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Current Status and Potential Invasiveness Evaluation of an Exotic Mangrove Species, *Laguncularia racemosa* (L.) C.F. Gaertn, on Hainan Island, China

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Abstract: *Laguncularia racemosa* is widely planted in coastal mudflats as a pioneer species of mangrove afforestation in China; however, whether it exhibits invasiveness as an exotic species has been a topic of debate. In this study, we investigated the distribution, community structure, and population characteristics of *L. racemosa* on Hainan Island, China, to discuss its potential invasiveness. The results showed that Hainan Island has become an important distribution area for *L. racemosa* in China, covering a total area of 64.90 ha. In this investigation, a total of 11 true mangrove species, belonging to six families and 11 genera, were discovered in the *L. racemosa* community throughout Hainan Island. Furthermore, *L. racemosa* exhibited a strong adaptive range to seawater salinity and demonstrated a high capacity for natural dispersion. *L. racemosa* exhibited high importance values in the tree, shrub, and seedling layers of this artificial community, indicating its dominance and potential exclusion of other mangrove species. Over time, the importance values of *L. racemosa* in the tree and shrub layers initially decreased and then increased, while the opposite trend was observed in the seedling layer. Overall, the diversity indexes, including the Simpson index, Shannon–Wiener index, and Pielou community evenness index, were low in the planted *L. racemosa* forest on Hainan Island, suggesting a relatively simple species composition within the *L. racemosa* community. Additionally, based on the height levels of the *L. racemosa* population, we found that it mainly belonged to the first level, characterized by a large number of seedlings on Hainan Island. The number of *L. racemosa* seedlings gradually decreased in subsequent levels, and higher height levels of *L. racemosa* appeared with longer planting times, indicating a growing trend of potential invasiveness of *L. racemosa* on Hainan Island over an extended period. We suggest that the government should be able to list *L. racemosa* as an invasive species that can be harvested in the future. Based on this, this study provides fundamental data and theoretical references for the sustainable prevention, control, and management of the exotic species *L. racemosa* on Hainan Island, and also in other mangrove wetlands in China.

Keywords: mangrove forest; natural dispersion; biodiversity; invasive species

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1. Introduction

Mangroves are particular wetland ecosystems that dominate along the intertidal estuaries and shallow coasts in tropical and subtropical areas [1]. In a global context, mangrove ecosystems occupy approximately 1.7 $\times$ 10^7 ha of coastline, which can cover 60%–75% of tropical and subtropical seacoasts [2,3]. Mangrove forests possess four high properties, including high productivity, a high restitution ratio, a high decomposition ratio, and high stress resistance [2,4]. Since mangrove forests own various large-scale ecosystem services, they are generally considered as "green littoral guardians" [1,5]. To be specific, mangroves themselves can spontaneously serve as a tremendous carbon sink worldwide, and they can also offer indispensable support, for instance, nutrients and shelters, to intertidal living organisms, such as fishes, shrimps, shells, etc. [6,7]. Moreover, for the daily life of human beings, mangroves can form a coastal buffer zone against floods and tsunamis because of their large coverage [8,9]. Therefore, mangrove forests play a vital role in effectively and sustainably maintaining the development of intertidal and marine surroundings.

Globally, despite their huge economic and ecological values, mangrove ecosystems are extremely liable to suffer continuous degradation and destruction due to manifold natural and artificial threats, e.g., gales, temperature and precipitation fluctuations, sea level rising, disease, insect pests, aquaculture, deforestation, pollution, urbanization, and so forth [10–12]. Specifically, Polidoro et al., (2010) and Goldberg et al., (2020) pointed out that mangrove forests have lost more than 30% of their area over the last 50 years [13], and human activities accounted for almost 62% of the total mangrove loss from 2000 to 2016 [14]. In China, the National Investigation of Forest Resource reported that the initial mangrove area covered around 2.5×10^5 ha; nevertheless, it sharply plunged to 4.2×10^4 ha in 1956 [15]. Even worse, at the end of 1980s, Chinese mangrove forests declined to 2.1×10^4 ha and then to 1.5×10^4 ha after a decade because seaside residents carried out land reclamation from 1970 to 1980 [15]. In short, China's mangrove reserves have decreased by approximately 50% from 1950 to 2001 via a sequence of natural and anthropogenic factors. China is thus one of the countries with the highest reduction in mangrove forests worldwide [15,16]. Replanting is a potentially available solution to prevent mangrove destruction. Indeed, taking China as an example, it performed a decade of mangrove afforestation in the early 1990s, increasing the area of its mangrove forests to 2.2×10^4 ha; unfortunately, more than 80% of these planted mangroves belong to degraded secondary forests [15].

Biological invasion has posed a great threat to the biodiversity, functions, and stability of native ecosystems in recent decades [17]. Some essential components, such as water, light, and nutrients, which should belong to native species, can be unscrupulously despoiled by invaders' severe interspecific competitions [18]. Given the characteristics of fragmentation and vulnerability in wetland ecosystems, they are particularly susceptible to invasion by exotic vegetation compared to other ecosystem types [19]. For instance, in order to lessen littoral erosion, southern China purposefully introduced an exotic cordgrass, *Spartina alterniflora* Loisel., from the USA in 1979 [20]. However, *S. alterniflora* has overwhelmingly occupied and expanded native mangrove habitats and ruined the storage of soil organic matter in marshes on a large scale, fixed via two native mangrove species, *Kandelia obovata* Sheue, H.Y. Liu and J. Yong. and *Avicennia marina* (Forssk.) Vierh., which directly posed a great threat to the blue carbon storage and biogeochemical cycle of carbon in mangrove ecosystems [21]. Meanwhile, it is worth noting that replanting a large number of introduced mangrove species must be a new challenge in terms of indigenous mangroves and their environmental rehabilitation. Fourqurean et al., (2010) reported that the crazy invasiveness of Indo-Pacific mangrove plants in South Florida, such as *Bruguiera gymnorrhiza* (L.) Lam. and *Lumnitzera racemosa* Willd., caused severe harm to the survival of tropical Atlantic mangrove forests, including *L. racemosa*, *Rhizophora mangle* L., and *Avicennia germinan* (L.) L. [22]. In addition, the growth and livability of the seedlings of two native mangrove trees, *K. obovata* and *Rhizophora stylosa* Griff., in Leizhou Bay, China, were found to be negatively influenced by the planting density of the exotic mangrove species *Sonneratia apetala* Buch.-Ham. [23]. To sum up, performing intensive research to evaluate the potential invasiveness of exotic species in mangrove wetlands plays a key role in the growth and health of the native mangrove forests.

