forests

MDPI

Article

Unveiling Distribution Patterns and Community Characteristics of Rare and Endangered Plants in the Sanya River Basin, China

Hongjuan Zhu [1,2,3,4], Dan He [1,2,3,4], Xialan Cheng [5], Liufeng Chen [6], Zhenyuan Zhang [6], Yi Tang [7], Jing Yu [1,2,3,4] and Dongmei Yang [1,2,3,4,*]

1 Sanya Nanfan Research Institute, Hainan University, Sanya 572025, China
2 School of Horticulture, Hainan University, Haikou 570228, China
3 Key Laboratory for Quality Regulation of Tropical Horticultural Crops of Hainan Province (Hainan University), Haikou 570228, China
4 Hainan Yazhou Bay Seed Laboratory, Sanya 572025, China
5 School of Life Since and Technology, Lingnan Normal University, Zhanjiang 524048, China
6 College of Forestry and Landscape Architecture, South China Agriculture University, Guangzhou 510642, China
7 College of Horticulture and Gardening, Southwest Forestry University, Kunming 650224, China
* Correspondence: ydm5711@hainanu.edu.cn

Abstract: Wetlands have an important ecological function and economic value. However, with economic development and urban expansion, wetland plants have suffered serious damage. Rare and endangered plants are "thermometers" that reflect the health processes of their ecosystems. To better protect the wetlands in Sanya, China, we systematically investigated and analyzed the species, quantities, distributions, and community characteristics of the rare and endangered plants in the Sanya River basin using the sample and sample strip methods. We established a total of 152 quadrats, of which 46 contained rare and endangered plants. We identified 27 rare and endangered plants that mainly appeared in the tree and shrub layers. The dominant families and genera of the community were evident. However, the proportion of families and genera with fewer or single species was high, indicating that the species composition of the community is complex, and the plant species diversity is rich. The dominant species in each layer of the community were evident, and the rare and endangered plants are occasional species of the community. The community similarity in the urban areas was high, indicating that the rare and endangered plants in these areas require highly homogenous habitats. The community similarity in the suburbs was low, indicating that the rare and endangered plants in these areas are highly adaptable to different habitats. Threat factors and vegetation coverage degree had a significant impact on the number of species and population size of rare and endangered plants. Finally, according to our study and IUCN classification criteria for the endangered levels, Sonneratia × gulngai meets the CR (Critical Endangered) assessment criteria, thus we recommend upgrading it to the endangered level from VU (Vulnerable).

Keywords: rare and endangered plants; wetlands; Sanya River basin; quadrat survey; community characteristics; spatial distribution; plant protection

Citation: Zhu, H.; He, D.; Cheng, X.; Chen, L.; Zhang, Z.; Tang, Y.; Yu, J.; Yang, D. Unveiling Distribution Patterns and Community Characteristics of Rare and Endangered Plants in the Sanya River Basin, China. *Forests* **2023**, *14*, 176. https://doi.org/10.3390/f14020176

Academic Editors: Nancai Pei, Qian (Chayn) Sun, Jiali Jin and Zezhou Hao

Received: 1 December 2022
Revised: 12 January 2023
Accepted: 16 January 2023
Published: 18 January 2023

1. Introduction

Urbanization primarily includes economic development, spatial expansion, and population migration, and it is necessary to realize the transformation from rural areas to modern cities, promote regional socioeconomic development, and modernize China [1–3]. As a smokeless industry, tourism has become an important driving force for urban economic growth, and its development has a profound impact on local economies, cultures, and ecological environments [4]. Urbanization is a double-edged sword. In the process of urbanization and tourism development, the ecological environment is often the victim of the urbanization process [5]. Excessive urbanization leads to changes in the structures and functions of ecosystems, poses a serious threat to local ecological environments, and creates enormous pressure on resources and challenges to environmental protection [6].

Wetlands are transitional zones that are formed by the interaction between aquatic and terrestrial ecosystems [7,8] and include river, lake, marsh, coastal, and artificial wetlands, with important ecological functions and economic value [9,10]. Moreover, wetlands are the ecosystems with the highest primary productivity and richest biodiversity on earth [11], and wetland vegetation can prevent or mitigate the erosion of the coastlines and rivers in estuaries caused by sea waves, thereby promoting siltation and land formation [9,12,13]. At the same time, the aquatic plants in wetlands can help to absorb and metabolize heavy metals and decompose organic pollutants, thereby playing a critical role in water purification. Therefore, wetlands are of enormous importance to the maintenance of the ecological balance and the sustainable development of human society.

China's wetland areas cover 660,000 km^2, accounting for one-tenth of the world's wetlands, and ranking first in Asia and fourth in the world. The wetland areas of Hainan Province, China, cover about 3822 km^2 [14], with a wetland rate of one-ninth, of which the offshore and coastal wetlands make up the largest area, with mangroves, coral reefs, and seagrass beds, followed by artificial wetlands, while the lake and marsh wetland areas are relatively small. Hainan has superior water and temperature conditions, where mangroves account for one-third of the total mangrove area in China [15]. With rich plant species, Hainan is a good subject for studying the formation and maintenance mechanisms of the mangrove plants in China, and even globally. Sanya is in the southernmost part of Hainan Province, China, with a wetland rate of about one-twentieth, accounting for 125/3 of the total wetland area of the province [16]. Although the wetland area in Sanya is small and the proportion of wetlands in the whole province is not high, Sanya is rich in wetland types. According to a 2019 survey, the wetland coverage rate of the Sanya River Basin National Wetland Park is one-third, with 473 species of vascular plants that belong to 333 genera and 110 families [17].

Rare and endangered plants are plants that have important economic, scientific, cultural, and educational value. However, their distribution areas are relatively limited and their populations are usually small [18]. Their distributions are highly dependent on haphazard diffusion, the early land use, and specific habitats [19]. In recent years, the rapid increase in the human population and scientific and technological progress have led to the uncontrolled plundering of natural resources, and rare and endangered plants have been subjected to the double stresses of human interference and their own evolutionary bottlenecks. The disappearance and extinction of rare and endangered plants will destroy the balance of entire ecosystems because the extinction of one plant not only means the loss of its genetic, cultural, and scientific contributions but also the loss of from 10 to 30 other associated plants [20]. To more effectively protect rare and endangered plants and their ecosystems, researchers have begun to conduct studies on their genetic diversity, the community characteristics, distribution patterns, and dynamic changes in their populations and communities, their interspecific relationships with one another, and their in situ and ex situ protection [18,21–25]. Researchers have demonstrated that rare and endangered plants are often in weak positions in terms of community competition, and the competition between the different growth types of endangered plant communities may be quite different [26,27]. By analyzing the characteristics of endangered plants and their communities, as well as the development trends of the communities and the dynamic changes in the numbers of species, we can effectively reveal the endangerment processes and mechanisms of rare and endangered species [28].

With economic development and urban expansion, wetland plants have suffered serious damage. The mangrove area on Hainan Island has decreased from nearly 10,000 hectares in the 1950s to 4891 hectares in 2013 [29], which has seriously affected the survival of rare and endangered plants, such as *Scyphiphora hydrophyllacea* Gaertn. F., Lumnitzera littorea (Jack) Voigt, and *Sonneratia alba* J. Smith [30–33]. Conversely, the living statuses of rare and endangered plants can reflect the health levels of the ecosystems in which they live. Therefore, it is urgent that we strengthen the protection of wetlands, maintain the balance of wetland ecosystems, protect wetland plant germplasm resources, and especially protect rare and endangered plants for the maintenance and protection of wetland ecosystems.

Sanya is an international tourism city with tropical seashore scenery that is known as the "Oriental Hawaii". Sanya's unique natural environment has also become a habitat for many plants. Since the construction of an international free trade port in Hainan began in 2019, Sanya has become a pioneer in Hainan's internationalization and has accelerated its urbanization process, and its tourism has also seen vigorous development. Therefore, Sanya is a unique region for evaluating the relationship between urbanization and urban biodiversity, and especially the protection of endangered species. The Sanya River basin is a typical tropical urban watershed that includes hills, sea, reservoirs, and grasslands, and it is a part of the urban green space system. The basin is close to people and has frequent human activities; thus it is a good model for studying the survival statuses of urban wetland plants. The rare and endangered plants in urban wetlands are "susceptible groups" in the urbanization and internationalization of Sanya, and their survival statuses are the "thermometer" of the health of Sanya's urban wetland ecosystems. Therefore, systematic analyses of the statuses of the rare and endangered plants in Sanya's urban wetlands are of critical importance for their protection and management.

2. Materials and Methods

2.1. Overview of Study Area

The research area was the center of the city of Sanya, Hainan Province, China, which is at 18.2179° N–18.3940° N and 109.3866° E–109.5896° E. The region has a typical tropical marine monsoon climate with long summers and short winters. The hottest month of the year is June, with an average temperature of 29 °C. The coldest month is January, with an average temperature of 22 °C. The annual precipitation is 1500–2200 mm, and the relative humidity is 77% (data source: https://www.timeanddate.com/ 15 August 2022).

The research areas in this study were the Sanya River National Wetland Park and the Sanya River Mangrove Nature Reserve, with a total area of 2368.26 hectares (Figure 1). Sanya River National Wetland Park is mainly located in the suburbs of Sanya, and it is used for agricultural production activities. The park consists of the Sanya East River District, with 703.45 hectares, and the Sanya West River District, with 1139.79 hectares, with a total planning area of 1843.24 hectares, including the Tangta, Shuiyuanchi, Banling, and Caopeng Reservoirs. The latter is located in the urban center of Sanya with frequent human activities, and it includes the mangroves of the Sanya and Linchun Rivers, including Mangrove Ecological Park, Jinjiling Qiaotou Park, and Egret Park.

