Degrading Large Old Tree Population Deserves More Conservation Effort: A Case of Endangered *Barringtonia racemosa* in Tropical Rural China

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The large old tree population of *Barringtonia racemosa* (L.) Spreng plays a crucial ecological and cultural role in rural areas (Danzhou, tropical China). This study investigates the population structure, demographic characteristics, and conservation status of *B. racemosa* in remnant forest stands. The findings reveal a skewed distribution towards smaller to intermediate-size classes, with a significant decline in larger-size classes. The static life table highlights high mortality rates in the early stages and moderate survivorship in mid-size classes, indicating a bottleneck in the transition from medium to larger-size classes. The study identifies external interference as a potential threat to the *B. racemosa* population. Based on these findings, a multifaceted conservation approach is proposed to integrate traditional ecological knowledge, implement community-based conservation programs, enhance habitat protection and restoration, and strengthen legal protection and policy support. This research underscores the critical role of large old trees in ecosystem health. It highlights the need for targeted conservation strategies to preserve these vital components of natural landscapes in rural China.

DOI: 10.15376/biores.20.1.1584-1599

Keywords: Large old tree; Remnant forest stand; Tree population structure; Static life table; Community-based conservation

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INTRODUCTION

The Role of Large Old Trees in Rural Ecosystems

Large old trees (LOTs) in rural areas play paramount and multifaceted roles that extend well beyond their physical presence (Blicharska and Mikusiński 2014; Yao *et al*. 2024). These majestic trees serve as pertinent pillars in the ecosystem, offering myriad benefits to enrich both the environment and the communities they inhabit. They play key roles in biodiversity conservation by furnishing multiple micro-habitats for diverse wildlife species (Lindenmayer 2017). From nesting sites for birds to shelter for mammals and insects, these aged giants support a complex web of life, fostering ecological balance and resilience (Kebrle *et al*. 2021).

These sizeable trees are crucial in maintaining soil health and preventing erosion (Dean *et al*. 2020). Their extensive root systems stabilize soil structure, promote nutrient cycling, and enhance ecosystem productivity (Gilhen-Baker *et al*. 2022). Moreover, LOTs are essential players in the fight against climate change (Moomaw *et al*. 2019). Through carbon sequestration, they mitigate the impacts of greenhouse gas emissions by absorbing carbon dioxide from the atmosphere and storing it in their sizeable biomass. These ecosystem services can contribute to ameliorating global warming and overall environmental health (Gilhen-Baker *et al*. 2022).

Beyond ecological significance, LOTs hold immense cultural and aesthetic value in rural areas (Blicharska and Mikusiński 2014). These iconic landmarks often bestow historical significance, serving as tangible links to the past and embodying the pride of heritage and tradition in local communities. Furthermore, their towering and sprawling stature enhances the visual quality and appeal of rural areas. They offer generous shade, sanctuary, tranquility, and a sense of timelessness to enrich the human experience (Huang *et al*. 2020).

In economic terms, these trees' outstanding scenic and environmental qualities can boost property values and tourism. They draw visitors eager to explore these rural natural beauties with unique characters (Lindenmayer and Laurance 2017). In essence, LOTs in rural areas perform as guardians of biodiversity, climate stability, cultural heritage, and economic well-being, symbolizing the profound interconnectedness between nature and society (Blicharska and Mikusiński 2014; Huang *et al*. 2020; Gilhen-Baker *et al*. 2022).

Some important remnant forest stands in isolated locations can be left relatively undisturbed by default as literal habitat islands amongst the sea of human perturbation. They survive for various reasons despite centuries of nearby human activities and impacts. Some LOTs can reach considerable age and dimensions within these remnant vegetation patches to offer crucial natural and cultural ecosystem services. This study investigates the LOT population of an endangered species discovered recently in remnant forest stands in coastal south China. After assessing the key innate traits of the precious population, conservation measures and strategies were derived to protect the precious arboreal endowment.

Research Target and Objectives

Due to extensive settlements, infrastructural developments, farming, and aquacultural and maricultural activities in the coastal belt, many mangroves and associated halophyte plants have been eradicated. The remaining ones are threatened with continued human impacts. Efforts have to be made to protect the small amount of such remnant coastal ecosystems.

Halophytes refer to amphibious woody plants with strong salt, waterlogging and wind tolerance that can grow in the relatively confined intertidal zone and non-saline soil on adjacent land (Saddhe *et al*. 2020). Dwelling in the transitional zone between mangroves and terrestrial plants, their range traverses two distinct heterogeneous habitats: the coastal intertidal zone and inland areas (Finlayson *et al*. 2006).

