the variance of AGB is relatively high and the plants did not exhibit significant growth after eight months of plantation. The large deviation may be due to inappropriate operations, as practitioners had the possibility to excavate to a greater depth or cover one-year-old seedlings with larger amounts of mudflats. These factors, combined with hydrological movements, collectively contributed to the observed reduction in height as documented during the field investigation. In addition, the lack of growth could be attributed to the unfavorable planting season. Winter season, during which the research was first conducted, is not a suggested season for mangrove plantations since the growth rates are lower compared to summertime [40]. The project was supposed to start in the spring 2022, but due to the Covid-19 pandemic situation, the whole schedule had to be postponed until October and November 2022. Beihai experienced a cold winter in January and February 2023 with minimum temperatures dropping to 6 - 7 degrees Celsius, according to the data of China Meteorological Administration. Such unfavorable meteorological conditions may have caused undetectable damage to plant tissues and bio-membranes, requiring longer periods for recovery and growth [63]. To mitigate the potential extensive damages caused by extreme cold winters, it is recommended to employ supplementary maintenance approaches such as antifreeze chemicals or additional fertilizers [40].

Limited research has been dedicated to examining the growth conditions of newly planted mangrove seedlings. Most family-specified or species-specified allometric equations for biomass calculation typically concentrate on mature stands and rely on the variable of DBH [60]. Formulas using diameter from the ground (D) or $D_{0.3}$ can be relatively scarce in the available literature, posing additional challenges while attempting to make comparisons and validate accuracy in the context of the present study. Additionally, research focusing on the early establishment or regeneration of mangroves primarily investigated survival rates and heights [64]. Although the application of the current allometric equation may not yield the expected accuracy, it is proposed that such a formula could still hold values for future researchers as a reference among East Asia and Southeast Asia, and further validations would be suggested.

Results of bird monitoring have demonstrated the potential significance of this intertidal wetland as most avian species have been documented with certain levels of values. Among all the 29 recorded bird species, two species, namely the white-throated kingfisher (*Halcyon smyrnensis*) and the greater coucal (*Centropus sinensis*) are classified as China's national second-level protected animals.

Additionally, 25 species are listed in China's "three haves" list of animals considered to have ecological, scientific, or social value. Despite being designated as one of the Ramsar Sites (https://rsis.ramsar.org/ris/1153) that provides crucial habitats for endangered species black-faced spoonbill *Platalea minor*, as well as numerous other migratory birds, Shankou Nature Reserve has long faced severe challenges of *Spartina* invasion. This high percentage of important species not only holds an inherent appeal for various avian species but may also attract birdwatchers. Such preliminary research could serve as a worthwhile reference for administrative departments to devise treatment proposals to effectively eliminate invasive species on a larger scale.

Species richness and abundance of birds showed seasonality patterns but appear to be lower than other research in the surrounding area. The amount of available food resources is a key factor driving avian species to select their habitat. In the present study, winter birds tended to choose intertidal mudflats with lower foraging costs and higher possibilities to acquire sufficient food resources, which is similar to other research as well [65]. April 2023, representing the transitional season for both winter and summer birds, recorded the highest abundance and diversity of bird species. Compared to the present study, bird monitoring results in Leizhou Peninsula, Guangdong and Shanxinsha Island, Guangxi possessed comparatively higher magnitudes [66] [67]. One possible explanation is that the eradication of smooth cordgrass was only conducted on a relatively small scale, the remaining *S. alterniflora* to the west still posed threats to avian species because of restricted food resources and limited range of visibility. In addition, Shatian Harbor is situated ~600 m south of the study area, and daily transportation and construction activities potentially accompanied by sound pollution may have influenced birds to move further seaward.