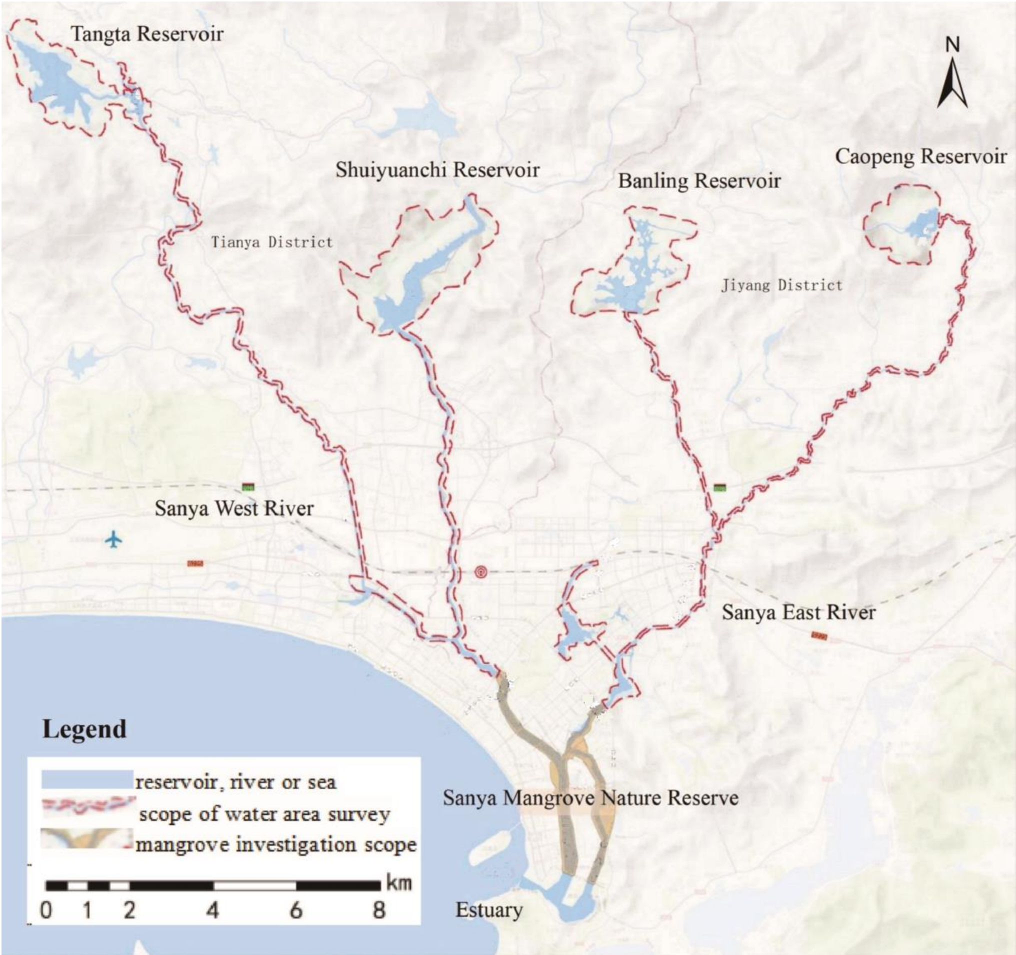

Figure 1. Map of Sanya River Basin in Sanya City, Hainan Province, China. The study area includes Tangta Reservoir and Shuiyuanchi Reservoir on the West River of Sanya, Banling Reservoir and Caopeng Reservoir on the East River of Sanya, and the mangrove nature reserve in the city center.

2.2. Study Design

From March to July 2022, we investigated the entire Sanya River basin. For the sections with rich species and that were relatively concentrated in wide distribution areas, we adopted the typical sampling method, according to the different vegetation and habitat types [34,35]. We established quadrats of either 10 m $\times$ 10 m or 5 m $\times$ 20 m, and we obtained the number of quadrats for each sample plot by using the "species-area curve" method [34]. For arbors with DBHs (diameters at breast height) $\geq$ 2 cm and heights $\geq$ 2 m, we measured their numbers, heights, DBHs, and crown widths. For the shrubs and arbors with DBHs < 2 cm and heights < 2 m, we measured their numbers, heights, base diameters, and crown widths. For the herbs, we established another 2 m $\times$ 2 m quadrat, and we measured the numbers, areas, and average heights of the herbs. For the vines, we included herbaceous vines in the herb layer, woody vines with DBHs $\geq$ 2 cm in the tree layer, and woody vines with DBHs < 2 cm in the shrub layer.

For the areas where the species were not abundant and the distribution scopes were relatively scattered, we adopted the transect method to record the names and numbers of the plant species.

In this study, we recorded the plants with protection grades from I to II on the List of National Key Protected Wild Plants in China (2021), and we regarded the plants with VU (vulnerable), EN (endangered), and CR (critically endangered) threat levels on China's Biodiversity Red List (Ministry of Environmental Protection and Chinese Academy of Sciences, 2015) as rare and endangered plants (Figure S1). *Sonneratia* $\times$ *gulngai* N.C. Duke

& B.R. Jackes is not listed on the List of National Key Protected Wild Plants (2021), and it is classified as VU but at the NT (near threatened) level on China's Biodiversity Red List (Ministry of Environmental Protection and Chinese Academy of Sciences, 2015). However, it has also been recorded as a rare and endangered plant. We adopted *Flora of China* (2013) for plant identification [36]. According to the distribution areas and origins of the plants, we divided them into Chinese endemic, Hainan endemic, and invasive alien species.

2.3. Data Processing

We calculated species importance value with Excel, to clarify the statuses of the dominant species and the rare and endangered plants in the community. We calculated the species diversity indexes of the tree, shrub, and herb layers and the similarity degree between communities with Excel, to analyze the species richness and community complexity and similarity. We used SPSS25 to clarify the main factors influencing the population size and species number of rare and endangered plants.

In addition, we input the data required for the mapping into Excel, such as the longitudes and latitudes of the sample plots and the distributions of rare and endangered plants, and then imported the Excel data into the software Arcmap.

2.3.1. Species Importance Value

The importance value of a species can reflect the value and role of the species in the community to a certain extent, and we can use it to compare the importance values of various species in the community. We calculated the importance value of each species in the tree, shrub, and herb layers of the communities in which rare and endangered plants were located [37,38]:

$$\text{Relative abundance}(A_R) = \frac{\text{Number of trees of a species in the sample plot}}{\text{The total number of all species in the sample plot}} \times 100\%$$

$$\text{Relative frequency}(F_R) = \frac{\text{Frequency of a species in the sample plot}}{\text{Sum of frequency of all species in the sample plot}} \times 100\%$$

$$\text{Relative significance}(D_R) = \frac{\text{Average sum of DBH of a species in the sample plot}}{\text{Sum of average DBH of all species in the sample plot}} \times 100\%$$

$$\text{Relative coverage}(C_R) = \frac{\text{Coverage of a species in the quadrat}}{\text{Total coverage of all species in the sample plot}} \times 100\%$$

Importance value of tree layer: (IV) = $(A_R + F_R + D_R)/3$
Importance values of shrub layer and herb layer: (IV) = $(A_R + F_R + C_R)/3$

2.3.2. Community Species Diversity

(1) The species richness index is a quantitative index that we can use to describe the species richness of a community. The commonly used index is the Margalef richness index (d_{Ma}), which we calculate as follows [37,38]:

$$d_{Ma} = \frac{(S-1)}{lnN}$$

where S is the number of species in the sample plot, and N is the number of total individuals in the observed quadrat;

(2) The diversity index is an indicator that we can use to judge whether a community is stable. The index combines species diversity and abundance. The common diversity index and its calculation formula are as follows [37,38]:

Shannon–Wiener (H) calculation formula:

$$H = 1 - \sum_{i=1}^{s} (P_i ln p_i)$$

Simpson diversity index (D) calculation formula:

$$D = 1 - \sum_{i=1}^{s} P_{i^2}$$

where S is the number of all species in the quadrat and Is the ratio of the number of species individuals (i) to the number of individuals of all the species in the quadrat;

(3) Community evenness (E) refers to the evenness of species abundance. The calculation formula is as follows [37,38]:

$$E = \frac{H}{lnS}$$

where H refers to the Shannon–Wiener index and S refers to the number of species in the community.

2.3.3. Community Similarity

Community similarity refers to the similarity degree between different community structures [39], and it has two methods of expression: (1) common species similarity; (2) species composition similarity [40]. We can use the Jaccard similarity index to indicate the similarity degree of the species composition [41], which we calculate as follows:

$$C_j = \frac{j}{a + b - j}$$

where C_j is the similarity coefficient of the species in different communities, a and b represent the numbers of species in two different communities, and j represents the same number of species in two different groups. A C_j value between 0 and 0.25 indicates "very different", a C_j value between 0.25 and 0.5 indicates "medium dissimilarity", a C_j value between 0.5 and 0.75 indicates "medium similarity", and a C_j value between 0.75 and 1 indicates "very similar".

2.3.4. Correlation Analysis

In order to assess which factor influences population size and species number of rare and endangered plants significantly, we analyzed the correlation between four influencing factors (vegetation types, vegetation coverage degree, vegetation improvement degree, and threat factors) and population size and species number of rare and endangered plants, respectively. Individual number represent population size. The influencing factors, individual number, and species number were recorded respectively for each plot with rare and endangered plants. Vegetation coverage degree and vegetation improvement degree were cited from land use reports of Sanya river national wetland park [42] (data are not yet published). Vegetation improvement degree reflects the change in vegetation in the Sanya river basin from 1991 to 2021 based on NDVI (Normalized Difference Vegetation Index), and vegetation coverage degree is based on the vegetation coverage in the Sanya river basin in 2021. We assigned different values for different vegetation types, vegetation coverage degree, vegetation improvement degree, and threat factors (Table 1). Single-factor analysis, two-factor analysis, and multi-factor analysis were conducted. There were in total 30 correlation analyses. $p < 0.05$ indicates significant difference; $p < 0.01$ indicates extremely significant difference.