Laguncularia racemosa (L.) C.F. Gaertn, which belongs to a white mangrove, is naturally distributed along the Atlantic coastline of the Americas (from Bermuda to Brazil, including Florida, the Bahamas, Mexico, and the Caribbean south), the Pacific coastline of the Americas (from Mexico to northwestern Peru), and the west coast of Africa (from

Senegal to Cameroon) [24]. *Laguncularia racemosa* usually acts as a pioneer species in the gaps of disturbed forests or newly created mangrove species, and then overwhelmingly forms a pure stand [25]. In China, *L. racemosa* was first introduced into Dongzhai Harbor Mangrove Natural Reserve, Hainan Province, from La Paz, Mexico, in 1999, which was mainly used to accelerate afforestation in the mangrove ecosystem of southern China as it was reclaimed unscrupulously at the end of the 20th century [26,27]. Since then, based on *L. racemosa*'s specific characteristics, such as quick propagation, fast growth, wide distribution, and strong environmental stress resistance, it has been widely well liked and cultivated in the estuarine and coastal regions of Hainan, Guangxi, Guangdong, and Fujian for mangrove remediation [27]. However, these properties of *L. racemosa* have two sides, which simultaneously bring powerful competition with native mangrove trees and increase *L. racemosa*'s invasion risk [28,29]. Hence, a better assessment of the entire distribution and potential invasiveness of *L. racemosa* would largely maintain the health of native mangrove ecosystems.

In the present work, we aimed to evaluate the distribution status, community structure, and population characteristics of the exotic mangrove species *L. racemosa* across Hainan Island, China, and we also discussed its potential invasiveness with accompanying ecological problems. This study, as a typical case, can provide theoretical references for reasonable management of exotic mangrove species and protection and restoration of native mangrove forests in the future.

2. Materials and Methods

2.1. Research Area

This study was conducted across the entire Hainan Island, China, spanning from 18°8′ N to 20°10′ N and from 108°36′ E to 111°3′ E (Figure 1) during the growing seasons of 2022. Hainan Province, the second largest island in China, is situated at the southernmost tip of the country and is separated from Guangdong Province by the Qiongzhou Strait to the north. Covering an area of approximately 3.39×10^6 ha, Hainan Island experiences a typical tropical monsoon climate. The terrain of the island is predominantly low and flat, with mountainous areas in the central region. The western part of Hainan Island has an annual precipitation of $1.0–2.0 \times 10^3$ mm, with an average of 1600 mm, while the eastern part experiences rainfall of $2.0–2.4 \times 10^3$ mm [30]. With its suitable combination of annual average precipitation and temperature (22–27 °C), Hainan Island boasts abundant forest resources, maintaining a year-round stable forest cover of over 60%, and possesses one of the most favorable ecotopes in China. The island's coastline stretches approximately 1823 km and is dotted with numerous rivers and streams that flow into the sea, creating a rich network of estuary deltas and providing an ideal environment for the growth and reproduction of mangrove forests. Consequently, Hainan Island stands out as one of the regions in China with the widest distribution, the greatest variety, and the richest biodiversity of mangroves [31].

This study was conducted in 8 regions on Hainan Island, and the specific information for our investigated locations is as follows (Table 1).

2.2. Experimental Design

Firstly, the large space, absence of animal interference, and dominance of *L. racemosa* as the primary mangrove tree in the study area were the basic criteria for selecting the sample quadrats for our ecological investigations [32]. We completed 57 quadrat surveys in 8 regions. Since the mangrove trees and shrubs were sparsely distributed within each quadrat, we established a size of 10×10 m^2 for the tree layer and 5×5 m^2 for the shrub layer. The distance between two adjacent sampling quadrats ranged from 0.5 to 1.0 km. The survey was carried out on each arbor and shrub with heights ≥50 cm in all the well-setting quadrats [33]. The following details were noted during the ecological investigation at each sample site:

(1) Plant species, abundance, height, diameter at breast height, and ground diameter;

(2) To comprehensively understand the distribution of *L. racemosa* on Hainan Island, China, we meticulously recorded detailed information regarding its distribution, accurate positioning, acreage, habitat characteristics, origin, sediment type, planting years, mangrove species, and salinity. Salinity was measured in the field using a salinometer (SSG 1000). The planting years and species were known from the government department that grew the mangroves.