Among the macrobenthos, gastropods and malacostracans are dominant, yet the compositions remained variant within the considerations of total richness, abundance, and biomass. Gastropoda species in mangrove wetlands are known to be efficient consumers of microalgae, suggesting that their populations and distributions are primarily influenced by the presence of microalgae [68] [69]. Young mangrove seedlings with fewer branches and leaves may contribute to higher efficiency in the photosynthesis of microalgae [68]. Several crab species belonging to Malacostraca also have a preference for habitats with favorable sunlight [11]. However, biodiversity indices of benthos have also shown fluctuations during the research period. One possible explanation might be engineering activities such as deep turning and landfills for cordgrass treatments. Such approaches, combined with the presence of remaining belowground *S. alterniflora* roots and shoots may exert additional efforts for benthic communities to resettle and recover [70] [71]. In addition, planted mangroves in early stages may not yet have the capability to produce adequate litterfalls to feed benthos and to trap the organic matter by root systems compared to mature forests [72] [73]. This suggests that the biodiversity of benthic communities may increase in the long term as the mangrove stands continue to mature.

This study, which focuses on the preliminary stage of mangrove ecological restoration, has not shown anticipated improvements in ecological aspects. However, to achieve the success of mangrove restoration and conservation on a larger scale, the results still provide a valuable baseline for ongoing research in Beibu Gulf region. Methodology employed in this study, which synthesizes data within one year of investigations into plants, birds, and benthos, is valuable for project designers and implementers to consider and could be adapted in similar mangrove restoration projects with necessary adjustments based on the scale and specific conditions. It is strongly recommended to integrate following ecological monitoring activities during initial phases, including project design. In addition to the field survey, there have been small groups of cordgrasses recovering in the edge of study site after spring 2023. Despite efforts to increase planting density and improve competitiveness, *S. alterniflora* can still disperse and reestablish itself in certain areas. Regular maintenance is of paramount importance, not only to enhance the quality and effectiveness of ecological restoration but also to prevent other potential anthropogenic disturbances. Further research is necessary to evaluate the effectiveness of the entire project, and stakeholders should also contemplate comprehensive solutions on a larger scale to eliminate the threat of invasive species permanently.

5. Conclusions

Comprehensive approaches combining physical approaches with artificial plantation were implemented to address the issue of invasive cordgrass, specifically *Spartina alterniflora* invasion within mangrove wetlands. Monitoring results including the growth conditions of planted native one-year-old *R. stylosa* seedlings and propagules, as well as the biodiversity of avian and macrobenthic species were recorded every 3 - 4 months. Survival rate of planted seedlings reached 80.6% and the average above-ground biomass has 19 - 22 g improvements in three plots after investigations in 8 months, despite of significant growth based on statistical analysis. Monitored 29 avian species with 197 individuals appeared certain significance while the results of 163 individuals from 14 macrobenthic species indicated instability during the research period. The biodiversity of avian and benthic species within the study area also exhibited a similar seasonal pattern where biodiversity indices reached the peak in April 2023, indicating a level of preference for the transitional season. However, after monitoring for eight months, the changes and effects of the ongoing ecological restoration efforts in these wetlands remain uncertain at the current stage. It is important to acknowledge that this is merely a snapshot in time, and long-term monitoring is essential to gain a deeper understanding of the dynamics and success of coastal wetland ecosystems as they continue to evolve. Furthermore, this study holds particular significance given the limited existing research that addresses changes in the early stages of both mangrove restoration and smooth cordgrass clearance. The results may serve as a starting point for stakeholders to focus on the establishment of new seedlings and contemplate strategies to enhance ecosystem services on a larger scale, aligning with long-term sustainable development goals. As a valuable reference point, the present research sheds light on the initial outcomes of these conservation and restoration endeavors. Further investigations will be critical to track the progression and succession of these ecosystems, providing meaningful insights for ongoing and future restoration efforts.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Cui, B., Xie, T., Wang, Q., Li, S., Yan, J., Yu, S., Liu, K., Zheng, J. and Liu, Z. (2017) Impact of Large-Scale Reclamation on Coastal Wetlands and Implications for Ecological Restoration, Compensation, and Sustainable Exploitation Framework. *Bulletin of Chinese Academy of Sciences* (*Chinese Version*), **32**, 418-425.