Table 1. Assignment values of different influencing factors.

Threat Factor	Assignment Value	Vegetation Type	Assignment Value	Vegetation Coverage Degree	Assignment Value	Vegetation Improvement Degree	Assignment Value
Pests and diseases	1	Grassland	1	Medium vegetation coverage area	1	Unchanged	1
Entertainment activities	2	Bush and grass	2	Medium and high vegetation coverage area	2	Slightly improved	2
Native woody liana	3	Tropical shrub	3	High vegetation coverage area	3	Improved	3
Domestic sewage discharge	4	Mangrove	4				
Economic forest planting	5	Tropical monsoon secondary forest	5				
Crop planting	6						
Alien invasive species	7						
Urban construction project	8						

3. Results

3.1. Sample Plot Survey

In this survey, we established a total of 152 woody quadrats and 14 pure herb quadrats, and we screened 46 quadrats containing rare and endangered plants (Figure 2). The Sanya River basin has a variety of vegetation types due to the impact of the heterogeneous urban and rural habitats and water gradients. With reference to the vegetation type classification standard of Fang Jingyun et al. (2020), as well as the actual characteristics of the Sanya flora, we identified seven natural and two artificial vegetation types in the survey area (Table 2). The natural vegetation is primarily secondary tropical monsoon forest. The Shuiyuanchi Reservoir is rich in vegetation types, including secondary tropical monsoon forest, tropical shrubs, shrub grass, and grassland), and the six urban parks and vegetation areas on the Sanya River East Road contain typical mangroves, which are distributed in the saltwater areas at the lower reaches of the Sanya River.

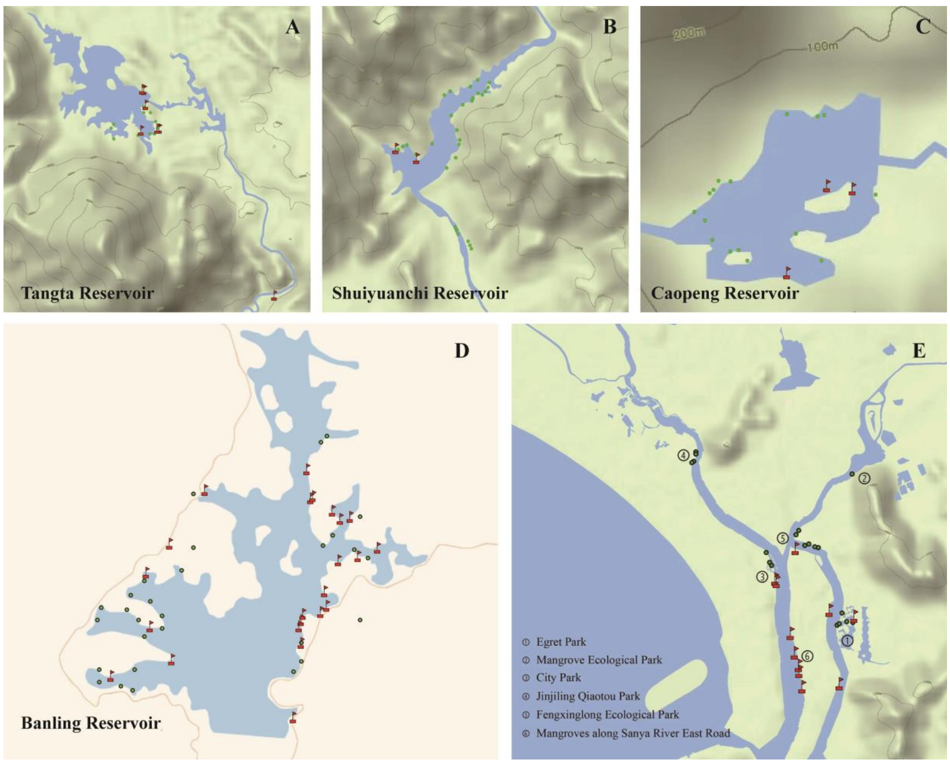

Figure 2. Distribution of samples in the Sanya River Basin, Hainan Province, China; representing

the quadrat containing rare and endangered plants; ● representing the quadrat without rare and endangered plants. (**A**): Sample plot distribution map of Tangta Reservoir; (**B**): Sample plot distribution map of Shuiyuanchi Reservoir; (**C**): Sample plot distribution map of Caopeng Reservoir; (**D**): Sample plot distribution map of Banling Reservoir with the second richest species and the largest species number of rare and endangered plants; (**E**): Distribution map of sample plots of six parks in the city center, mainly mangroves.

Table 2. Vegetation types and their coverage area in Sanya River Basin, Hainan Province, China. It can be divided into natural vegetation and artificial vegetation. The area of the reservoir is much larger than that of mangroves, and more plants can survive.

Vegetation Type		Area/hm^2	Quadrat Number	Main Distribution Location	Comment
Natural vegetation	Mangrove	24.5	45	Egret Park	
	Tropical monsoon secondary forest	11,908.2	90	Banling Reservoir, Tangta Reservoir	
	Tropical scrub		12	Shuiyuanchi Reservoir, Caopeng Reservoir	
	Bush and grass		5	Shuiyuanchi Reservoir	
	grassland	131.84	14	Shuiyuanchi Reservoir, Caopeng Reservoir	
	Herbaceous swamp			Banling Reservoir, Caopeng Reservoir	
	Aquatic vegetation	13.09		Tangta reservoir auxiliary reservoir	
Artificial vegetation	Agricultural vegetation	8485		Around reservoirs	Mainly orchard, rubber plantation, paddy fields, and vegetable farm
	Urban vegetation	3851.96		In the urban center	Covered by ornamental plants

3.2. Rare and Endangered Species and Spatial Distribution

We identified 27 rare and endangered plant species in our survey of the entire Sanya River basin, which belong to 25 genera and 19 families (Table S1). The rare and endangered plants in the Sanya River basin are of high protection grades or are seriously threatened, and some are endemic to China or Hainan. Among them, there are two national Class I protected plants, *Cycas taiwaniana* Carruth. and *Cycas rumphii* Miq., followed by eight species of national Class II protected plants, including *Aquilaria sinensis* (Lour.) Spreng., *Dalbergia odorifera* T. Chen, *Litchi chinensis* Sonn., and *Xylocarpus granatum* Koenig. A total of 1 species is classified as CR, 9 species are classified as EN, and 11 species are classified as VU on China's Biodiversity Red List.

From the spatial distribution perspective (Figure 3), the rare and endangered plants in the Sanya River basin are unevenly distributed, and mainly in the Banling Reservoir, Tangta Reservoir, Tangta Hydropower Station, and Sanya River Mangrove Nature Reserve, where human activities are infrequent, or the vegetation is in good condition. Conversely, rare and endangered plants are rarely seen or are even extinct in the areas with frequent human interference, such as the Shuiyuanchi and Caopeng Reservoirs, both of which are developing planting industries, and the downstream and estuary of the Sanya River, where the urbanization is highly developed. Moreover, most of the rare and endangered plants are only distributed in one or two places, and their individual numbers are small and mostly less than ten. *Xylocarpus granatum*, which grows in mangroves, has the largest number of individuals (55), followed by *Dimocarpus longan* Lour. (23), and *Aquilaria sinensis* (20).

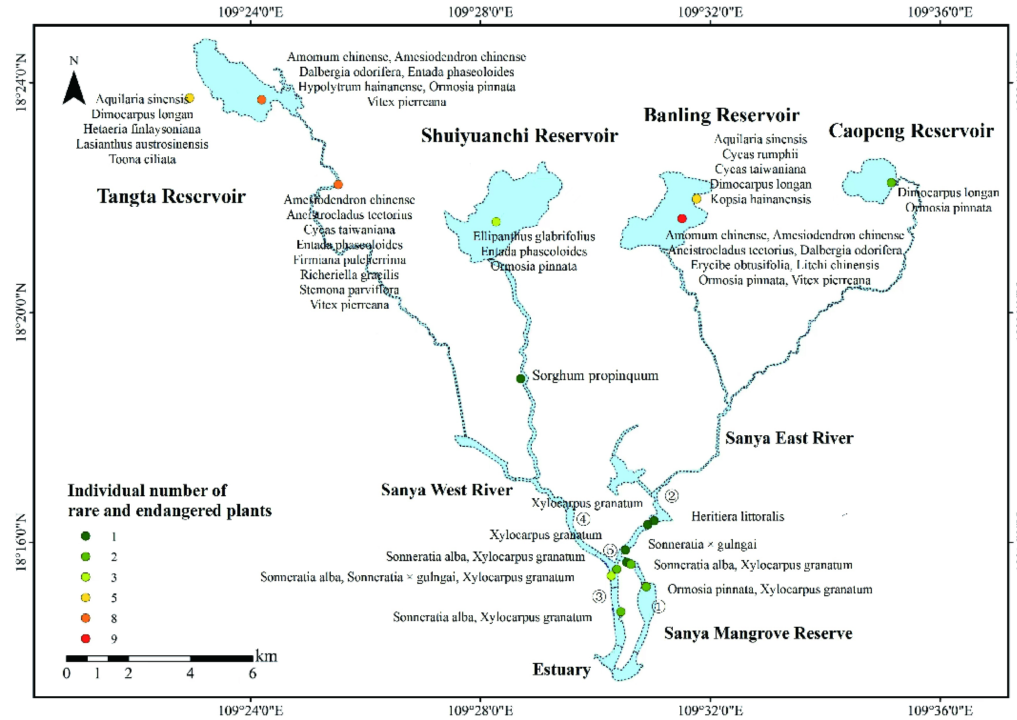

Figure 3. Locations of rare and endangered plants in the Sanya River Basin, Hainan Province, China; ①: Egret Park, ②: Mangrove Ecological Park, ③: City Park, ④: Jinjiling Qiaotou Park, ⑤: Fengxinglong Ecological Park.