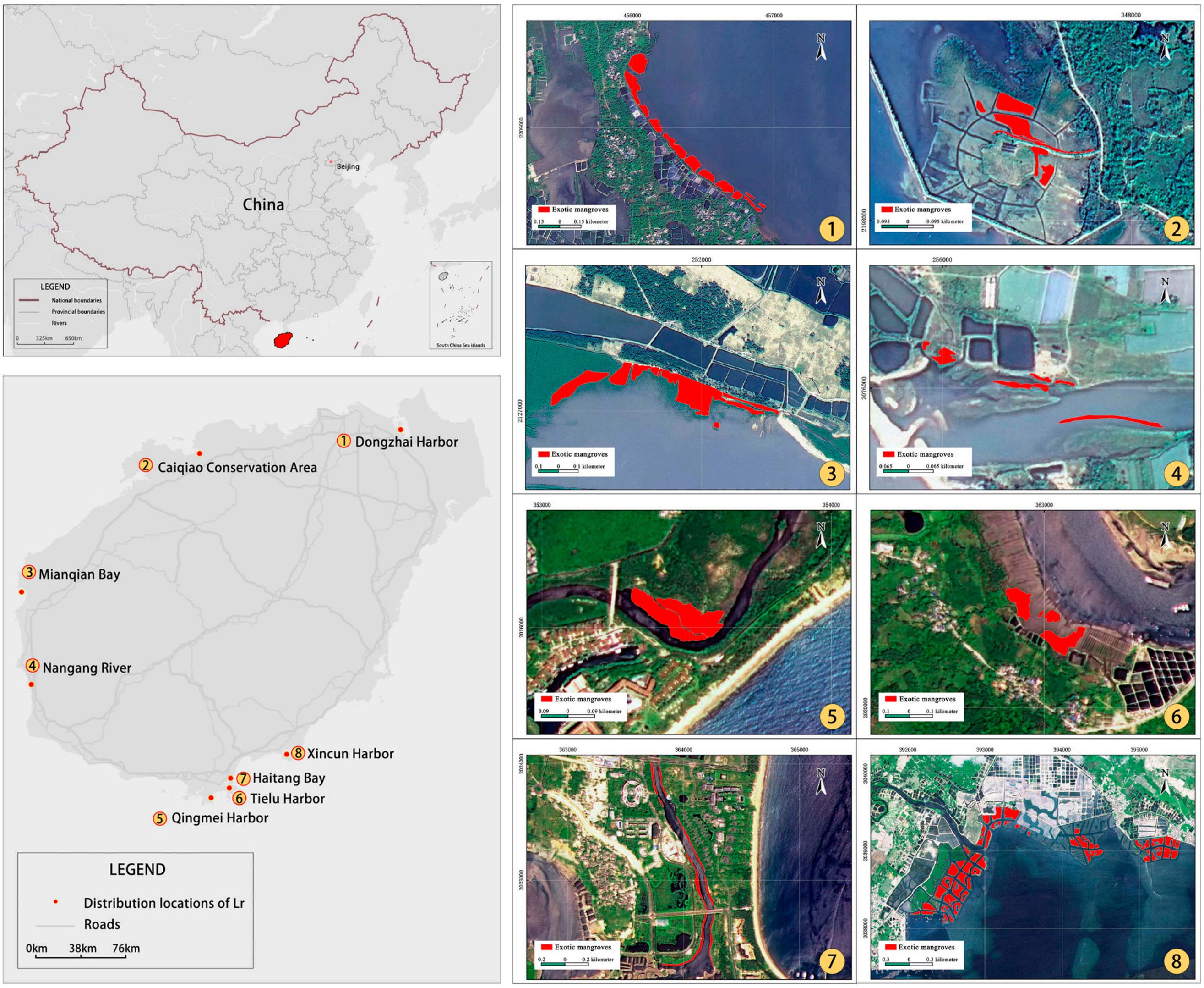

Figure 1. A combination figure showing the geographical research area of the forests of *L. racemosa* on Hainan Island, China. ① Distribution of *L. racemosa* in Dongzhai Harbor; ② distribution of *L. racemosa* in Caiqiao Conservation Area; ③ distribution of *L. racemosa* in Mianqin Bay; ④ distribution of *L. racemosa* in Nangang River; ⑤ distribution of *L. racemosa* in Qingmei Harbor; ⑥ distribution of *L. racemosa* in Tielu Harbor; ⑦ distribution of *L. racemosa* in Haitang Bay; ⑧ distribution of *L. racemosa* in Xincun Harbor.

2.3. Calculations of Several Related Ecological Indices

As a quantitative ecological index, the importance value reflects the status and function of a particular species within a community [34]. The important values were calculated for all mangrove species. The importance value is calculated using the following formula [35,36]:

$$\text{Importance value} = \frac{\text{relative density} + \text{relative frequency} + \text{relative dominance}}{3} \quad (1)$$

where relative density is the density of one species (the density of all species × 100%), relative frequency is the frequency of one species (the frequency of all species × 100%), and relative dominance is the coverage of one species (the dominance of all species × 100%).

Table 1. A table showing the sampled site information of *L. racemosa* forests on Hainan Island, China.

Distribution		Coordinate	Planted Years	Main Planted Mangrove Species
Haikou	Dongzhai Harbor	110°34′ N-19°58′ E–110°35′ N-19°57′ E	2010	*L. racemosa*, *S. apetala*
Lingshui	Xincun Harbor	109°58′ N-18°25′ E–110°0′ N-18°26′ E	2015–2016	*L. racemosa*, *R. stylosa*, *A. marina*
Sanya	Tielu Harbor	109°42′ N-18°15′ E	/	*L. racemosa*
	Qingmei Harbor	109°36′ N-18°13′ E	2009	*L. racemosa*, *S. apetala*
	Haitang Bay	109°42′ N-18°17′ E–108°38′ N-19°12′ E	2010–2011	*L. racemosa*, *S. apetala*
Dongfang	Mianqian Bay	108°38′ N-19°12′ E	2014	*L. racemosa*, *S. apetala*
	Nangang River	108°41′ N-18°45′ E	/	*L. racemosa*
Lingao	Caiqiao Conservation Area	109°32′ N-19°52′ E	2009	*L. racemosa*, *R. stylosa*, *A. corniculatum*

To assess mangrove species diversity in this study, we also calculated the Simpson index (D), Shannon–Wiener index (H′), and Pielou community evenness index (Jsw). These indices were computed as follows:

$$D = 1 - \sum\left(\frac{Ni}{N}\right)^2 \tag{2}$$

$$H' = -\sum\left(\frac{Ni}{N}\right)\ln\left(\frac{Ni}{N}\right) \tag{3}$$

$$Jsw = \frac{H'}{\ln S} = -\sum\frac{Ni}{N}\frac{\ln\frac{Ni}{N}}{\ln S} \tag{4}$$

where N is the total number of plant individuals in each plot, Ni is the number of individuals of a species in each plot, and S is the number of species in each community.

Moreover, the height class of individuals can reflect the dynamic characteristics of the population [37]. According to Zan et al., (2001), we divided the height of the population of *L. racemosa* into 6 levels based on its growth characteristics in this study (Table 2) [37].

Table 2. The definition of height class of the *L. racemosa* population on Hainan Island, China.

Height Range	Level
H < 0.5 m	1
0.5 m ≤ H < 3.0 m	2
3.0 m ≤ H < 5.0 m	3
5.0 m ≤ H < 10.0 m	4
10.0 m ≤ H < 15.0 m	5
15.0 m ≤ H < 20.0 m	6

2.4. Description of Statistical Analysis

All the obtained data were handled via Excel (version 2010), and all the figures in this work were drawn via OriginPro (version 2018). Scatter plots were drawn with Excel (version 2010), treating the importance values of *L. racemosa* in its tree, shrub, and seedling layers as dependent variables. We derived fitted equations that correlate these values with planting years.

3. Results

3.1. Basic Information and Distribution Status of L. racemosa on Hainan Island, China

In total, we investigated 11 species from six families and 11 genera, all of which were true mangrove plants. The mangrove species present in the *L. racemosa* community on Hainan Island included *L. racemosa*, *Sonneratia alba* Sm., *Excoecaria agallocha* L., *K. obovata*, *L. racemosa* (Willd.), *S. apetala*, and *Rhizophora apiculata* Blume. in the tree layer, *L. racemosa*, *S. apetala*, *A. marina*, *S. alba*, *E. agallocha*, *R. stylosa*, *L. racemosa* (Willd.), *B. gymnorhiza*, and *Scyphiphora hydrophyllacea* C. F. Gaertn. in the shrub layer, and *L. racemosa*, *A. marina*, *R. stylosa*, *B. gymnorhiza*, *S. hydrophylacea*, and *K. obovata* in the seedling layer (Appendix A). The total area covered by *L. racemosa* was approximately 64.89 ha, with the main distribution areas being Haikou, Lingshui, Sanya, and Dongfang cities on Hainan Island, China (Table 3).

Table 3. Basic information and distribution status of *L. racemosa* on Hainan Island, China.