[2] Feller, I.C., Lovelock, C.E., Berger, U., McKee, K.L., Joye, S.B. and Ball, M. (2010) Biocomplexity in Mangrove Ecosystems. *Annual Review of Marine Science*, **2**, 395-417. https://doi.org/10.1146/annurev.marine.010908.163809

[3] Costanza, R., Pérez-Maqueo, O., Martinez, M.L., Sutton, P., Anderson, S.J. and Mulder, K. (2008) The Value of Coastal Wetlands for Hurricane Protection. *AMBIO*: *A Journal of the Human Environment*, **37**, 241-248. https://www.jstor.org/stable/25547893 https://doi.org/10.1579/0044-7447(2008)37[241:TVOCWF]2.0.CO;2

[4] Howard, J., Hoyt, S., Isensee, K., Telszewski, M. and Pidgeon, E. (2014) Coastal Blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors in Mangroves, Tidal Salt Marshes, and Seagrass Meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature, Arlington.

[5] Rogers, K., Saintilan, N., Mazumder, D. and Kelleway, J.J. (2019) Mangrove Dynamics and Blue Carbon Sequestration. *Biology Letters*, **15**, Article ID: 20180471. https://doi.org/10.1098/rsbl.2018.0471

[6] Chen, L. (2019) Invasive Plants in Coastal Wetlands: Patterns and Mechanisms. In: An, S. and Verhoeven, J., Eds., *Wetlands*: *Ecosystem Services*, *Restoration and Wise Use*, Springer, Cham, 97-128. https://doi.org/10.1007/978-3-030-14861-4_5

[7] Lee, S.Y. and Khim, J.S. (2017) Hard Science Is Essential to Restoring Soft-Sediment Intertidal Habitats in Burgeoning East Asia. *Chemosphere*, **168**, 765-776. https://doi.org/10.1016/j.chemosphere.2016.10.136

[8] Lin, P. (1999) Mangrove Ecosystem in China. Science Press, Beijing.

[9] Wang, W. (2021) Research of Conservation and Restoration Strategy of Mangrove Wetlands in China. China Environmental Science Press, Beijing.

[10] Wang, W. and Wang, M. (2007) The Mangroves of China. Science Press, Beijing.

[11] Macintosh, D.J., Ashton, E.C. and Havanon, S. (2002) Mangrove Rehabilitation and Intertidal Biodiversity: A Study in the Ranong Mangrove Ecosystem, Thailand. *Estuarine, Coastal and Shelf Science*, **55**, 331-345. https://doi.org/10.1006/ecss.2001.0896

[12] Fan, H. and Li, G. (1997) Effect of Sea Dike on the Quantity, Community Characteristics and Restoration of Mangrove Forest along Guangxi Coast. *Chinese Journal of Applied Ecology*, **3**, 240-244.

[13] Bernhardt, K.G. and Koch, M. (2003) Restoration of a Salt Marsh System: Temporal Change of Plant Species Diversity and Composition. *Basic and Applied Ecology*, **4**, 441-451. https://doi.org/10.1078/1439-1791-00180

[14] Zhang, Y., Huang, G., Wang, W., Chen, L. and Lin, G. (2012) Interactions between Mangroves and Exotic *Spartina* in an Anthropogenically Disturbed Estuary in Southern China. *Ecology*, **93**, 588-597. https://doi.org/10.1890/11-1302.1

[15] National Forestry and Grassland Administration of China, Ministry of Natural Resources of the People's Republic of China, Ministry of Ecology and Environment of the People's Republic of China, Ministry of Water Resources of the People's Republic of China and Ministry of Agriculture and Rural Affairs of the People's Republic of China (2023) Special Action Plan for *Spartina alterniflora* Treatment (2022-2025).

[16] Ayres, D.R., Smith, D.L., Zaremba, K., Klohr, S. and Strong, D.R. (2004) Spread of Exotic Cordgrasses and Hybrids (*Spartina Sp.*) in the Tidal Marshes of San Francisco Bay, California, USA. *Biological Invasions*, **6**, 221-231. https://doi.org/10.1023/B:BINV.0000022140.07404.b7

[17] Lacambra, C., Cutts, N., Allen, J., Burd, F. and Elliot, M. (2004) Spartina Anglica: A Review of Its Status, Dynamics and Management. Research Report, English Nature, Peterborough.