3.3. Community Characteristics

3.3.1. Species Composition

Among the 46 quadrats with rare and endangered plants, there were a total of 269 species from 214 genera and 87 families. The dominant families were Fabaceae Lindl., Euphorbiaceae Juss., Poaceae Barnhart, and Rubiaceae Juss. Their species numbers were more than ten, accounting for 12.27%, 7.43%, 5.20%, and 4.09% of the total species, respectively. However, nearly half of the species come from families with fewer than five species (Figure 4). Among them, there were 31 families that had from two to five species, including Liliaceae Juss., Zingiberaceae Martinov, Combretaceae R. Br., and Convolvulaceae Juss, and there were 45 families with only one species, including Passifloraceae Juss. ex Roussel, Ebenaceae Gürke, Opiliaceae Valeton, and Bombacaceae Kunth. At the genus level, *Mallotus* Lou., *Lygodium* Sw., *Sonneratia* L. f., and *Ficus* L. were the dominant genera, with from four to five species each. However, 83.18% of the genera only had one species. According to the family and genus compositions, the dominant families and genera of the community were obvious. However, the proportion of families and genera with fewer or single species was high, which indicates that the species composition of the community is complex and that the plant species diversity is rich.

In the vertical structure (Figure 5), we identified 85 species from 72 genera and 38 families in the arbor layer, including nine rare and endangered plants, including *Sonneratia alba* J. Smith, *Ormosia pinnata* (Lour.) Merr., *Dalbergia odorifera* T. Chen, Vitex pierreana P. Dop, and *Amesiodendron chinense* (Merr.) Hu. We identified 154 species from 127 genera and 58 families in the shrub layer, including six rare and endangered plants, including *Cycas rumphii*, *Sonneratia × gulngai*, *Ancistrocladus tectorius* (Lour.) Merr., and *Erycibe obtusifolia* Benth. We identified 66 species from 60 genera and 33 families in the herb layer, including the rare and endangered plant *Hypolytrum hainanense* (Merr.) Tang et Wang. The rare and endangered plants in the Sanya River basin were primarily distributed in the arbor and shrub layers.

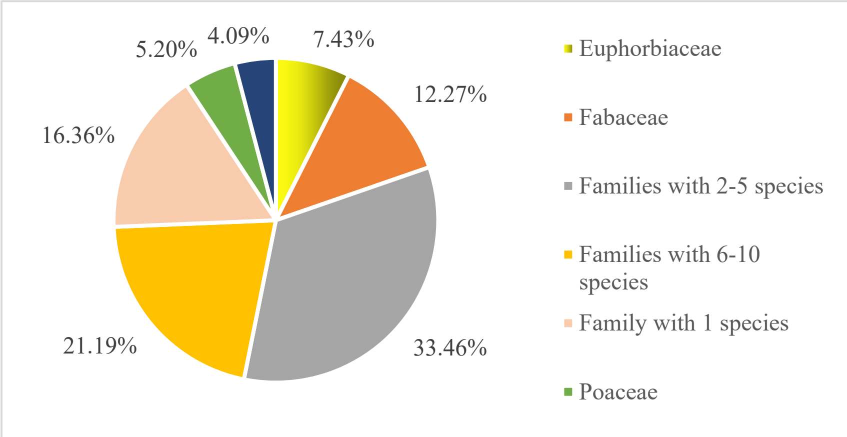

Figure 4. Species composition of the samples with rare and endangered plants in the Sanya River Basin, Hainan Province, China.

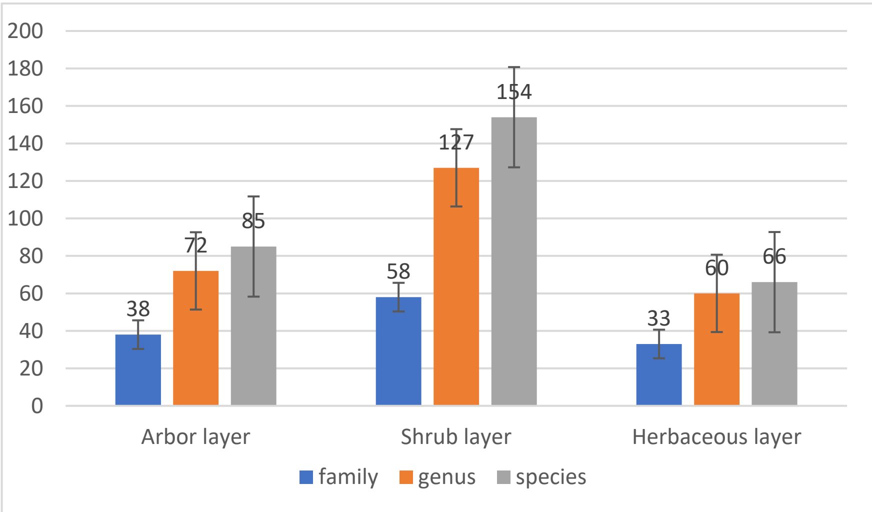

Figure 5. Vertical structure of the samples with rare and endangered plants in the Sanya River Basin, Hainan Province, China.

3.3.2. Importance Value of Species

According to the importance values of the species in each layer (Table 3), the dominant species in each layer were obvious. The dominant species in the arbor layer were primarily *Rhizophora apiculata* Blume, *Sonneratia apetala* Buchanan-Hamilton, *Syzygium cumini* (L.) Skeels, and *Acacia auriculiformis* A. Cunn. ex Benth. The species richness of the community in the shrub layer was more abundant than those in the arbor and herb layers. The importance value of *Phyllanthus reticulatus* Poir., which was dominant in the shrub layer, was 21.75%. The other dominant species in the shrub layer were *Ficus heterophylla* L. f., *Streblus taxoides* Kurz, and *Lepisanthes rubiginosa* (Roxb.) Leenh. The dominant species in the herb layer were *Panicum repens* L., *Cyclosorus parasiticus* (L.) Farwell., *Merremia umbellate* subsp. *Orientalis* (H. Hallier) v. Ooststr., *Passiflora foetida* L., and *Praxelis clematidea* Cassini.

A total of 77 species had importance values > 1%, accounting for 27.91% of the total species, including six rare and endangered plants. A total of five rare and endangered plants had importance values > 1% in the arbor layer, including *Ormosia pinnata*, *Xylocarpus granatum*, and *Sonneratia* × *Gulngai*, while the importance values of *Sonneratia alba* and *Dalbergia odorifera* were only 0.19%–0.15%. In the shrub layer, there was only one rare and endangered plant (*Ancestrocladus tectorus*) with an importance value of more than 1%, while the importance values of *Dimocarpus longan*, *Cycas rumphii*, *Sonneratia alba*, *Ormosia pinnata*, and *Erycibe obtusifolia* were 0.42%–0.08%. The importance value of the rare and endangered plant *Hypolytrum hainanense* in the herb layer was less than 1%. The importance values of the rare and endangered plants in each layer were low, and most were less than 1%, which indicates that the rare and endangered plants are the occasional species in the community.

In contrast, the exotic plants had high importance values in each layer. For example, in the arbor layer, the importance values of *Sonneratia apetala* Buchanan-Hamilton, *Acacia auriculiformis* A. Cunn. ex Benth, and *Mimosa bimucronata* (Candolle) O. Kuntze were in the top ten (higher than 2.90%), and the importance value of *Mimosa bimucronata* in the shrub layer was nearly 1.50%. Moreover, 10 species with importance values higher than 1% in the herb layer were exotic plants. The importance values of the exotic plants in this layer were substantially related to their invasiveness. For example, six species had importance values higher than 3%, three of them had invasion levels of 1, and two species had invasion levels of 2.

Table 3. The top 15 species with high importance value in each layer; all important values retain 2 digits after the decimal point. * representing exotic plants: species of the invasive level 1 including *Mimosa sepiaria, Praxelis clematidea, Ageratum conyzoides,* and *Chromolaena odorata*; species of the invasive level 2 including *Panicum repens* and *Passiflora foetida*; species of the invasive level 5 including *Sonneratia apetala* and *Acacia auriculiformis*.