Distribution		Acreage (ha)	Habitat Characteristics	Origin	Salinity (%)
Haikou	Dongzhai Harbor	7.29	Mudflat, Silt	Artificial Planting	17.0
Lingshui	Xincun Harbor	36.59	Lagoon, Silt	Artificial Planting	30.4
Sanya	Tielu Harbor	2.31	Lagoon, Silt	Natural Spread	29.5
	Qingmei Harbor	2.79	Riverway, Silt	Artificial Planting	32.2
	Haitang Bay	5.65	Riverway, Silt	Artificial Planting	25.0
Dongfang	Mianqian Bay	7.43	Mudflat, Sand	Artificial Planting	32.0
	Nangang River	0.68	Sea Outfall, Sand	Natural Spread	15.0
Lingao	Caiqiao Conservation Area	2.15	Mudflat, Sand	Artificial Planting	22.5

In addition, the habitat characteristics of *L. racemosa* on Hainan Island were classified into mudflat, lagoon, riverway, and sea outfall. The sediment in these areas consisted mainly of silt or sand due to the species' low living requirements (Table 3). All *L. racemosa* forests were artificially planted in 2009–2016, except for cases of natural spread observed in Tielu Harbor (Lingshui) and Nangang River (Dongfang), indicating the species' strong capacity for autonomous migration (Table 2). The highest salinity value was recorded in Qingmei Harbor (Sanya) at 32.2%, while the lowest value was found in Nangang River (Dongfang) at 15.0% (Table 3).

3.2. Importance Values of L. racemosa on Hainan Island, China

In the case of Hainan Island, where *L. racemosa* and *S. apetala* are two exotic mangrove species, we selected Xinghui Village, Qingmei Harbor, and Haitang Harbor as examples to compare their importance values and assess their current growth statuses. Additionally, Xincun Harbor, known for its diverse native mangrove species, was included as a typical case for importance value research.

As shown in Table 4, it is evident that L. racemosa dominates the community structure of mangroves on Hainan Island. The accompanying woody species in these communities are also mangroves, with *S. apetala* from Xinghui Village, Qingmei Harbor, and Haitang Harbor being the main exotic tree species (Table 4). In contrast, Xincun Harbor only showed a small presence of other mangrove species, such as *A. marina*, *R. stylosa*, *K. obovata*, and *B. gymnorhiza* (Table 4). The importance values of *L. racemosa* were both 100% in the seedling layer of Haitang Harbor and the tree layer of Xincun Harbor, indicating that *L. racemosa* trees dominated these specific communities (Table 4). Interestingly, the importance values of accompanying mangrove species in *L. racemosa* communities were relatively low, suggesting that *L. racemosa* occupies the main ecological niche in all investigated regions on Hainan Island, China (Table 4). Another important finding is that the importance values of *L. racemosa* in its seedling layer were significant, indicating a potential long-term trend of increasing invasiveness on Hainan Island, China (Table 4).

Table 4. The importance values of mangroves in each layer of Dongzhai Harbor, Qingmei Harbor, Haitang Bay, and Xincun Village, Hainan Island, China.

Region	Layer	Species	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	Importance Value (%)
Xinghui Village	Tree	*L. racemosa*	85.93	58.62	82.41	75.65
		S. apetala	12.59	37.93	17.48	22.67
	Shrub	*L. racemosa*	7.33	21.43	19.34	16.03
		S. apetala	1.11	7.14	37.72	15.33
	Seedling	*L. racemosa*	81.13	63.64	/	72.38
Qingmei Harbor	Tree	*L. racemosa*	98.81	77.14	99.67	91.87
		S. apetala	0.22	5.71	0.14	2.03
	Shrub	*L. racemosa*	71.16	57.89	57.76	62.27
	Seedling	*L. racemosa*	51.83	40.91	/	46.37
Haitang Harbor	Tree	*L. racemosa*	90.57	72.73	76.05	79.78
		S. apetala	7.55	18.18	23.09	16.27
	Shrub	*L. racemosa*	95.05	66.67	93.35	85.02
	Seedling	*L. racemosa*	100.00	100.00	/	100.00
Xincun Harbor	Tree	*L. racemosa*	100.00	100.00	100.00	100.00
	Shrub	*L. racemosa*	94.60	42.31	97.37	78.09
		A. marina	2.84	25.27	1.26	9.79
		R. stylosa	2.22	24.73	1.26	9.40
		K. obovata	0.24	3.85	0.06	1.38
		B. gymnorhiza	0.10	3.85	0.06	1.33
	Seedling	*L. racemosa*	99.94	98.75	/	99.35
		B. gymnorhiza	0.06	1.25	/	0.65

By treating the importance values of *L. racemosa* in its tree, shrub, and seedling layers as dependent variables, we derived fitted equations that correlate these values with planting years (Figure 2). The importance value of *L. racemosa* in the tree layer initially decreased and then increased with planting years, maintaining a consistently high level without showing a downward trend (Figure 2a). The relationship between the importance values of *L. racemosa* in the shrub layer and planting years had a relatively weak correlation, with the values declining initially and then increasing (Figure 2b). Conversely, the importance values of *L. racemosa* in the seedling layer exhibited a clear pattern of initially increasing and then decreasing with planting years (Figure 2c). Moreover, the longer the planting time, the more pronounced the decline in importance values of the *L. racemosa* seedling layer (Figure 2c). Once the planting year reached the 10th year, the importance values of *L. racemosa* in its seedling layer declined rapidly (Figure 2c).

3.3. Biodiversity Indexes of L. racemosa Community on Hainan Island, China

Overall, the D values in the tree layer of the *L. racemosa* community were significantly higher compared to the H′ and Jsw values (Figure 3a). However, no clear patterns were observed in the shrub and seedling layers of the *L. racemosa* community (Figure 3b,c). Additionally, in the Nangang River, which consisted of a pure planted forest of *L. racemosa*, the values of D, H′, and Jsw were all integrated as 1, 0, and 0, respectively (Figure 3). The H′ and Jsw values were relatively high in Xinghui Village, Qingmei Harbor, and Tielu Harbor, indicating a rich species diversity and relatively uniform distribution of individual species, while the D index values were low, suggesting that the dominance of *L. racemosa* was not prominent in these regions (Figure 3). On the other hand, in the Nangang River and Xincun Harbor, the H′ and Jsw values were low, while the D index values were high, indicating the dominance of *L. racemosa* with other species also occupying a significant proportion of the ecological niche (Figure 3). Moreover, the shrub layer exhibited higher H′ and Jsw values compared to both the tree layer and seedling layer, while the D index values showed the opposite trend (Figure 3). In the seedling layer, only *L. racemosa* seedlings were found, and no other mangrove species' seedlings were present in Xincun Harbor, Haitang Bay Inner River, Mianqian Bay, and Nangang River (Figure 3c).