[18] Adams, J., van Wyk, E. and Riddin, T. (2016) First Record of *Spartina Alterniflora* in Southern Africa Indicates Adaptive Potential of This Saline Grass. *Biological Invasions*, **18**, 2153-2158. https://doi.org/10.1007/s10530-015-0957-5

[19] Xu, G. and Zhuo, R. (1985) Preliminary Studies of Introduced *Spartina Alterniflora* Loisel in China. *Journal of Nanjing University*, **40**, 212-225.

[20] Mao, D., Liu, M., Wang, Z., Li, L., Man, W., Jia, M. and Zhang, Y. (2019) Rapid Invasion of *Spartina Alterniflora* in the Coastal Zone of Mainland China: Spatiotemporal Patterns and Human Prevention. *Sensors*, **19**, Article 2308. https://doi.org/10.3390/s19102308

[21] Chen, L., Wang, W., Zhang, Y. and Lin, G. (2009) Recent Progresses in Mangrove Conservation, Restoration and Research in China. *Journal of Plant Ecology*, **2**, 45-54. https://doi.org/10.1093/jpe/rtp009

[22] Wan, S., Qin, P., Liu, J. and Zhou, H. (2009) The Positive and Negative Effects of Exotic *Spartina Alterniflora* in China. *Ecological Engineering*, **35**, 444-452. https://doi.org/10.1016/j.ecoleng.2008.05.020

[23] Meng, W., Feagin, R.A., Innocenti, R.A., Hu, B., He, M. and Li, H. (2020) Invasion and Ecological Effects of Exotic Smooth Cordgrass *Spartina Alterniflora* in China. *Ecological Engineering*, **143**, Article ID: 105670. https://doi.org/10.1016/j.ecoleng.2019.105670

[24] An, S., Gu, B., Zhou, C., Wang, Z., Deng, Z., Zhi, Y., Li, H., Chen, L., Yu, D. and

Liu, Y. (2007) *Spartina* Invasion in China: Implications for Invasive Species Management and Future Research. *Weed Research*, **47**, 183-191. https://doi.org/10.1111/j.1365-3180.2007.00559.x

[25] Chen, B., Liu, C. and Yuan, Y. (2020) Harm and Control Measures of *Spartina Alterniflora* Based on Bibliometrics. *Acta Agriculturae Shanghai*, **36**, 90-95.

[26] Strong, D.R. and Ayres, D.A. (2016) Control and Consequences of *Spartina Spp.* Invasions with Focus upon San Francisco Bay. *Biological Invasions*, **18**, 2237-2246. https://doi.org/10.1007/s10530-015-0980-6

[27] Patten, K. (2003) Persistence and Non-Target Impact of Imazapyr Associated with Smooth Cordgrass Control in an Estuary. *Journal of Aquatic Plant Management*, **41**, 1-6.

[28] Mo, X., Dong, P., Xie, L., Xiu, Y., Wang, Y., Wu, B., Liu, J., Song, X., Zhang, M. and Zhang, Z. (2021) Effects of Imazapyr on *Spartina Alterniflora* and Soil Bacterial Communities in a Mangrove Wetland. *Water*, **13**, Article 3277. https://doi.org/10.3390/w13223277

[29] Yuan, L., Zhang, L., Xiao, D. and Huang, H. (2011) The Application of Cutting plus Waterlogging to Control *Spartina Alterniflora* on Saltmarshes in the Yangtze Estuary, China. *Estuarine*, *Coastal and Shelf Science*, **92**, 103-110. https://doi.org/10.1016/j.ecss.2010.12.019

[30] Vila, M. and Weiner, J. (2004) Are Invasive Plant Species Better Competitors than Native Plant Species?—Evidence from Pair-Wise Experiments. *Oikos*, **105**, 229-238. https://doi.org/10.1111/j.0030-1299.2004.12682.x

[31] Grevstad, F., Wecker, M. and Strong, D. (2004) Biological Control of *Spartina*. *Proceedings of the Conference on Invasive Spartina*, San Francisco, 8-9 November 2004.