Arbor Layer			Shrub Layer			Herbaceous Layer		
Number	**Species Name**	**Important Value**	**Number**	**Species Name**	**Important Value**	**Number**	**Species Name**	**Important Value**
1	*Rhizophora apiculata*	9.63%	1	*Phyllanthus reticulatus*	21.74%	1	*Panicum repens* *	9.43%
2	*Sonneratia apetala* *	7.24%	2	*Ficus heterophylla*	5.58%	2	*Cyclosorus parasiticus*	6.66%
3	*Syzygium cumini*	6.59%	3	*Streblus taxoides*	5.41%	3	*Merremia umbellata* *	6.42%
4	*Acacia auriculiformis* *	5.94%	4	*Lepisanthes rubiginosa*	4.92%	4	*Passiflora foetida* *	5.98%
5	*Dalbergia pinnata*	3.77%	5	*Sphenodesme pentandra*	3.10%	5	*Praxelis clematide a* *	5.69%
6	*Avicennia marina*	3.72%	6	*Ancistrocladus tectorius*	3.08%	6	*Isachne globosa*	4.65%
7	*Phanera erythropoda*	3.24%	7	*Arytera littoralis*	2.29%	7	*Ageratum conyzoides* *	4.42%
8	*Strychnos angustiflora*	3.20%	8	*Salacia chinensis*	1.95%	8	*Ottochloa nodosa*	3.55%
9	*Mimosa bimucronata* *	2.97%	9	*Microcos paniculata*	1.93%	9	*Merremia vitifolia*	3.32%
10	*Aporosa dioica*	2.59%	10	*Derris trifoliata*	1.49%	10	*Chromolaena odorata* *	3.09%
11	*Syzygium claviflorum*	2.09%	11	*Abrus precatorius*	1.47%	11	*Scleria ciliaris*	2.84%
12	*Tetracera sarmentosa*	2.03%	12	*Jasminum ligustrioides*	1.47%	12	*Merremia hederacea*	2.74%
13	*Ormosia pinnata*	1.80%	13	*Mimosa bimucronata* *	1.40%	13	*Eragrostis atrovirens*	2.47%
14	*Lannea coromandelica*	1.79%	14	*Gnetum montanum*	1.22%	14	*Pericampylus glaucus*	2.29%
15	*Microcos paniculata*	1.75%	15	*Smilax ocreata*	1.20%	15	*Thysanolaena latifolia*	2.03%

3.3.3. Community Species Diversity

As shown in Table 4, the Margalef species richness index (M_D) of each layer was as follows: shrub layer (M_D = 20.20) > arbor layer (M_D = 12.51) > herbaceous layer (M_D = 11.93). The Shannon–Wiener indexes (Hs) of the species diversity were as follows: herbaceous layer (H = 3.718) > arbor layer (H = 3.573) > shrub layer (H = 2.848). The species dominance Simpson diversity indexes (Ds) were as follows: herbaceous layer (D = 0.9446) > arbor layer (D = 0.9443) > shrub layer (D = 0.7828). The Pielou indexes (Es) of the species evenness were as follows: herbaceous layer (E = 0.624) > arbor layer (E = 0.4192) > shrub layer (E = 0.1128).

The Margalef index of the shrub layer was the highest, which indicates that the species richness, species number, and community complexity of the shrub layer were the highest. The Shannon–Wiener index and Simpson diversity index were both the highest in the herb layer. However, the values of each layer were similar, which indicates that the species richness and dominant species of the community were similar. The Pielou index of the shrub layer was the lowest, and the Pielou index of the herb layer was the highest, which indicates that the species distribution in the shrub layer was the most uneven, while the species distribution in the herb layer was relatively uniform.

Table 4. Species diversity indexes of the samples with rare and endangered species in the Sanya River Basin, Hainan Province, China.

Level	Margalef	Shannon_H	Simpson_D	Evenness_E
Arbor layer	12.51	3.573	0.9443	0.4192
Shrub layer	20.20	2.848	0.7828	0.1128
Herbaceous layer	11.93	3.718	0.9664	0.624

3.3.4. Community Similarity

Due to the high frequencies of *Ormosia pinnata*, *Dimocarpus longan*, *Xylocarpus granatum*, Sonneratia × *gulngai*, and *Ancistrocladus tectorius* in the quadrats, we calculated the community similarities of the quadrats that contained these five species, and we analyzed their adaptabilities and dependences on the environment.

Among the 36 pairs of similarity indexes for the nine quadrats containing *Ormosia pinnata* (Table S2), the highest C_j value was for the Y-B-4 and Y-B-10 quadrat (0.3208). The C_j values of the Y-B-4 and Y-B-6, Y-B-6 and Y-B-10, and Y-B-X-5 and Y-S-11 quadrats were between 0.25 and 0.5, which indicates that these quadrats were "moderately different". The other C_j values were less than 0.25, which means that they were very different, accounting for 89% of the total. The species compositions of the quadrats in which the *Ormosia pinnata* were located were very different, reflecting the low similarity of the *Ormosia pinnata* habitat, which indicates that *Ormosia pinnata* is highly adaptable to community changes and changing habitats.

Similar to *Ormosia pinnata*, among the 10 pairs of similarity indexes (Table S3) of the five quadrats that contained *Dimocarpus longan*, the Y-C-3 and Y-C-6 quadrat had the highest C_j value (0.3704). The C_j value for the Y-C-2 and Y-C-6 quadrat was between 0.25 and 0.5, which indicates that this quadrat was moderately different. Among the similarity indexes of the remaining eight pairs of quadrats, the C_j values were less than 0.25, which indicates that these quadrats were very different, accounting for 80% of the total. The species composition of the quadrats in which *Dimocarpus longan* was located substantially varied, which suggests that the species is highly adaptable to different habitats.

In contrast, the similarities of the communities in the quadrats in which *Ancistrocladus tectorius* was located were the lowest, and the species compositions among the quadrats changed the most. In the 136 pairs of diversity indices (Table S4) of the 17 quadrats that contained *Ancistrocladus tectorius*, all the C_j values were less than 0.5. Among them, 90.44% of the C_j values were $\leq$0.25, which indicates that the quadrats were very different. *Ancistrocladus tectorius* can adapt well to changing habitats and has strong viability.

In contrast to *Ormosia pinnata*, *Dimocarpus longan*, and *Ancistrocladus tectorius*, among the 10 pairs of similarity indexes (Table S5) of the five quadrats that contained *Xylocarpus granatum*, the C621-14 and C621-9 and C621-5 and C621-2 quadrats had the highest C_j values (0.625), indicating medium similarity, and the C621-9 and C621-2 quadrat was also moderately similar. The remaining C_j values were between 0.25 and 0.5, which indicates moderate differences, accounting for 70% of the total. The species composition and habitats of the quadrats in which *Xylocarpus granatum* was located were similar, indicating that *Xylocarpus granatum* has higher requirements for habitat homogeneity.

Similar to *Xylocarpus granatum*, *Sonneratia* × *gulngai* prefers habitats with high homogeneity because the species compositions of its quadrats were also similar, and the habitat similarity was also high. Among the 10 pairs of diversity indexes (Table S6) of the five quadrats that contained *Sonneratia* × *gulngai*, the LCH and L-4 and LCH and C621-4 quadrats had the highest C_j values (0.6250), which indicates that they were moderately similar, while the L-4 and C621-10, L-4 and C621-7, L-4 and C621-4, LCH and C621-10, LCH and C621-7, C621-10 and C621-4, and C621-7 and C621-4 quadrats had C_j values between 0.25 and 0.5, which indicates they were moderately dissimilar, accounting for 70% of the total.

3.4. Factors Affecting the Population Size and Species Number of Rare and Endangered Plants

According to the result of correlation analysis, threat factors and vegetation coverage degree significantly affected the number of species respectively ($p < 0.05$), and based on the joint analysis of these two factors, there is significant correlation between the two factors and the number of species ($p < 0.01$), as well as the population size ($p < 0.05$). In addition, threat factors and vegetation types together significantly influence the number of species ($p < 0.05$), based on the joint analysis of these two factors. Therefore, threat factors and vegetation coverage degree are the main factors affecting the number of species and population size, and vegetation types can also significantly affect the number of species under the influence of threat factors (Table S7).

4. Discussion

The community characteristics and distribution patterns of the rare and endangered plants in the Sanya wetlands are affected by human activities of varying degrees under the urbanization process. The rare and endangered plants in the suburbs and urban areas are different in terms of species, community similarity, and threat factors. When formulating protection measures, they should be separately treated to improve the protection effect.

4.1. Community Characteristics of Rare and Endangered Plants in Sanya River Basin, China

From the species composition and importance value perspectives, the dominant families, genera, and species of the communities of the rare and endangered plants in the Sanya River basin were prominent, and the proportion of families and genera with fewer or single species was high, which indicates high species richness and complex species compositions. According to the community species diversity index, the shrub layers of the communities with rare and endangered plants had the richest species and most uneven distributions, and thus their complexities were also the highest, while the herb layers had more uniform distributions, which indicates that the species compositions of the herb layers in the different samples were similar. From the spatial distribution, species composition, and importance value perspectives, the rare and endangered plants in the Sanya River basin have no advantages and are occasional species in the community. Only six species had importance values higher than 1%.

These research results are consistent with previous research results on the community characteristics and spatial distributions of rare and endangered plants. Researchers analyzed the species composition and spatial distribution of *Ormosia boluoensis* Y.Q. Wang &

P.Y. Chen [37], and they found 84 species that belong to 57 genera and 38 families in the community, with 65.79% of the families with only one genus or species, which indicates that the species composition of the community is relatively complex and the plant biodiversity is rich. However, the importance value of *Ormosia boluoensis* was 1.84%, ranking 19th among all the species, and it is not dominant in the community. Researchers studied the *Syzygium album* Q.F. Zheng community in Fujian [38]. The community includes 240 species that belong to 170 genera and 80 families, and 52.5% of the families have only a single species. The genera with a single species account for 78.36% of the total genus number, which also indicates that the flora composition of the community of *Syzygium album* is complex. The importance values of *Syzygium album* in the tree and shrub layers were only 2.14% and 0.44%, respectively, while its largest importance values in the arbor and shrub layers were 12.96% and 12.25%, respectively, which means that it is not dominant in the community and is the companion of other dominant species. Consistent with the results of previous studies, the rare and endangered plants in the Sanya River basin have low importance in the community, do not dominate it, and are associated species within it.

4.2. Environmental Adaptability of Rare and Endangered Plants in Sanya River Basin, China

The community similarity results imply that the rare and endangered plants located in the Sanya suburbs are better able to adapt to different habitats. Those in the mangroves in the urban areas are relatively large in number. However, their ability to adapt to environmental changes is relatively weak, which implies that, for the rare and endangered plants closer to urban areas, more attention should be paid to reducing external threats and providing them with stable habitats during conservation, while for those in the suburbs, it is necessary to protect the diverse habitats and reduce the human interference with the different types of plant communities. However, be it in suburban or urban areas, we need to minimize the disturbance to the natural vegetation because the survival of rare and endangered plants is highly dependent on it.