Barringtonia racemosa (L.) Spreng., (powder-puff tree) is a typical halophyte in southern China's coastal areas. It is known as "yurui" (literally "jade stamen") in Chinese, alluding to its attractive floral structure. The large evergreen tree with a graceful form can reach a height of 20 m. It has been adopted as a valuable landscaping species on account of its ornamental and fragrant inflorescence with a pendulous form that can reach up to 1 m long (Wang *et al*. 2019). Its cultivation as an ornamental plant in Chinese settlements could be traced to the Tang Dynasty (CE 618 to 907). *B. racemosa* is native to tropical and subtropical Africa, Asia, and Oceania regions. It grows well in warm areas with 22 to 30°C air temperature and friable, moist, fertile soil. In China, it is naturally distributed in very limited numbers in the southern coastal provinces of Hainan, Guangxi, Guangdong and Taiwan (Hu *et al*. 2024). Wild communities of *B. racemosa* are found in low-salinity, high-tidal zones along the coast, often mixed with the dominant mangrove plants. They contribute to coastal protection by sand fixation and dampening the impacts of waves, storm surges and strong winds. However, the LOT population of *B. racemosa* that was considered in this work is not part of a typical coastal distribution. It is located at a certain distance from the coast, making it a unique and noteworthy find.

Since the 1980s, extensive habitat destruction and disturbances have induced a drastic decline and loss of wild *B. racemosa* in China. In response, the species has been classified as a "vulnerable" species since 1998, a "rare and endangered plant in Hainan" in 2009, and a "progressively endangered" species in 2011. Finally, it was listed as an "endangered plant" in China in 2017 due to the continual decline in habitat quality and population dominance (Qin *et al*. 2017). The escalation of endangerment status in the last several decades sends an unequivocal message of the unrelenting pressure on its survival and the failure of conservation efforts. Therefore, researching the habitat shrinkage and deterioration of *B. racemosa* under multiple stress factors deserves urgent attention.

While conducting field surveys on plant resources in 2023, the research team discovered the only known population of large old trees of *B. racemosa* in remnant forest stands on Hainan Island, South China (Fig. 1). According to interviews with local residents, this population consists of approximately 13,800 individuals of *B. racemosa*, with some trees reaching over a thousand years old. It denotes an exceptionally valuable botanical treasure that deserves special attention and protection.

Research on *B. racemosa* mainly focuses on its chemical composition and medicinal properties (Chan *et al*. 2017; Kong *et al*. 2020), ecology (Aluri *et al*. 2019; Guo *et al*. 2019), environmental science (Thomas and Fernandez, 1997; Liang *et al*. 2022), and physiological responses to salt stress (Xie *et al*. 2023; Hu *et al*. 2024). No research has been conducted on this species' LOT population. Therefore, this study aimed to investigate the current status of the LOT population of *B. racemosa* through field surveys. The findings can establish a scientific basis for conserving this unique and precious remnant population. Additionally, this research will raise awareness and prompt the forestry department to prioritize the protection of this extraordinary LOT resource.

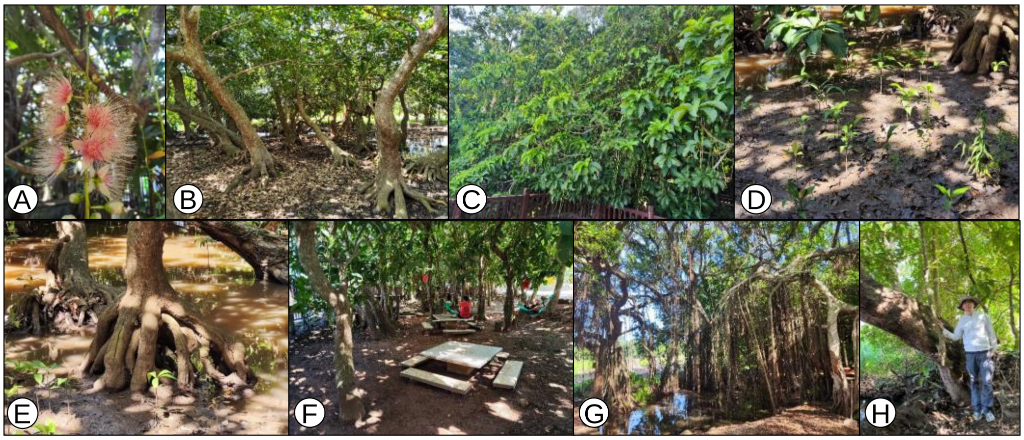

Fig. 1. Overview of the old-growth *B. racemosa* population in the study area (109°22'40"E, 19°45'42"N), located at Qili Village, Danzhou Prefecture, Hainan Province, tropical South China. A: ornamental pendulous flowers with filamentous stamens; B: tree distribution in the forest stand; C: biomass structure in the stand; D: regeneration features; E: prop root development; F: habitat disturbance by recreational facilities and visitors; G: invasive banyan tree; H: field investigation.