[32] Wundrow, E.J., Carrillo, J., Gabler, C.A., Horn, K.C. and Siemann, E. (2012) Facilitation and Competition among Invasive Plants: A Field Experiment with Alligatorweed and Water Hyacinth. *PLOS ONE*, **7**, e48444. https://doi.org/10.1371/journal.pone.0048444

[33] Wang, Q., Duarte, C., Song, L., Christakos, G., Agusti, S. and Wu, J. (2021) Effects of Ecological Restoration Using Non-Native Mangrove Kandelia Obovata to Replace Invasive *Spartina Alterniflora* on Intertidal Macrobenthos Community in Maoyan Island (Zhejiang, China). *Journal of Marine Science and Engineering*, **9**, Article 788. https://doi.org/10.3390/jmse9080788

[34] Zhou, T., Liu, S., Feng, Z., Liu, G., Gan, Q. and Peng, S. (2015) Use of Exotic Plants to Control *Spartina Alterniflora* Invasion and Promote Mangrove Restoration. *Scientific Reports*, **5**, Article No. 12980. https://doi.org/10.1038/srep12980

[35] Tomlinson, P.B. (2016) The Botany of Mangroves. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781139946575

[36] Duke, N., Ball, M. and Ellison, J. (1998) Factors Influencing Biodiversity and Distributional Gradients in Mangroves. *Global Ecology & Biogeography Letters*, **7**, 27-47. https://doi.org/10.2307/2997695

[37] Alongi, D.M. (2008) Mangrove Forests: Resilience, Protection from Tsunamis, and Responses to Global Climate Change. *Estuarine*, *Coastal and Shelf Science*, **76**, 1-13. https://doi.org/10.1016/j.ecss.2007.08.024

[38] Kathiresan, K. and Bingham, B.L. (2001) Biology of Mangroves and Mangrove Ecosystems. *Advances in Marine Biology*, **40**, 81-251. https://doi.org/10.1016/S0065-2881(01)40003-4

[39] Zhou, Y., Huang, J., Han, W. and Yang, S. (2013) Spatial Distribution Patterns of Natural *Rhizophora Stylosa* Population. *Guihaia*, **33**, 496-501.

[40] Forestry Bureau of Guangxi Zhuang Autonomous Region (2021) Guangxi Mangrove Afforestation and Restoration Technical Guide (Trial).

[41] Guangdong Provincial Department of Natural Resources and Guangdong Provincial Forestry Bureau (2022) Mangrove Ecological Restoration Technical Guide. Guangdong Province.

[42] Fan, H. and Wang, W. (2017) Some Thematic Issues for Mangrove Conservation in China. *Journal of Xiamen University* (*Natural Science*), **56**, 323-330.

[43] Wang, L., Yu, H., Li, C. and Sun, N. (2018) Progress in Marine Ecosystem Restoration. *Journal of Applied Oceanography*, **37**, 435-446.

[44] Fan, H. and Mo, Z. (2018) The History, Achievements and Lessons Learnt for Mangrove Restoration in Guangxi, China. *Guangxi Science*, **25**, 363-371.

[45] State Oceanic Administration of China (2017) Technical Guideline for Mangrove Vegetation Restoration.

[46] Evin, L.A. and Talley, T.S. (2000) Influences of Vegetation and Abiotic Environmental Factors on Salt Marsh Invertebrates. In: Weinstein, M.P. and Kreeger, D.A., Eds., *Concepts and Controversies in Tidal Marsh Ecology*, Springer, Dordrecht, 661-707. https://doi.org/10.1007/0-306-47534-0_30

[47] Borja, A., Franco, J. and Pérez, V. (2000) A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos within European Estuarine and Coastal Environments. *Marine Pollution Bulletin*, **40**, 1100-1114. https://doi.org/10.1016/S0025-326X(00)00061-8

[48] Lee, S. (2008) Mangrove Macrobenthos: Assemblages, Services, and Linkages. *Journal of Sea Research*, **59**, 16-29. https://doi.org/10.1016/j.seares.2007.05.002

[49] Zhu, Z., Cozzoli, F., Chu, N., Salvador, M., Ysebaert, T., Zhang, L., Herman, P.M. and Bouma, T.J. (2016) Interactive Effects between Physical Forces and Ecosystem Engineers on Seed Burial: A Case Study Using *Spartina Anglica*. *Oikos*, **125**, 98-106. https://doi.org/10.1111/oik.02340

[50] Choi, C., Li, J. and Xue, W. (2020) China Coastal Waterbird Census Report (Jan. 2012-Dec. 2019). Hong Kong Bird Watching Society. Hong Kong.