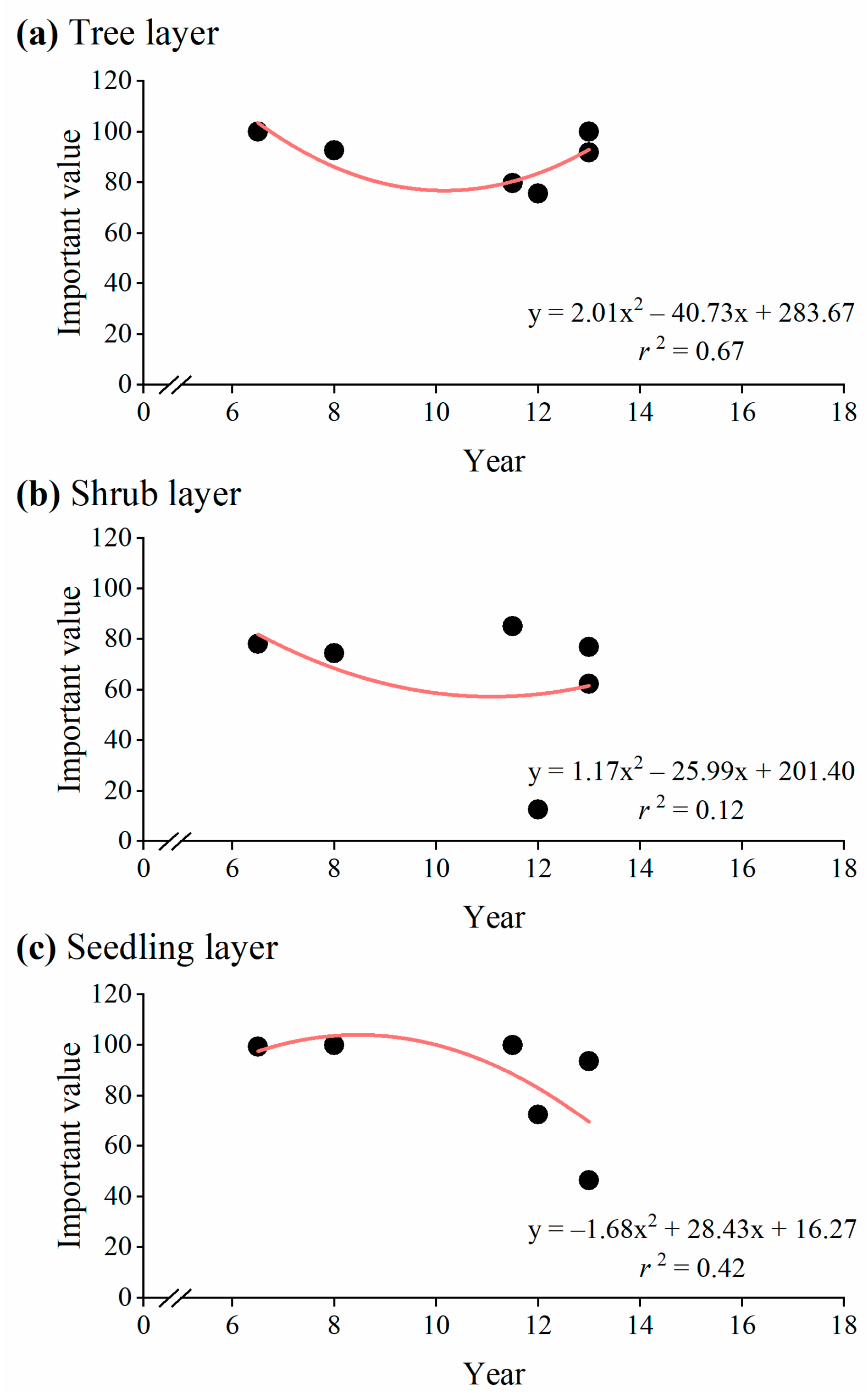

Figure 2. The relationship between importance values and planting years of *L. racemosa* in terms of layers of trees (**a**), shrubs (**b**), and seedlings (**c**) on Hainan Island, China. Each dark spot indicates a value of three replicates. The curved line in each figure stands for a fitted equation that correlates important values with planting years for *L. racemosa*.