4.3. Endangered Level of Sonneratia × gulngai

This taxon is the natural hybrid of *Sonneratia alba Smith* and *S. caseolaris* (L.) Engl., and it is distributed in China, Indonesia, Malaysia, and East Australia. In China, *S. × gulngai* is only distributed in Wenchang, Qionghai, and Sanya in Hainan Province (Figure 6). In addition to its limited distribution, *S. × gulngai* has small populations. Li et al. (2006) investigated the distribution status of *S. × gulngai* in China, and they found that it is only naturally distributed on the east of Hainan Island, with eight individuals in the city of Qionghai growing along the edges of tidal ditches, as well as about fifty in the city of Wenchang, including two growing alone on the outer beach of the village of Paigang, with the rest growing along the fish pond at the Wenchang Touwan Conservation Station. The plants are strongly impacted by wind, waves, and human activities. In the Sanya River basin, we only found 17 *Sonneratia × gulngai* plants, which were scattered among the mangroves and had serious diseases [43].

In brief, the number of *Sonneratia × gulngai* individuals is limited and the distribution range is narrow. Because it is a hybrid, its reproduction ability may be poor. Although it is in a difficult position, it is not included on the National Key Protected Wild Plants List (2021), and it is classified as NT on China's Biodiversity Red List (Ministry of Environmental Protection and Chinese Academy of Sciences, 2015). Zhang et al. (2021) suggest that the endangered level of *Sonneratia × gulngai* should be upgraded from NT to EN [44]. Based on the results of this study and those of previous studies, and according to the classification standard of the IUCN, we recommend upgrading the endangered level of *S. × gulngai* to CR. Moreover, because *S. × gulngai* grows in urban areas with frequent human activities and requires high community similarity, it is critical that we take active measures to reduce human activities and strengthen the monitoring of its population dynamics.

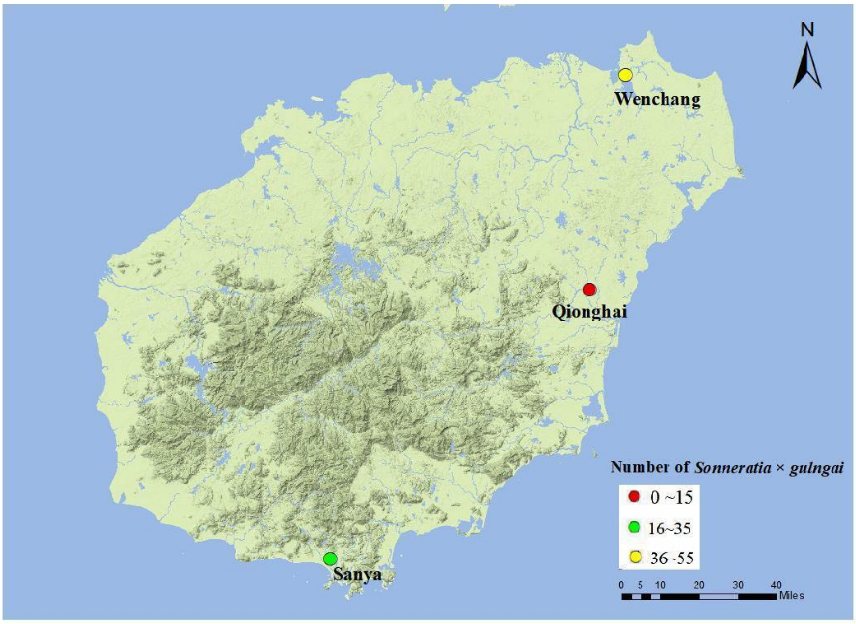

Figure 6. Distribution of *Sonneratia* × *gulngai* in Hainan Province, only in Sanya, Qionghai, and Wenchang, with a total number of no more than 100 individuals.

4.4. Threat Factors of Rare and Endangered Plants in Sanya River Basin, Hainan

The endangerment of plants is caused by internal and external factors. The external factors are natural and human factors, while the internal factors are presented in the plants themselves, such as low genetic capacities, pollen abortion, poor reproductive capacities, and weak environmental adaptabilities, which together hinder their survival and reproduction [45]. According to the community similarity analyses, the similarities of the communities of rare and endangered species in the Sanya River basin were different between the urban and suburban areas. The rare and endangered plants in the suburbs are better able to adapt to different habitats than those in the urban areas. In addition, the suburban plant habitat area is much larger than that of the city, and thus more species can survive. The species compositions and community structures in the suburbs are more complex than those in the mangroves. The rare and endangered plants in the reservoirs must survive and adapt to a variety of habitats more than the rare and endangered plants in the mangroves. However, regardless of whether the rare and endangered plants in the Sanya River basin are in the urban areas or not, external factors are one of the main reasons for their endangerment. The results of the multi-element variance analysis show that in the whole Sanya River basin, threat factors and vegetation coverage have a significant impact on the number of species and population size. It can be seen that external factors are the key factors affecting the survival of rare and endangered plants. We summarize the external threats to the rare and endangered plants in the Sanya River basin in the following sections (Figure 7).

4.4.1. Land Use and Urban Expansion

Urban expansion is seriously affected by human factors, especially the land use pattern. According to the third national land survey of China in 2021 [46], Sanya has 79,737.15 hm2 of woodland, 60,026.59 hm2 of garden plot, 20,670.44 hm2 land for towns, villages, and industrial mines, 15,905.85 hm2 cultivated land, and 8024.67 hm2 of land for water area and water conservancy facilities. Zhang et al. found the area of cultivated land and woodland in Sanya has decreased yearly and most areas have evolved into construction land [46]. The proportion of construction land increased from 4.39% in 2004 to 20.66% in 2019 [46]. It can be seen that the urbanization of Sanya depends on transforming woodland and cultivated land into construction land. In our survey of the Sanya River basin, rare and endangered plants are mainly distributed in woodland. Therefore, the expansion of urbanization has probably threatened their habitat. The strict control of the ecological red line and reasonable urban construction are required to maintain biodiversity in Sanya.

4.4.2. Economic Forest or Crop Planting

Hainan is the main production base of the winter "vegetable basket" in China. Sun et al. investigated the winter melons and vegetables in Hainan Province. The average annual planting area is about 200,000 hm^2, and the total output is about 5 million tons [47]. Since 1980, the Sanya planting industry has vigorously developed, and the planting area has rapidly expanded. Some rare and endangered plants in the Sanya River basin, and especially those in the suburbs, such as *C. rumphii*, *C. taiwaniana*, and *Toona ciliata Roem*, are seriously threatened by the planting of economic forests and crops. The expansion of the economic forest and crop planting areas and the destruction of the original vegetation have resulted in the narrow distribution ranges and small population sizes of the local plants. In addition, the use of chemical fertilizers and pesticides during crop planting has also seriously threatened the survival of the rare and endangered plants in the Sanya River basin. In this case, the rare and endangered plants in the suburbs suffer more than those in the urban areas.

4.4.3. Urban Activities

Wang (2020) studied the impact of human activities on the environment [48]. With urbanization, water resources have been seriously damaged, 50% of the mangroves have disappeared, half of the wetlands have shrunk, and marine fishing far exceeds the limit. Swedish and British scientists have pointed out that, after they are affected by human beings, plants disappear 500 times faster than before they are affected. From 1750 to 2018, 571 species of plants became extinct, which is about four times higher than previously predicted. Urban expansion has led to the occupation of land resources, damage to many land irrigation facilities, the decline of soil quality, and reductions in the habitats [49] and living environments of rare and endangered plants. The natural vegetation in the Sanya River basin has been damaged, or even eliminated, by construction projects, dredging projects, and river hardening. The existing natural vegetation in the Sanya River basin has also been subjected to frequent human production and entertainment activities. For example, the main branch of *X. granatum* in Egret Park was broken due to the rain and sewage diversion project, and there is a large amount of domestic sewage that is discharged to the habitats in which *S. alba* and *S.* × *gulngai* are located.

4.4.4. Invasive Alien Plants

Invasive alien species are species that are intentionally or unintentionally introduced into new habitats through human activities and that rapidly grow in new habitats, thereby posing a serious threat to the stability and biodiversity of the ecosystems of the areas to which they are introduced [50]. Due to their lack of natural enemies, strong reproductive capacities, and rapid proliferation and growth, invasive alien species quickly become the dominant species in the introduction area [51]. Invasive alien species often compete with other species in the same community for limited resources, which leads to the destruction of the original community structure and a decline in community stability [51]. Based on the results of our study, the importance values of the rare and endangered plants in the Sanya River basin are low. However, the importance values of exotic plants, and especially invasive plants, are high. Therefore, a long-term and effective prevention and control mechanism for invasive alien plants should be established in the Sanya River basin to improve the protection efforts of local rare and endangered plants.

Zhou et al. (2010) studied the invasive alien plants of mangroves, and they did not find any invasive alien plants other than *S. apetala* outside the coast [52]. However, they found a large number of invasive alien plants on both sides of the beach and the shore road, including *Mimosa pudica* L., *Lantana camara* L., *Stachytarpheta jamaicensis* (L.) Vahl, and *Passiflora foetida* L., which were widely distributed. The authors also proved that the proportion of invasive species typically increases with the degree of urbanization. In brief, urban areas tend to support more invasive species than suburban areas. In this case, rare and endangered plants in urban areas, such as *X. granatum* and *S.* × *gulngai*, are more vulnerable to the invasion and expansion of alien species than those in the suburbs. Moreover, due to their weaker adaptabilities to community changes, the rare and endangered plants in urban areas require that we pay more attention to invasive alien plant prevention and reduction.

4.4.5. Local Woody Vines with Vigorous Growth

In previous studies, researchers have shown that tropical rain forests are rich in vines, and mostly woody vines [53]. Moreover, woody vines are increasing with global climate change and habitat destruction [54].