EXPERIMENTAL

Study Area and Field Survey

The LOT population of *B. racemosa* is distributed in the Qili Village (109.38E, 19.76N) of Danzhou Prefecture, Hainan Province, South China. The region has a tropical monsoon climate with an average annual temperature of 23℃, an average temperature of 17.8℃ in January and 28.8℃ in July, and an average annual rainfall of 1500 mm. As an ancient village with a history of over 1300 years, Qili is home to the largest and best-preserved LOT population of *B. racemosa* in China, with over 10,000 individuals.

Viewed from above using a drone, the "one river, one forest" special geographical setting of the village is vividly demonstrated (Fig. 2). The Maopo River runs through the village, with farmland and forests on one side of the river and the village houses on the other. The LOTs of *B. racemosa* are mainly distributed along the river, forming a riparian green belt stretching continuously for 3 km. Covering an area of over 30 ha, the linear forest accommodates some exceptionally large trees, with the tallest reaching 15 m. In Fig.2 (b), P1-P20 indicates the plot number in the study area.

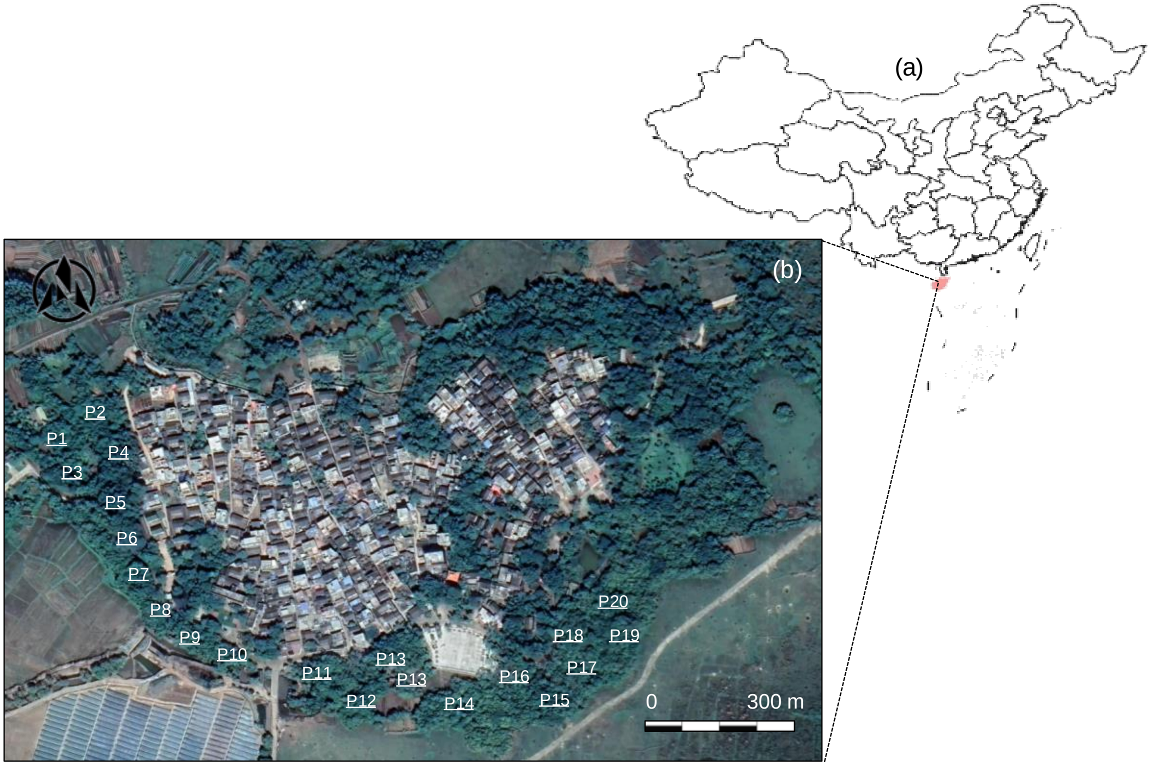

Fig. 2. The study area: (a) location of the study area, Qili Village, in Danzhou, Hainan Island (south China), and (b) satellite image of the linear forest stand indicating the study plots.