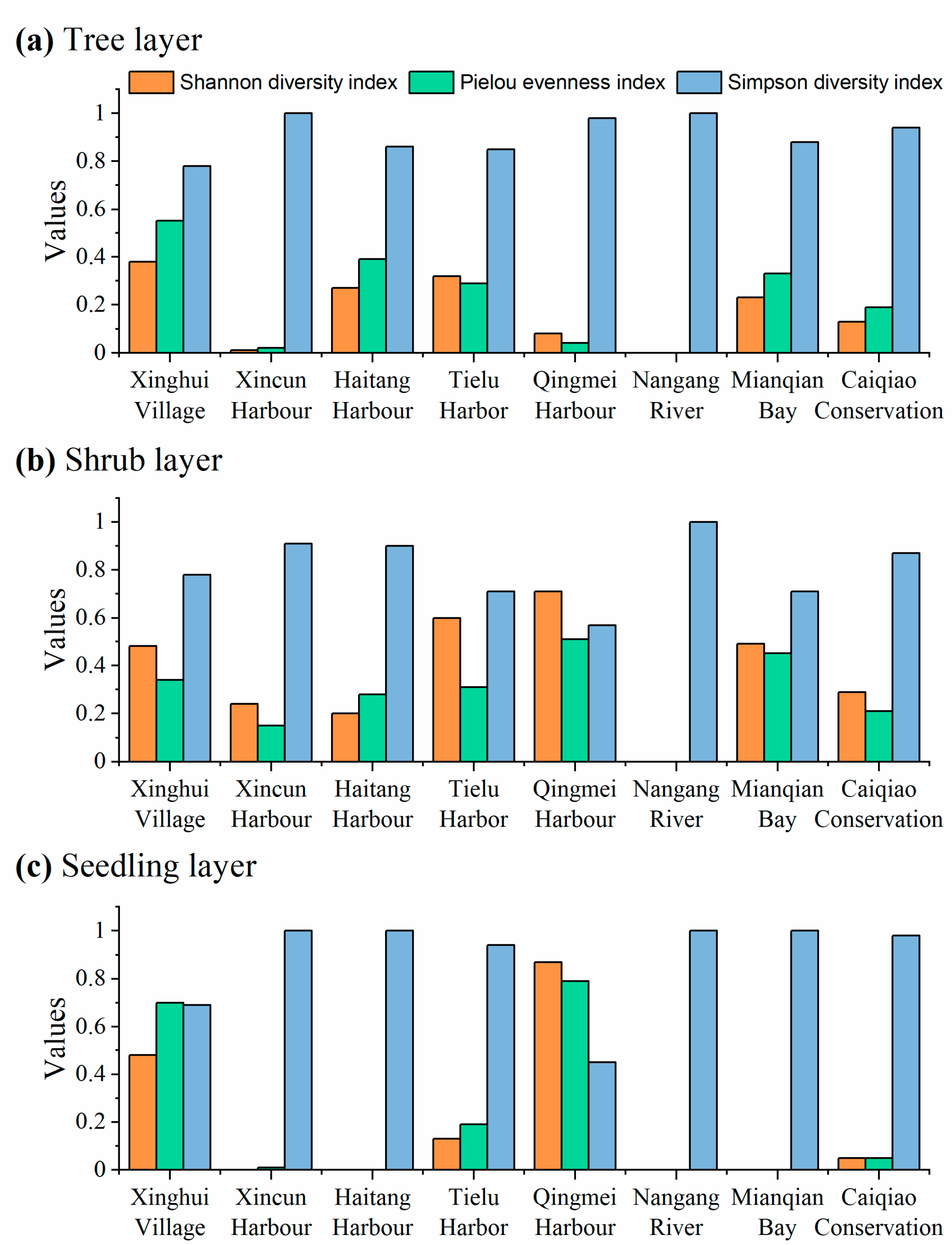

Figure 3. The Simpson, Shannon, and Pielou diversity indexes of *L. racemosa* in terms of layers of trees (**a**), shrubs (**b**), and seedlings (**c**) on Hainan Island, China. Each column indicates a value of three replicates.

3.4. Population Characteristics of L. racemosa on Hainan Island, China

As depicted in Figure 4, the height levels of the *L. racemosa* population in this study were categorized into five classes. The majority of *L. racemosa* individuals on Hainan Island belonged to level 1, with fewer individuals at levels 4 and 5 (Figure 4). Specifically, in Xincun Harbor, Nangang River, Caiqiao Conservation Area, and Tielu Harbor, the height levels were primarily composed of level 1, with a smaller proportion in level 2 (Figure 4). On the other hand, Mianqian Bay had the highest representation of different height levels, with a decreasing trend as the levels increased (Figure 4). Qingmei Harbor and Haitang Bay exhibited levels 4 and 5 in the height distribution of *L. racemosa*, accompanied by the highest number for level 1 and the lowest number for level 3 (Figure 4). Xinghui Village had the highest value for level 1 in the height levels of *L. racemosa*, with level 4 being more prevalent than level 2 and level 3 (Figure 4). Notably, Qingmei Harbor, Haitang Bay, and Xinghui Village, where *L. racemosa* had been planted for a longer period artificially, showed the presence of level 5, and the value of level 1 in Qingmei Harbor, which had the longest planting time, was the lowest (Figure 4). Conversely, Tielu Harbor, characterized by natural diffusion, had the highest value for level 1 (Figure 4). The densities of *L. racemosa* populations in Xincun Harbor, Nangang River, and Tielu Harbor were significantly higher, with values of 130.81 individuals (ind)/m^2, 68.42 ind/m^2, and 66.29 ind/m^2, respectively, compared to other regions (Figure 4).

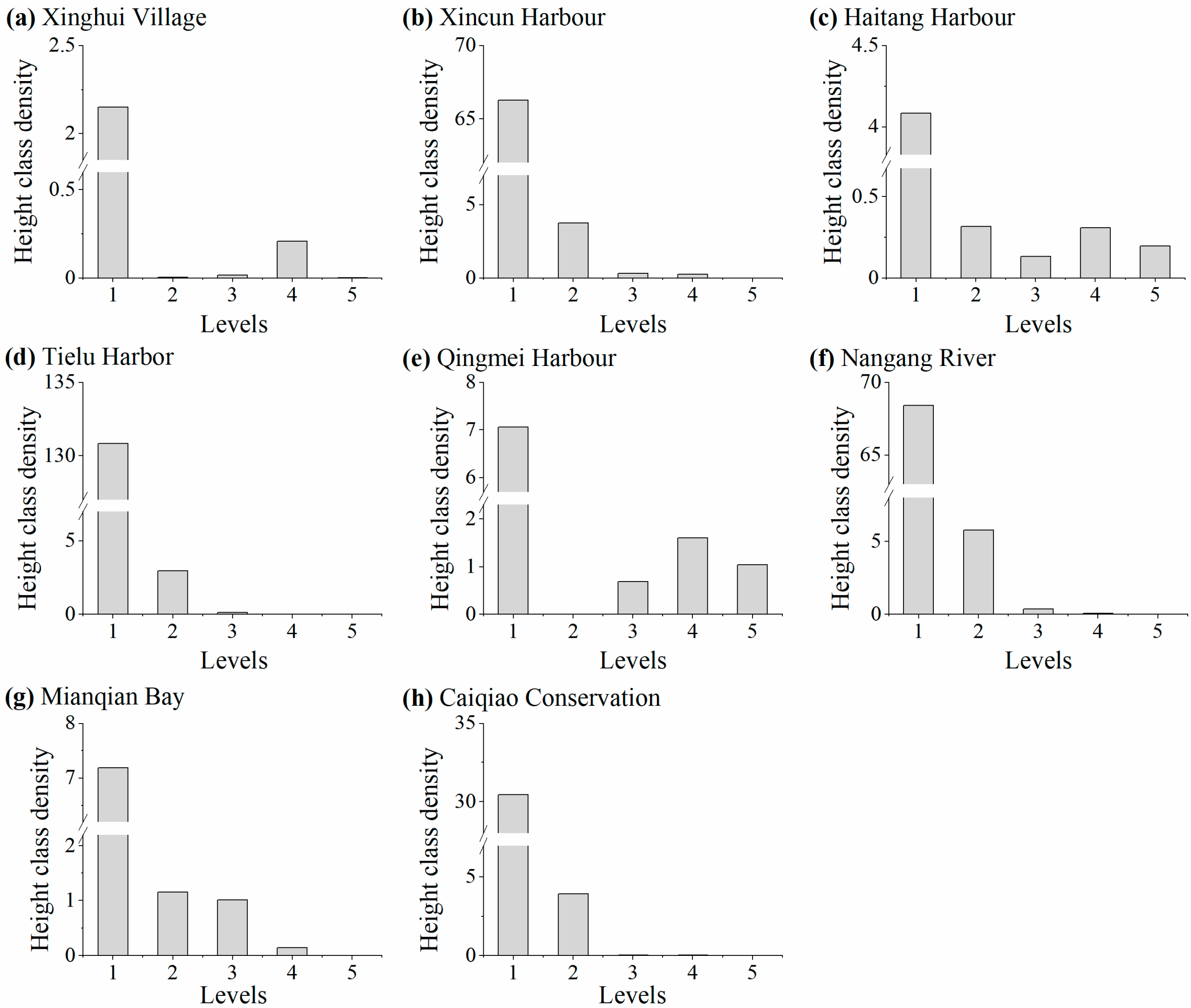

Figure 4. The height levels of *L. racemosa* population on Hainan Island, China. Each column indicates a value of three replicates.