The increasing abundance of woody vines may have a profound influence on the structure, function, and dynamics of tropical forests. When woody vines reach the forest canopy, their leaves form a "carpet" that covers the host trees, causing them to compete with the other coexisting trees for light resources [55]. In addition, woody vines have developed root and vascular systems that help them to more effectively compete with trees for water and nutrients [55,56]. Therefore, the competition between woody vines and the coexisting trees on the ground and underground may affect the reproduction, diversity, growth, and death of the trees, and it may further disturb the spatial distribution patterns of and dynamic changes in the species of the entire community [56].

In the Sanya River basin, woody vines are common, and they cover large areas in some reservoirs and mangroves, especially in the Banling Reservoir and Mangrove Ecological Park. For example, woody vines on the east side of the Banling Reservoir, such as *Phanera erythropoda* (Hayata) Mackinder & R.Clark, are carpeted on the trees, which are mainly *Lepisanthes rubiginosa* and *Streblus taxoides*, and the trees covered by *Phanera erythropoda* are low and small. The trees in Mangrove Ecological Park, such as *Kandelia obovata* Sheue et al. and *Avicennia marina* (Forsk.) Vierh, suffer from the vigorous growth of *Derris trifoliata* Lour.

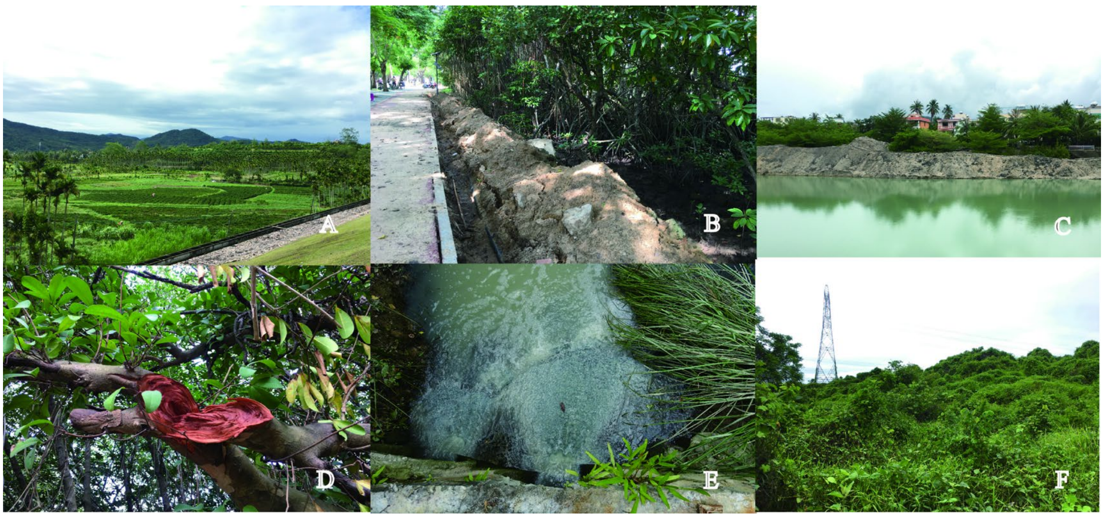

Figure 7. External threat factors to rare and endangered plants in the Sanya River Basin, Hainan Province, China. (**A**): Economic forest and crop planting (Caopeng Reservoir); (**B**): Rainwater and sewage diversion project (Egret Park); (**C**): River dredging project (Areca Cultural Park); (**D**): Broken branches (Egret Park, *Xylocarpus granatum*); (**E**): Domestic sewage discharge (Mangrove Ecological Park); (**F**): Covering of exotic invasive species and native woody vines (Banling Reservoir).

5. Conclusions

We identified 27 species of rare and endangered plants in the Sanya River basin, China, which were distributed in areas with infrequent human interference, and mainly in the tree and shrub layers of the communities. The species compositions of the communities were complex and the dominant species in each layer were obvious. In addition, the rare and endangered plants with importance values less than 1% are occasional species of their communities, but the exotic plants had high importance values in each layer, and some of them are highly invasive. The city of Sanya has paid attention to the protection of wetlands and their endangered plants. However, more actions are required. Here are feasible suggestions: (1) the reasonable division of the cash crop planting areas; (2) the establishment of key protection areas for plant diversity to reduce human interference and protect biodiversity; (3) the proper clearance of the invasive alien species and woody vines with high dominance in the community; (4) expansion of vegetation coverage and protection of different vegetation types to enhance sustainable development of rare and endangered plants. In addition, publicity should be strengthened to enhance the people's protection awareness and to lay a good foundation for the protection of wetlands and endangered plants.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f14020176/s1. Figure S1: Pictures of rare and endangered plants; Table S1: List of rare and endangered species in the Sanya River Basin, Hainan Province, China.; Table S2: Community similarity of the samples with *Ormosia pinnata*; Table S3: Community similarity of the samples with *Dimocarpus longan*; Table S4: Community similarity of the samples with *Ancistrocladus tectorius*; Table S5: Community similarity of the samples with *Xylocarpus granatum*; Table S6: Community similarity of the samples with *Sonneratia* × *gulngai*. Table S7: Probability value of correlation between influencing factors and the species number and population size of rare and endangered plants, respectively.

Author Contributions: Conceptualization, H.Z.; methodology, H.Z. and D.Y.; software, H.Z.; validation, X.C. and D.Y.; formal analysis, H.Z.; investigation, H.Z., D.H., X.C., L.C., Z.Z., Y.T. and D.Y.; resources, J.Y.; data curation, H.Z., X.C. and D.Y.; writing—original draft preparation, H.Z.; writing—review and editing, D.Y.; visualization, D.H.; supervision, D.Y.; project administration, D.Y.; funding acquisition, D.Y. All authors have read and agreed to the published version of the manuscript.

Funding: Fund Project: Hainan Provincial Natural Science Foundation of China (grant number 322RC571) and the Horizontal Natural Science Project (grant number HD-KYH-2022087); Hainan Postgraduate Innovation Project (grant number Qhys2022-102).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhu, C.; Jiang, F.Q.; Wu, L.; Zeng, M.X.; Jia, T.J.; Zhou, S.L.; Ning, Y.M.; Yu, J.; Feng, X.Z. Reflections on the scientific problems of urbanization development in the Yangtze River Delta under the background of global change. *J. Geogr.* **2017**, *72*, 633–645. [CrossRef]
2. Zhao, A.Z.; Pei, T.; Cao, S.; Zhang, A.B.; Fan, Q.Q.; Wang, J.J. The Impact of Beijing Tianjin Hebei Urban Expansion on Vegetation and Surface Urban Heat Island. *China Environ. Sci.* **2020**, *40*, 1825–1833. [CrossRef]
3. Chen, H.B.; Ai, J.G.; Lu, L. Analysis on Coupling and Coordination between Urbanization Development and Ecological Environment in Hubei Province. *Hubei Soc. Sci.* **2012**, *03*, 59–64. [CrossRef]
4. Wang, X.Y.; Liu, E.R.; Hou, J.J. Research on the spatio-temporal differentiation characteristics and types of tourism urbanization response in Shandong Province. *Geogr. Sci.* **2017**, *37*, 1087–1094. [CrossRef]
5. Hu, Z.P.; Huang, X.X.; Fu, C.; Yu, D.J. Quantitative comparison and evolution analysis of tourism industry urbanization ecological environment interaction coupling in Poyang Lake region. *Resour. Environ. Yangtze River Basin* **2015**, *24*, 2012–2020. [CrossRef]
6. Chen, W.X.; Liu, Z.L.; Li, J.F.; Ran, D.; Zeng, J. Research on the Spatial Relationship between Ecosystem Services and Urbanization of Urban Agglomerations in the Middle Reaches of the Yangtze River. *J. Ecol.* **2020**, *40*, 5137–5150. [CrossRef]
7. Chen, Y.Y. Strengthen the research of wetland basic theory to serve the national wetland protection strategy. *China Sci. Found.* **2022**, *36*, 363. [CrossRef]
8. Zou, C.Y.; Duan, X.M.; Wei, X.B.; Xie, Z.J.; Wang, Y.Y. Status quo of wetland resources protection and development suggestions in Ji'an City. *Anhui Agric. Sci.* **2022**, *50*, 56–59. [CrossRef]
9. Feng, F.J.; Mu, L.Q.; Tao, L.; Zheng, B.J. Investigation on plant resources of Harbin urban wetland. *J. Northeast For. Univ.* **2010**, *38*, 119–121. [CrossRef]