Given the relatively simple community structure of the study site, where other tree species are present sparsely, but *B. racemosa* overwhelmingly dominates the tree layer, a random sampling method was employed for selecting the sample plots. Twenty 10 m × 10 m plots were set arbitrarily in the distribution areas of LOTs of *B. racemosa*, in which all plants were recorded. A focused investigation was conducted into the occurrences of *B. racemosa* in the plots. For individuals with a diameter at breast height (DBH) greater than 2 cm, detailed information such as height, DBH, crown width, and growth status were recorded. Individuals with a DBH of less than 2 cm were counted as saplings and seedlings. Tree DBH was measured using a caliper gauge. Plant cover was estimated visually. Tree height was measured using a height meter (CGQ-1, Habin Optical, China) (direct reading type forestry surveying and measuring instrument) for larger trees and a measuring tape for saplings, seedlings, shrubs, and herbs.

Data Analysis

Accurately determining tree age can be challenging. Therefore, the 'space-for-time substitution' method was employed (Yang *et al*. 2018), using DBH size classes as a proxy for age classes in the analysis (O'Brien *et al*. 1995; Venter and Witkowski 2010). This approach is based on the significant correlation between DBH and tree age in many tree species (Morgenroth *et al*. 2020). To assess the population structure and dynamics of *B. racemosa*, a static life-table and survival curve were utilized to delineate its characteristics. The analysis focused on DBH size classes, and DBH was categorized into ten size classes: I represents seedlings and saplings with DBH <2 cm; II with 2 to 9.99 cm; III with 10 to 19.99 cm; IV with 20 to 29.99 cm; V with 30 to 39.99 cm; VI with 40 to 49.99 cm; VII with 50 to 59.99 cm; VIII with 60 to 69.99 cm; IX with 70 to 79.99 cm; and X with ≥80 cm.

RESULTS AND DISCUSSION

The population structure of *B. racemosa* in the study area is depicted in Fig. 3, showing the distribution of tree counts across ten DBH size classes (Fig. 3).

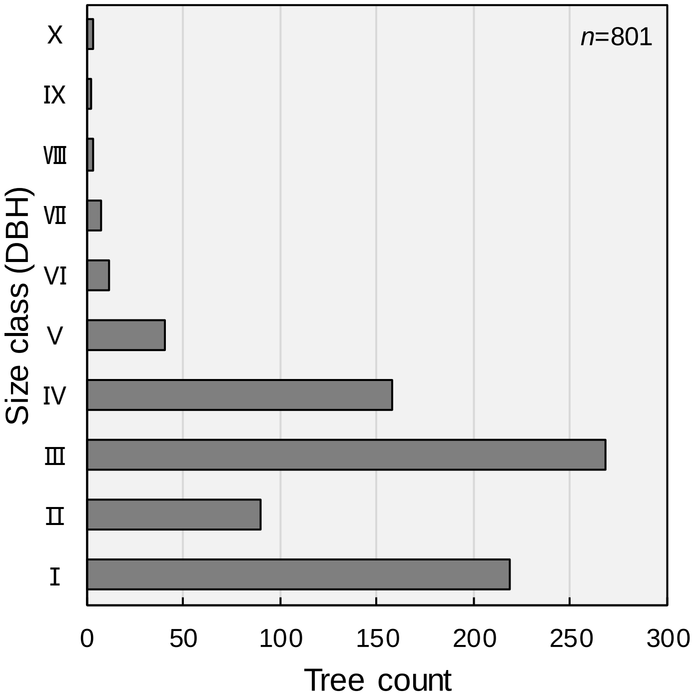

Fig. 3. Population structure of *B. racemosa* in the study plots. Size class I seedlings and saplings, DBH <2 cm; II: 2–9.99 cm; III: 10–19.99 cm; IV: 20–29.99 cm; V: 30–39.99 cm; VI: 40–49.99 cm; VII: 50–59.99 cm; VIII: 60–69.99 cm; IX: 70–79.99 cm; X: DBH ≥80 cm.