[51] Xia, S., Yu, X., Millington, S., Liu, Y., Jia, Y., Wang, L., Hou, X. and Jiang, L. (2017) Identifying Priority Sites and Gaps for the Conservation of Migratory Waterbirds in China's Coastal Wetlands. *Biological Conservation*, **210**, 72-82. https://doi.org/10.1016/j.biocon.2016.07.025

[52] Gan, X., Cai, Y., Choi, C., Ma, Z., Chen, J. and Li, B. (2009) Potential Impacts of Invasive Smooth Cordgrass *Spartina Alterniflora* Spread on Bird Communities at Chongming Dongtan, a Chinese Wetland of International Importance. *Estuarine, Coastal and Shelf Science*, **83**, 211-218. https://doi.org/10.1016/j.ecss.2009.03.026

[53] Okoye, O.K., Li, H. and Gong, Z. (2020) Retraction of Invasive *Spartina Alterniflora* and Its Effect on the Habitat Loss of Endangered Migratory Bird Species and Their Decline in YNNR Using Remote Sensing Technology. *Ecology and Evolution*, **10**, 13810-13824. https://doi.org/10.1002/ece3.6971

[54] Zhao, C., Li, J., Gong, L. and Luo, J. (2014) Effect of *Spartina Alterniflora* Invasion on Benthic Macro-Invertebrates in Coastal Wetlands of Beihai,Guangxi Zhuang Autonomous Region. *Wetland Science*, **12**, 733-739.

[55] Wan, H., Wang, Q., Jiang, D., Fu, J., Yang, Y. and Liu, X. (2014) Monitoring the Invasion of *Spartina Alterniflora* Using Very High Resolution Unmanned Aerial

Vehicle Imagery in Beihai, Guangxi (China). *The Scientific World Journal*, **2014**, Article ID: 638296. https://doi.org/10.1155/2014/638296

[56] Zhao, C., Liu, X., Bai, J., Lü, F. and Li, J. (2014) Impact of *Spartina Alterniflora* on Benthic Macro-Invertebrates Communities on Mangrove Wetland in Xicungang Estuary, Guangxi. *Biodiversity Science*, **22**, 630-639.

[57] Yang, J., Tang, J. and He, S. (1994) Characterization and Chemical Composition of Forest Trees and Their Interrelationships with Coastal Broken Soils and Tidal Flats Salt Soils in Beihai City, Guangxi, China. *Chinese Journal of Soil Science*, **25**, 158-162.

[58] National Forestry and Grassland Administration of China (2013) Technical Regulation for Control of *Spartina* Species by Mangroves.

[59] Komiyama, A., Poungparn, S. and Kato, S. (2005) Common Allometric Equations for Estimating the Tree Weight of Mangroves. *Journal of Tropical Ecology*, **21**, 471-477. https://doi.org/10.1017/S0266467405002476

[60] Komiyama, A., Ong, J.E. and Poungparn, S. (2008) Allometry, Biomass, and Productivity of Mangrove Forests: A Review. *Aquatic Botany*, **89**, 128-137. https://doi.org/10.1016/j.aquabot.2007.12.006

[61] Ardhana, I.P.G., Rimbawan, I.M.G.S., Cahyo, P.N., Fitriani, Y. and Rohani, S. (2018) The Distribution of Vertical Leaves and Leaves Biomass on Ten Mangrove Species at Ngurah Rai Forest Park, Denpasar, Bali, Indonesia. *Biodiversitas Journal of Biological Diversity*, **19**, 918-926. https://doi.org/10.13057/biodiv/d190322

[62] State Oceanic Administration of China (2005) Technical Specification for Eco-Monitoring of Mangrove Ecosystem.