10. Shen, Y.C.; Yang, Z.X.; Fang, Z.S.; Song, X.Q.; Pei, H.Q.; Zhang, Y. Plant Resources and Vegetation Types of Hainan Qiongzhong Wetland. *Mol. Plant Breed.* **2019**, *17*, 673–682. [CrossRef]
11. Finlayson, M.; Cruz, R.D.; Davidson, N. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*; World Resources Institute: Washington, DC, USA, 2005.
12. Deng, H.B.; Ren, X.Y.; Zhang, Y. Development, utilization and protection of wetland resources in China. *Trop. Geogr.* **2003**, *299–303*.
13. Shao, Y.Y.; Zhou, J.W.; Mu, Y.M.; Zhu, L.; Jiang, T.Y. Study on urban development and wetland protection in china. *J. Ecol. Environ.* **2018**, *27*, 381–388. [CrossRef]
14. Li, Y.Z.; Pu, L.H.; Sun, T. Research on Wetland Types and Ecological Service Values in Hainan Province. *Jiangxi Agric.* **2018**, *22*, 51–52. [CrossRef]
15. Lin, P. *Mangrove Ecosystem in China*; Science Press: Beijing, China, 1997; pp. 1–342.
16. Special Report on Wetland Resources Investigation in Sanya. Available online: http://lyj.sanya.gov.cn/ (accessed on 15 August 2022).
17. Detailed Construction Plan of Sanya River National Wetland Park Project (2018–2021). Available online: http://lyj.sanya.gov.cn/lyjsite/tzgg/201909/e6b1c186a6dd4004a362a04e5143b717.shtml (accessed on 15 August 2022).
18. Wu, X.Q.; Huang, B.L.; Ding, Y.L. Research status and progress on the protection of rare and endangered plants in China. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2004**, *2*.
19. Qian, S.H.; Qin, D.Y.; Wu, X.; Hu, S.W.; Hu, L.Y.; Lin, D.M.; Zhao, L.; Shang, K.K.; Song, K.; Yang, Y.C. Urban growth and topographical factors shape patterns of spontaneous plant community diversity in a mountainous city in southwest China. *Urban For. Urban Green.* **2020**, *55*, 126814. [CrossRef]
20. Hong, D.Y. The crisis facing biodiversity. *J. Chin. Acad. Sci.* **1990**, *02*, 117–120. [CrossRef]
21. Zang, R.G. Research Progress on the Protection of Wild Plants with Minimal Populations in China. *Biodiversity* **2020**, *28*, 263–268. [CrossRef]
22. Qin, A.L.; Ma, F.Q.; Xu, G.X.; Shi, Z.M.; Chen, Q.Y. Population structure and dynamic characteristics of rare and endangered species Michelia wilsonii. *J. Ecol.* **2020**, *40*, 4445–4454. [CrossRef]
23. Yu, X.A.; Tian, H.L.; Guo, Z.Y. Study on the characteristics and interspecific relationship of *Bretschneidera sinensis* community in southern Guizhou. *J. Sichuan Agric. Univ.* **2016**, *34*, 29–33. [CrossRef]
24. Zhang, Y.; Li, Z.; An, M.T.; Li, X.F.; Wang, W. Niche characteristics and interspecific relationships of the minimal population wild plant *Geodorum eulophioides*. *J. Plant Resour. Environ.* **2022**, *31*, 1–10. [CrossRef]
25. Zheng, S.Q.; Yang, W.Q.; Fang, Z.F.; Zheng, N.; Liu, J.F.; Lin, K.Q.; Xiao, L.F.; Li, L. The current situation and protection evaluation of the extremely small population plant *Syzygium album*. *J. Appl. Ecol.* **2021**, *32*, 103–112. [CrossRef]
26. Xu, H.; Liu, Y.H. Population structure and dynamic characteristics of minimum population Acer catalpa. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2019**, *43*, 47–54. [CrossRef]
27. Du, X.F.; Tang, M.P.; Pan, J.Y.; Shen, Q.Y.; Yang, F. Comparative study on competition index of different forest types in Lin'an District. *J. Ecol.* **2020**, *40*, 4064–4072. [CrossRef]
28. Zhang, J.; Shangguan, T.L.; Duan, Y.H.; Guo, W.; Liu, W.H.; Guo, D.G. Age structure and dynamics of *Quercus mongolica* population in Lingkong Mountain. *J. Appl. Ecol.* **2014**, *25*, 3125–3130. [CrossRef]
29. Liao, B.W.; Zhang, Q.M. Distribution, area and species composition of mangroves in China. *Wetl. Sci.* **2014**, *12*, 435–440. [CrossRef]
30. Xie, W.; Li, X.N.; Zhong, C.R.; Yuan, J.; Shi, S.H. Natural hybridization between exotic species of mangrove Sonneratia apetala and Sonneratia alba. Compilation of abstracts from the eighty-fifth annual academic meeting of the Chinese Botanical Society. 1993–2018. Kunming, China, 11–13 October 2018; Chinese Botanical Society: Yunnan Science and Technology Association: Yunnan, China.
31. Yang, Q.Q.; Chen, X.H.; Du, Z.H. Status Quo and Protection Countermeasures of Mangrove Biological Community in Hainan Island. *Trop. For.* **2017**, *45*, 22–24. [CrossRef]
32. Wang, L.R.; Li, Z.; Pu, Y.J.; Liao, W.B.; Zhang, Q.M.; Yu, K.F. Changes of mangrove communities in Hainan Island in recent 50 years and their relationship with the environment—Taking Dongzhaigang, Sanya River and Qingmei Port mangrove nature reserves as examples. *Trop. Geogr.* **2010**, *30*, 11. [CrossRef]
33. Zhang, R.S.; Liu, T.; Wu, W.; Li, Y.Q.; Chao, L.F.; Huang, L.S.; Huang, Y.L.; Shi, S.H.; Zhou, R.C. Molecular evidence for natural hybridization in the mangrove fern genus Acrostichum. *BMC Plant Biol.* **2013**, *13*, 74. [CrossRef]
34. Chang, C.R.; Chen, M.C.; Su, M.H. Natural versus human drivers of plant diversity in urban parks and the anthropogenic species-area hypotheses. *Landsc. Urban Plan.* **2021**, *208*, 104023. [CrossRef]
35. Jia, Z.J.; Zhou, S.B.; Lin, W.; Li, M.; Fu, F.H.; Xie, Q.L. Analysis of plant community structure and diversity in tropical parks – taking Sanya Egret Park as an example. *J. Hainan Trop. Oceanogr. Univ.* **2016**, *23*, 33–37. [CrossRef]
36. Flora of China Editorial Committee. *Flora of China*; Science Press: Beijing, China; Missouri Botanical Garden Press: St. Louis, MO, USA, 2013.
37. Guo, Y.; Kang, N.; Dong, H.; Zhang, Y.; Wu, W.H.; Wu, L.F.; Cao, H.L. Community species composition and spatial distribution pattern of Borneo adzuki bean of minimal population. *J. Trop. Subtrop. Bot.* **2020**, *28*, 301–309. [CrossRef]
38. Xiao, L.F.; Luo, M.X.; Chen, X.H.; Yang, W.Q.; Fang, Z.F.; Zheng, S.Q. Habitat community characteristics and species diversity of the extremely small population plant *Syzygium album* in Fujian. *J. Northeast. For. Univ.* **2022**, *50*, 26–31. [CrossRef]
39. Song, H.H.; Zhou, C.L.; Liu, Z.K. Study on Similarity of Woody Plant Communities in Qingdao. *Chin. Landsc. Archit.* **2014**, *30*, 90–93.

40. Zhang, N.; Zhong, M.; Shi, L.; Guan, Q.K.; Qin, F.H. Analysis of community characteristics and interspecific relationship of *Eria coronaria*. *Guizhou For. Sci. Technol.* **2022**, *50*, 36–41. [CrossRef]
41. Zhang, J.T. *Quantitative Ecology*; Science Press: Beijing, China, 2004; pp. 1–351.
42. Cao, W.J.; Mou, X.L.; Xu, H. Land Use Report of Sanya River National Wetland Park. Beijing Senwang Forestry Engineering Design Co., Ltd.: Haikou, China, 2022; manuscript in preparation.
43. Li, H.S.; Chen, G.S. Distribution Status and Protection of *Sonneratia* × *gulngai*. *J. Guangdong Univ. Educ.* **2006**, *5*, 81–83.
44. Zhang, Y.; Chen, G.C.; Zhong, C.R. Research and restoration status of endangered mangrove plants in China. *J. Appl. Oceanogr.* **2021**, *40*, 142–153.
45. Shi, X.Y.; Fu, D.; Hu, Y.J.; Chen, Z.H.; Wang, L.L. The Endangering Mechanism of the Minimal Population Plant *Ostrya rehderiana*. *For. Sci.* **2020**, *56*, 142–150.
46. Zhang, J.; Huang, J.J.; Zhao, R.J.; Liu, Y.N.; Wang, Y.Z.; Lin, S.F. Study on spatial-temporal changes of land use landscape pattern in sanya city. *J. Northwest For. Univ.* **2022**, *37*, 224–231. [CrossRef]
47. Sun, T.Y. Current Situation of Production and Marketing of Winter Melons and Vegetables in Hainan and Its Development Countermeasures. *Chin. Melon Veg.* **2022**, *35*, 105–109. [CrossRef]
48. Wang, B.Z. Impact of human activities on the environment. *Rural. Sci. Exp.* **2020**, *7*, 51–52.
49. Xu, H. Problems and Countermeasures of Land Use Management in the Process of Urbanization. *South. Agric.* **2022**, *16*, 136–138. [CrossRef]
50. Xu, J. Distribution and Control of *Mimosa bimucronata*, an invasive alien species in China. *Weed Sci.* **2014**, *32*, 41–43. [CrossRef]
51. Liu, M. Population Dynamics and Risk Assessment of Rorippaamphibia, an Alien Invasive Species on Lawn. Master's Thesis, Shenyang Agricultural University, Shenyang, China, 2019. [CrossRef]
52. Zhang, R.J.; Xing, F.W. Ecological Characteristics of Tropical Rainforest. *Bull. Biol.* **2007**, *04*, 21–23.
53. Ding, L.Z.; Chen, Y.J.; Zhang, J.L. Leaf characters and their associations of woody vines in tropical rainforest. *Plant Sci. J.* **2014**, *32*, 362–370. [CrossRef]
54. Avalos, G.; Stephen, S.M.; Kaoru, K. Leaf Optical Properties of Trees and Lianas in the Outer Canopy of a Tropical Dry Forest. *Biotropica* **1999**, *31*, 517–520. [CrossRef]
55. Schnitzer, S.A.; Bongers, F. The ecology of lianas and their role in forests. *Trends Ecol. Evol.* **2002**, *17*, 223–230. [CrossRef]
56. Schnitzer, S.A. A mechanistic explanation for global patterns of liana abundance and distribution. *Am. Nat.* **2005**, *166*, 262–276. [CrossRef]