A pronounced skew is expressed towards the medium to small size classes. The highest number of trees is in size class III (268 individuals, DBH 10–19.99 cm), followed by size class I (219 individuals, DBH <2 cm) and size class IV (158 individuals, DBH 20–29.99 cm). As the size class increases, the number of trees sharply decreases. There are only 40 trees in size class V (DBH 30–39.99 cm) and just 11 in size class VI (DBH 40–49.99 cm). Larger size classes (VII to X, DBH ⩾50 cm) contain very few individuals, with the number dropping to single digits—size class VII has 7 trees, class VIII has 3, class IX has 2, and class X has 3 trees. This distribution reflects a skew towards younger, smaller trees and a critical shortage of older, larger trees, highlighting a need for conservation efforts to protect the aging population. The pattern implies a continual and markedly high mortality rate, which could be induced by environmental stresses or anthropogenic pressures suppressing the growth, health, and survival of mature trees.

The static life-table for the *B. racemosa* population in the study plots provides crucial insights into the demographic characteristics and survivorship patterns of this LOT species (Table 1). Encompassing ten size classes, the results reveal pronounced variations in survival rates and mortality across different growth stages. In class I, the population starts with 219 individuals, corresponding to a survivorship (l_x) of 817. This smallest class experiences the highest mortality rate (q_x) of 0.59, with 481 individuals dying (d_x). The number of survivors from size class I to II (L_x) is calculated to be 576, indicating significant early-stage attrition. This high mortality in the early stages is typical in many tree populations, reflecting the vulnerability of seedlings and young saplings to natural vagaries and human perturbations.

Table 1. The Static Life-Table of the *B. racemosa* Population in the Study Plots

Size class	a_x	l_x	$\ln l_x$	d_x	q_x	L_x	T_x	e_x	K_x
I	219	817	6.71	481	0.59	576	2580	3.16	0.89
II	90	336	5.82	-664	-1.98	668	2004	5.97	-1.09
III	268	1000	6.91	410	0.41	795	1336	1.34	0.53
IV	158	590	6.38	440	0.75	369	541	0.92	1.37
V	40	149	5.01	108	0.73	95	172	1.15	1.29
VI	11	41	3.71	15	0.36	34	76	1.86	0.45
VII	7	26	3.26	15	0.57	19	43	1.64	0.85
VIII	3	11	2.42	4	0.33	9	24	2.17	0.41
IX	2	7	2.01	-4	-0.50	9	15	2.00	-0.41
X	3	11	2.42			6	6	0.50	

**x* is size class, a_x is the number of survivors in *x* class, $l_x = (1000\, a_x)/ a_1$, $d_x = l_{(x-1)} - l_x$, q_x the mortality rate in *x* size class, $q_x = (d_x / l_x)$, L_x the number of survivors from *x* to *x*+1 age class, $L_x = (l_{x+1} + l_x)/2$, T_x the total number of survivor from *x* to the maximum age class, $T_x = l_x + l_{x+1} + \ldots\ldots + l_{x+n}$; $e_x = T_x / l_x$; $K_x = \ln l_x - \ln l_{x+1}$

Class II witnesses a reduction to 90 individuals, with a survivorship of 336 and a negative mortality rate (q_x = -1.98). The mean number of survivors transitioning to size class III is 668. Since the static life-table represents an overlay of multiple generations at a specific time (Orzack and Tuljapurkar, 1989), negative values are unavoidable. The population in class III increases to 268 individuals (l_x = 1000), indicating a recovery with a lower mortality rate (q_x = 0.41). Classes IV and V maintain intermediate numbers with relatively stable survivorship and moderate mortality rates (q_x = 0.75) and (q_x = 0.73), respectively, highlighting a critical phase where growth and survival are balanced.

In the large classes VI to X, the population steadily declines, with survivorship numbers dropping significantly, reflecting the natural aging process and intense external pressures. Class VI contains 11 individuals (l_x = 41) with a lower mortality rate of 0.36, while size class VII further reduces to 7 individuals. The largest classes from VIII to X have 3, 2 and 3 individuals, respectively, with significantly higher life expectancies (e_x) due to fewer remaining survivors. Generally, the table elucidates the survivorship curve and life expectancy across different size classes, indicating that *B. racemosa* faces a high mortality rate at the early stage, moderate survivorship in medium-size classes, and a sharp decline in large-size classes.

The survival curve ($\ln l_x$) of the *B. racemosa* population in the study plots displays a distinct and steep declining trend from the small to the large DBH classes (Fig. 4). The curve starts with a high $\ln l_x$ value for the smallest size class (I), indicating many individuals at the initial stage. From class I to X, the $\ln l_x$ values consistently decrease, suggesting a considerable progressive reduction in the number of surviving individuals. This decline pattern in the survival curve is characteristic of a population experiencing size-dependent mortality, where fewer individuals survive to reach the larger size classes. The steeper drop in $\ln l_x$ values from classes I to III, followed by a less steep drop in the subsequent classes, indicates a higher mortality rate in the early stage of growth and development.