4. Discussion

There is no doubt that mangrove forests play a critical role in coastal wetland ecosystems in tropical and subtropical regions worldwide, such as coastal protection and maintenance of wetland ecological functions [38]. However, the phenomenon of exotic invasion emerges in an endless stream while cultivating introduced mangrove trees [22,23]. In this study, we investigated the current status and tried to evaluate the potential invasiveness of an exotic mangrove species, *L. racemosa*, on the entire Hainan Island, China. This work may allow us to better understand how to manage exotic mangrove species reasonably and protect and restore native mangrove forests sustainably. At present, the invasive *L. racemosa* has not received enough attention in China, and the government has not realized the impact of *L. racemosa* on local species and ecosystems. We hope that *L. racemosa* can be classified as an invasive species and can be harvested reasonably and legally in the future. For China, *L. racemosa* is a typical exotic mangrove species artificially cultivated on Hainan Island in 1999 [26]. In this research, we first found that after 24 years of artificial afforestation and natural diffusion, the target exotic mangrove tree, *L. racemosa*, was distributed widely across the whole of Hainan Island, China (Figure 1). Meanwhile, *L. racemosa* could settle in mudflats, lagoons, estuaries, and bays with a large range of salinity resistance (15.0%–32.2%, Table 3). These results indicated that *L. racemosa* has a strong adaptability to various types of environments and possesses the abilities of strong natural diffusion and potential invasiveness. Indeed, a previous study from Lang et al., (2022) on the cold adaptation of *L. racemosa* reported that its seeds would not germinate at a relatively low temperature, such as 5 °C; however, they could recover themselves and germinate after transferring to a suitable temperature (25 °C), implying that it could also endure low temperatures (5 °C) and tolerate cold winters; hence, through ocean current shifting and invasiveness, its tens of thousands of seeds could settle spontaneously in coastal regions at high latitudes in China, such as northeastern Fujian and southeastern Zhejiang, and replace native mangrove plant species, thereby breaking the ecological structures and functions of local mangrove ecosystems [29].

Another finding from this research via the investigation of *L. racemosa* community structures was that the importance values of *L. racemosa* in its community were the highest despite the layers of trees, shrubs, and seedlings (Table 4), suggesting that the reserve of *L. racemosa* was overwhelmingly higher than that of any other accompanying species. Indeed, a previous study reported that *L. racemosa* was widely considered a typical pioneer species found in the interior of mangroves and the transition to restinga forests [39]. This result was roughly identical to our latest study reporting that the importance values of the planted *K. obovata* and *S. caseolaris* were significantly higher than those of their accompanying species, such as *S. apetala* and *B. gymnorrhiza*, in the Pearl River Estuary, China [40]. Interestingly, the importance values of *L. racemosa* in terms of its tree and shrub layers first decreased and then increased with the increase in planting years; however, the dynamic result was the opposite in its seedling layer, which implied that with the increase in planting years, *L. racemosa* grew into shrubs and trees and dominated in their layers, while *L. racemosa* decreased gradually with the increase in planting years in the seedling layer since it was a light-loving species and not shade tolerant (Figure 2). Indeed, a low temperature (5 °C) inhibited the net photosynthetic rate, water use efficiency, transpiration rate, and stomatal conductance in seedlings of *L. racemosa*, whose leaves elicited an obvious symptom of wilting at the same time, and, surprisingly, these abovementioned photosynthetic parameters exhibited a self-restoring performance immediately when these *L. racemosa* seedlings were transferred to an appropriate temperature [29], which could account for our findings in the present study.

Through the research on biodiversity indexes of the *L. racemosa* community, overall, we found that the values of D, H′, and Jsw from the *L. racemosa* community were relatively low (Figure 3). This result was mainly because *L. racemosa* had a stronger invasive potential, and it then occupied widespread natural habitats and an ecological niche, resulting in intense competition with other native mangrove species, especially for water and nutrients, which was strongly consistent with the theory proposed by Alexandra and Peter [41]. For starters, *L. racemosa* displayed stronger advantages in growth, dispersion, and tolerance to environmental stresses compared to native mangrove species [28,29]. Moreover, one of the previous studies from Li et al., (2019) held an ecological comparison analysis between *L. racemosa* and *S. apetala* (another exotic mangrove species in China), which revealed that *L. racemosa* possessed a wider ground diameter circumference, taller tree height, and lower leaf construction cost than *S. apetala*, indicative of a higher capacity of invasiveness from *L. racemosa* [42]. However, we also discovered that Xinghui Village, Qingmei Harbor, and Xincun Harbor exhibited higher biodiversity indexes of *L. racemosa* communities than other places (Figure 3), which was mainly because these three areas were close to the Mangrove Natural Reserve, where there were more provenances in the native mangroves surrounding, and the probability of seeds and seedlings drifting into the *L. racemosa* communities was relatively greater.

In various regions of Hainan Island, the height levels of the *L. racemosa* population belonged to level 1 seedlings, and it elicited a trend of the number of *L. racemosa* seedlings gradually decreasing (Figure 4). In addition, levels 4 and 5 appeared in the regions with a longer planting time (Figure 4). Indeed, the regeneration of the plant community depended first on the availability and quantity of plant propagules, especially seeds [43], whereas in wetland ecosystems, the availability and quantity of seedlings in the seedling layer played key roles in the regeneration of the mangrove forests [44]. Combining our findings and evidence, we assert that a growing tendency of potential invasiveness of *L. racemosa* on Hainan Island, China, would exist persistently without disappearing anytime soon. Therefore, how to limit the strong capacity of potential invasiveness from *L. racemosa* and its spread for the protection and management of native mangrove plants needs to be handled first in future research. However, at least at this stage, this work will be quite a challenge.