[63] Krauss, K.W., Lovelock, C.E., McKee, K.L., López-Hoffman, L., Ewe, S.M. and Sousa, W.P. (2008) Environmental Drivers in Mangrove Establishment and Early Development: A Review. *Aquatic Botany*, **89**, 105-127. https://doi.org/10.1016/j.aquabot.2007.12.014

[64] Peng, Y., Diao, J., Zheng, M., Guan, D., Zhang, R., Chen, G. and Lee, S.Y. (2016) Early Growth Adaptability of Four Mangrove Species under the Canopy of an Introduced Mangrove Plantation: Implications for Restoration. *Forest Ecology and Management*, **373**, 179-188. https://doi.org/10.1016/j.foreco.2016.04.044

[65] Musilová, Z., Musil, P., Zouhar, J., Šenkýřová, A., Pavón-Jordán, D. and Nummi, P. (2022) Changes in Wetland Habitat Use by Waterbirds Wintering in Czechia Are Related to Diet and Distribution Changes. *Freshwater Biology*, **67**, 309-324. https://doi.org/10.1111/fwb.13842

[66] Chen, Q., Xu, G., Wu, Z., Kang, P., Zhao, Q., Chen, Y., Lin, G. and Jian, S. (2020) The Effects of Winter Temperature and Land Use on Mangrove Avian Species Richness and Abundance on Leizhou Peninsula, China. *Wetlands*, **40**, 153-166. https://doi.org/10.1007/s13157-019-01159-6

[67] Liu, J., Yi, C., Tang, S., Zhang, W., Wen, K., Qin, C., Huang, L., Liu, D. and Jiang, A. (2023) Impact of Coastal Island Restoration Engineering and Subsequent Tourism on Migratory Waterbirds: A 3-year Case from Southern China. *Restoration Ecology*, **31**, e13974. https://doi.org/10.1111/rec.13974

[68] Chen, G.C. and Ye, Y. (2011) Restoration of *Aegiceras Corniculatum* Mangroves in Jiulongjiang Estuary Changed Macro-Benthic Faunal Community. *Ecological Engineering*, **37**, 224-228. https://doi.org/10.1016/j.ecoleng.2010.10.003

[69] Kon, K., Kurokura, H. and Tongnunui, P. (2010) Effects of the Physical Structure of Mangrove Vegetation on a Benthic Faunal Community. *Journal of Experimental*

Marine Biology and Ecology, **383**, 171-180.
https://doi.org/10.1016/j.jembe.2009.11.015

[70] Lyu, C., Zhang, S., Ren, X., Liu, M., Leung, K.K., He, T., Chen, Q. and Choi, C. (2023) The Effect of *Spartina Alterniflora* Eradication on Waterbirds and Benthic Organisms. *Restoration Ecology*, **31**, e14023. https://doi.org/10.1111/rec.14023

[71] Neira, C., Grosholz, E.D., Levin, L.A. and Blake, R. (2006) Mechanisms Generating Modification of Benthos following Tidal Flat Invasion by a *Spartina* Hybrid. *Ecological Applications*, **16**, 1391-1404.
https://doi.org/10.1890/1051-0761(2006)016[1391:MGMOBF]2.0.CO;2

[72] Chen, G., Gao, M., Pang, B., Chen, S. and Ye, Y. (2018) Top-Meter Soil Organic Carbon Stocks and Sources in Restored Mangrove Forests of Different Ages. *Forest Ecology and Management*, **422**, 87-94. https://doi.org/10.1016/j.foreco.2018.03.044

[73] Feng, J., Zhou, J., Wang, L., Cui, X., Ning, C., Wu, H., Zhu, X. and Lin, G. (2017) Effects of Short-Term Invasion of *Spartina Alterniflora* and the Subsequent Restoration of Native Mangroves on the Soil Organic Carbon, Nitrogen and Phosphorus Stock. *Chemosphere*, **184**, 774-783.
https://doi.org/10.1016/j.chemosphere.2017.06.060