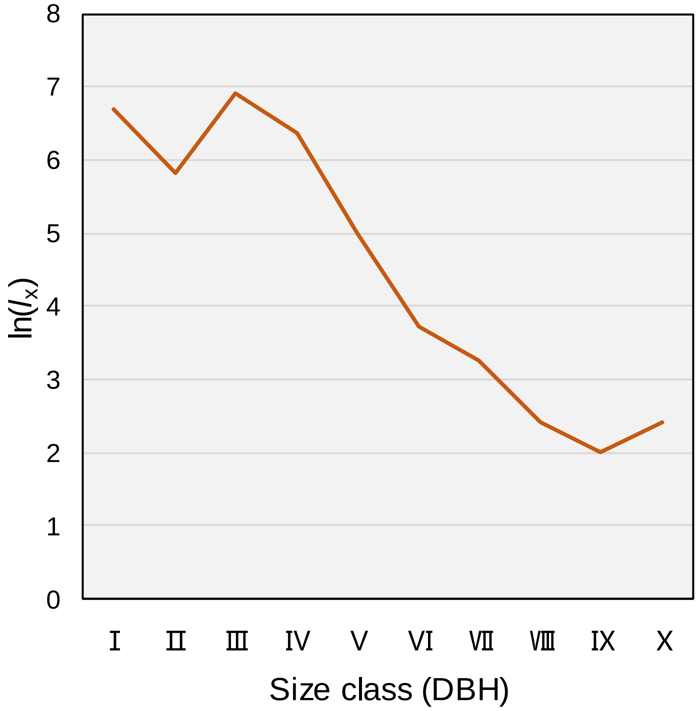

Fig. 4. Survival curve ($\ln l_x$) of the *B. racemosa* population in the study plots

Discussion

Natural history can be demonstrated not only by museum artifacts but also by the organisms still surviving in nature, especially if they are recognized as uncommon or rare "living relics" (Krebs *et al*. 2012). Over centuries of growth, LOTs have faithfully recorded continual changes in the natural environment and their resilience and longevity through endurance and adaptation (Blicharska and Mikusiński 2014). Their ancient appearance, tenacious vitality and eventful vicissitudes have increasingly earned the respect and affection of people (Kawa *et al*. 2015). The large old *B. racemosa* in the study area have been deeply embedded into the lives of local villagers, closely linked to both ecological protection and the transmission of traditional culture. Therefore, research on LOT populations is crucial for their conservation in the study area.

Current Population Dynamics

There are 801 individuals of *B. racemosa* in the study plots, and the size class structure presents an atypical "pyramid" shape (Fig. 3, Table 1). Class III has the most individuals. Significant fluctuations are observed in classes I and II, with high seedling mortality, making it difficult for them to develop into young trees. After class IV, the population starts to decline sharply, indicating low stability and high risk in the population's development process. This situation is more obvious during the transition from seedlings (size class I) to young trees (size class II) (Fig. 4).

The static life table was constructed using DBH classes of all individuals in the population collected at the same period (Liu *et al*. 2023a). The data reflect a specific time in the age dynamics of overlapping generations rather than tracking the entire life history of a cohort. Due to systematic sampling errors in the survey, negative mortality rates may appear in the life table. Some scholars suggest that the occurrence of negative values in life table analysis may not align with data assumptions. However, the results can still offer valuable ecological records, indicating that the population is not static but undergoing development or decline (Wratten and Fry 1980).

The negative values in population dynamics reflect the population's fluctuation, an inherent property (Xie *et al*. 2010). The fluctuations in the number of individuals between different size-class cohorts reflect the population's updating dynamics, which can be seen in the cycle length of the population's basic waves. Therefore, the variability in population structure is an intrinsic property. Many studies use smoothing techniques in data processing to eliminate the effects caused by age fluctuations (Li *et al*. 2015; Liu *et al*. 2023b). While this approach conforms to some assumptions of population dynamic models, it inevitably obscures certain ecological phenomena in population number fluctuations (Zhu *et al*. 2008). Thus, this study does not smooth the relevant data to reflect better the reality of the old population of *B. racemosa*.