5. Conclusions

L. racemosa has been introduced in China for over 20 years, and its planting area has been gradually expanding. It has become one of the primary mangrove afforestation trees in China's coastal shelterbelts. In our study, we discovered a total of 11 true mangrove species belonging to six families and 11 genera during the investigation of the *L. racemosa* community on Hainan Island, China. The background investigation, community structure analysis, and population characteristics assessment of *L. racemosa* on Hainan Island revealed its wide salt-tolerant range and strong natural diffusion ability. As it grows, the importance values of *L. racemosa* in the tree, shrub, and seedling layers were significantly higher than those of other species, indicating its strong dominance. The importance values of *L. racemosa* in terms of its tree and shrub layers first decreased and then increased with the increase in planting years; however, the dynamic result was the opposite in its seedling layer. Overall, the biodiversity indexes of the *L. racemosa* community on Hainan Island were low, indicating that the species in the *L. racemosa* community were relatively simple. *L. racemosa* appears to be very invasive, and it has crowded out the growth space of other planted mangrove trees in the same period. Moreover, from the analysis of population characteristics of *L. racemosa*, we found that the high levels of the *L. racemosa* population was mainly in the stage of level 1 with a large number of seedlings; it elicited a trend of the number of *L. racemosa* seedlings gradually decreasing, and levels 4 and 5 appeared with a longer planting time, which showed that an increasing trend of potential invasiveness of *L. racemosa* would exist persistently with a long period of time on Hainan Island, China.

Author Contributions: C.C., H.Z. and Y.C. (Yiqing Chen) conceived of the original research project and selected methods. X.K. supervised the experiments. C.C., C.Z., X.L., M.Z., Y.C. (Yu Chen) and Z.F. performed most of the experiments. T.L. provided technical assistance to C.C., C.Z., X.L., M.Z., Y.C. (Yu Chen) and T.L. C.C. wrote the article. H.Z. and Y.C. (Yiqing Chen) refined the project and revised the writing. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. The importance values of all the species mangroves in each layer of Dongzhai Harbor, Qingmei Harbor, Haitang Bay, and Xincun Village, Hainan Island, China.

Region	Layer	Species	Relative Density (5%)	Relative Frequency (5%)	Relative Dominance (5%)	Importance Value (5%)
Xinghui Village	Tree	*L. racemosa*	85.93%	58.62%	82.41%	75.65%
		S. apetala	12.59%	37.93%	17.48%	22.67%
		K. obovata	1.48%	3.45%	0.11%	1.68%
	Shrub	*R. stylosa*	87.78%	50.00%	40.38%	59.39%
		K. obovata	7.78%	21.43%	8.56%	12.59%
		L. racemosa (Willd)	3.33%	21.43%	13.34%	12.70%
		S. apetala	1.11%	7.14%	37.72%	15.33%
	Seedling	*L. racemosa*	81.13%	63.64%	-	72.38%
		R. stylosa	18.87%	36.36%	-	27.62%
Xincun Harbor	Tree	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
	Shrub	*L. racemosa*	94.60%	42.31%	97.37%	78.09%
		A. marina	2.84%	25.27%	1.26%	9.79%
		R. stylosa	2.22%	24.73%	1.26%	9.40%
		K. obovata	0.24%	3.85%	0.06%	1.38%
		B. gymnorrhiza	0.10%	3.85%	0.06%	1.33%
	Seedling	*L. racemosa*	99.94%	98.75%	-	99.35%
		B. gymnorrhiza	0.06%	1.25%	-	0.65%
Tielu Harbor	Tree	*L. racemosa*	92.59%	71.43%	97.84%	87.29%
		S. apetala	5.56%	14.29%	1.78%	7.21%
		S. alba	1.85%	14.29%	0.38%	5.51%
	Shrub	*L. racemosa*	83.05%	45.71%	49.68%	59.48%
		A. marina	13.17%	25.71%	47.59%	28.82%
		K. obovata	3.01%	17.14%	2.57%	7.57%
		S. alba	0.49%	5.71%	0.05%	2.08%
		S. apetala	0.21%	2.86%	0.08%	1.05%
		B. gymnorrhiza	0.07%	2.86%	0.04%	0.99%
	Seedling	*L. racemosa*	97.03%	84.21%	-	90.62%
		A. marina	2.87%	10.53%	-	6.70%
		K. obovata	0.09%	5.26%	-	2.68%
Qingmei Harbor	Tree	*L. racemosa*	98.81%	77.14%	99.67%	91.87%
		K. obovata	0.67%	8.57%	0.03%	3.09%
		S. apetala	0.22%	5.71%	0.14%	2.03%
		L. racemosa (Willd)	0.15%	2.86%	0.02%	1.01%
		E. agallocha	0.07%	2.86%	0.13%	1.02%
		R. apiculata	0.07%	2.86%	0.02%	0.98%
	Shrub	*L. racemosa*	71.16%	57.89%	57.76%	62.27%
		K. obovata	25.34%	31.58%	36.51%	31.14%
		S. hydrophyllacea	3.45%	7.89%	5.40%	5.58%
		E. agallocha	0.06%	2.63%	0.33%	1.01%
	Seedling	*L. racemosa*	51.83%	40.91%	-	46.37%
		S.hydrophyllacea	5.96%	9.09%	-	7.53%
		K. obovata	42.20%	50.00%	-	46.10%
Haitang Harbor	Tree	*L. racemosa*	90.57%	72.73%	76.05%	79.78%
		A. marina	1.89%	9.09%	0.86%	3.95%
		S. apetala	7.55%	18.18%	23.09%	16.27%
	Shrub	*L. racemosa*	95.05%	66.67%	93.35%	85.02%
		A. marina	4.95%	33.33%	6.65%	14.98%
	Seedling	*L. racemosa*	100.00%	100.00%	-	100.00%
Mianqian Bay	Tree	*L. racemosa*	93.88%	84.62%	99.60%	92.70%
		A. marina	6.12%	15.38%	0.40%	7.30%
	Shrub	*L. racemosa*	82.62%	50.00%	90.46%	74.36%
		A. marina	16.67%	42.86%	8.87%	22.80%
		R. stylosa	0.72%	7.14%	0.67%	2.84%
	Seedling	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
Nangang River	Tree	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
	Shrub	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
	Seedling	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
Caiqiao Conservation Area	Tree	*L. racemosa*	100.00%	100.00%	100.00%	100.00%
	Shrub	*L. racemosa*	93.12%	41.30%	96.33%	76.92%
		A. marina	5.50%	34.78%	2.75%	14.34%
		R. stylosa	0.71%	17.39%	0.09%	6.06%
		L. racemose (Willd)	0.67%	6.52%	0.83%	2.68%
	Seedling	*L. racemosa*	99.19%	88.00%	-	93.59%
		R. stylosa	0.68%	8.00%	-	4.34%
		A. marina	0.14%	4.00%	-	2.07%

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