Previous research indicates that new seedlings are the most vulnerable in adapting to and resisting environmental challenges (Poorter and Markesteijn 2008). Limited resources and space constrain population renewal (Goessen *et al*. 2022). In the study area, there is a decline in the population curve between size class I and size class II, which indicates a lower survival rate at this early stage of development (Fig. 4). If the survival rate of seedlings does not improve, the population will likely decline over time. Firstly, intense intra- and interspecific competition for resources within the understory leads to self-thinning and density-dependent mortality (Gendreau-Berthiaume *et al*. 2016). However, as plants mature, their environmental adaptability and competitiveness increase, leading the population into a stable phase characterized by declining mortality and disappearance rates. Conversely, external disturbances, including livestock grazing, human trampling, and direct removal, significantly impact this population, severely hindering seedling establishment and growth. Hence, the successful transition of individuals from the young to the middle-aged class is essential for the persistence of the *B. racemosa* population. A comparison with the natural population structure of *B. racemosa* in other regions revealed similar findings to the present research: the transition from seedlings to saplings was hindered, and population development was in decline (Zhong *et al*. 2018). To effectively protect the current population, the most reliable strategy is to implement "in-situ protection," enhance seed germination rates, increase seedling numbers, and inhibit the growth of non-target tree species.

Threats from External Interference

Human activities pose significant threats to the regeneration and survival of *B. racemosa*, particularly in areas close to rural settlements where free-range livestock commonly roam in the remnant forest stand. Livestock such as pigs, cattle, chickens, and ducks frequently forage on *B. racemosa* seedlings, significantly reducing young plant populations and disrupting the natural regeneration process. This ongoing disturbance prevents many seedlings from reaching maturity, thereby diminishing the long-term viability of the species. Furthermore, the spatial proximity of settlements to *B. racemosa* populations exacerbates these pressures, as grazing and other human-related disturbances are more intense in areas where human and livestock activities overlap with the tree distribution. These chronic conflicts must be considered in assessing the conservation status and management needs of *B. racemosa*.

Moreover, the trampling of seedlings by villagers, who often gather under the shade of mature trees, exacerbates the site degradation problem (Fig. 1F). This human activity leads to soil compaction, which significantly hinders the germination of *B. racemosa* seeds (Benvenuti and Mazzoncini 2019). Soil compaction leads to restricted root growth, reduced nutrient availability, and increased nutrient loss through leaching, runoff, and gaseous emissions to dampen plant growth (Shaheb *et al*. 2021).

Furthermore, the soil is simultaneously affected by other degradation, such as salinity. Thus, the detrimental impacts of compaction on plant growth are exacerbated, resulting in mutually reinforcing negative effects (Singh 2022). Even if a limited number of seeds could successfully germinate, the subsequent establishment period for the seedlings is significantly influenced by the multiple soil limitations (Cambi *et al*. 2018).

Three large banyan trees (*Ficus altissima*) were found in the study area, and these compete with the current population of *B. racemosa*. Banyan trees in the community pose an additional threat to the *B. racemosa* population (Fig. 1G). Certain *Ficus* species exhibit a unique strangler habit, enabling successful establishment even within dense mature forests (Prósperi *et al*. 2001). The banyan’s frugivore-dispersed seeds can be deposited and germinate on elevated branches or forks of existing trees, initially developing as hemi-epiphytes (Putz and Holbrook 1986). Limited foliage under the host tree's canopy necessitates resource allocation toward the growth of flexible aerial roots. These roots descend towards the forest floor, where they develop a robust normal root system in the soil to expand significantly the capacity for nutrient and water acquisition. This transition from epiphytic dependence to soil-rooted growth provides a new lease of life for the strangler to flourish. Subsequently, the banyan produces many more aerial roots that descend and encircle the host tree’s trunk, thickening and lignifying to restrict phloem transport, ultimately leading to host tree death (Zimmermann *et al*. 1968; Fisher 1982). The deceased host's above- and below-ground niches, along with nutrients released from decomposition, are then inherited by the strangler. This strategy allows banyan trees to thrive in mature forests, contributing to their abundance and ecological dominance. Therefore, the presence of banyan trees in the community also threatens the *B. racemosa* population, which cannot be ignored.

The combined effect of livestock foraging, human trampling, and banyan trees creates a detrimental feedback loop that threatens the regeneration potential of *B.*

racemosa. The loss of seedlings due to these disturbances can lead to chronic population decline, ultimately jeopardizing the species' long-term viability. As such, it is imperative to implement conservation strategies that mitigate these human-induced pressures, including developing protective measures for seedlings and promoting sustainable land-use practices that minimize disturbance to this critical ecosystem.

Implications for Conservation

Based on field investigations and interpretations of research data, some conservation measures can be recommended:

(1) *Integrate traditional ecological knowledge and practices*. To effectively protect and manage the LOTs of *B. racemosa*, it is crucial to amalgamate modern ecological science with traditional ecological knowledge (TEK) and local residents' practices (Boafo *et al*. 2016). The village communities deeply understand the local ecosystems and have developed sustainable practices to live harmoniously with their companion nature over generations. Engaging with elders and community leaders to document and incorporate their knowledge into modern conservation strategies can provide valuable insights into the sustainable use and protection of these ancient trees. This could include traditional harvesting methods that minimize damage, culturally significant practices that promote tree health, and historical data on tree populations. By respecting and integrating TEK, conservation efforts can become more culturally relevant and gain stronger support from the community (Whyte 2013). Workshops and participatory meetings can help bridge the gap between scientific and traditional knowledge, fostering a collaborative approach to conservation that benefits both the ancient tree group and the local villagers who depend on them.

(2) *Implement community-based conservation programs*. Community-based conservation programs are essential for protecting *B. racemosa* by leveraging local villagers’ strong cultural ties with these LOTs. Establishing community-managed conservation areas can empower villagers to take ownership of the preservation efforts (Sam *et al*. 2023). These programs should involve local stakeholders in decision-making, ensuring that their needs and perspectives are considered, respected and applied. Capacity-building workshops can equip community members with the skills and knowledge to manage and monitor tree populations effectively, synergistically merging modern and traditional knowledge. Additionally, involving local schools in conservation education can foster a sense of stewardship among the younger generation (Couceiro *et al*. 2023). Incentives such as recognition awards or financial benefits for local villagers who successfully protect and manage their LOTs can further motivate participation (Awono *et al*. 2014). Community-based conservation programs create a sense of responsibility and pride among villagers, enhancing the long-term sustainability of conservation efforts (Turreira-García *et al*. 2018).

(3) *Enhance habitat protection and restoration and conduct long-term ecological research*. Protecting and restoring habitats where *B. racemosa* thrives is crucial for conserving this species. Efforts should focus on identifying and safeguarding critical habitats, which provide essential ecosystem services and support the species' growth and reproduction (Bruner *et al*. 2001). Restoration projects should aim to rehabilitate degraded areas by replanting *B. racemosa* seedlings and ensuring proper hydrological conditions. The harmful factors can be methodically mitigated or removed. For notably disturbed habitats, the re-wilding efforts can aim at removing extraneous elements and prevent their re-entry or re-invasion and recovery of ecosystem processes and ingredients (Mutillod *et*

al. 2024). Establishing protected areas or expanding existing ones can create refuge zones where the species can grow without the threat of habitat destruction and other deleterious intrusions (Belote *et al*. 2017). Enhanced habitat protection and restoration are vital for sustaining a healthy population of *B. racemosa* and preserving the ecological integrity of their habitats. At the same time, long-term ecological research is essential to understand the population dynamics and ecological requirements of *B. racemosa*. Establishing permanent research plots within various habitats can provide valuable data on growth rates, survival, and reproductive success. Regularly monitoring these plots will allow researchers to track changes in population structure and identify potential threats (Turreira-García *et al*. 2018). Research findings can inform adaptive management strategies that enhance the resilience of *B. racemosa* populations.

(4) *Enhance legal protection and policy support*. Strengthening legal protection and policy support for the ancient *B. racemosa* tree group is essential for their conservation. Establishing or reinforcing the legal framework that designates the forests harboring them as protected areas can provide a formal basis and agenda for conservation actions (Nik Mohamed Sukri *et al*. 2023). It is critical to conserve holistically the forest ecosystems that nurture the prized LOTs rather than just the collection of individual LOTs. Policies should include strict regulations on logging, land use changes, and other activities that threaten the trees. It is also important to facilitate legal recognition of community-managed conservation areas, providing villagers with the authority and resources to protect their LOTs (Rao *et al*. 2016). Regular reviews and updates of policies based on the latest ecological and social research can ensure they remain effective and relevant. Enhanced legal protection and policy support provide a robust framework for the long-term conservation of *B. racemosa*, safeguarding their ecological and cultural significance for future generations.

CONCLUSIONS

1. This study highlights the vulnerability of the *B. racemosa* population in rural China, particularly in the face of continued anthropogenic pressures and competition from invasive species. These trees are important for their age and size and serve as keystone species that support a wide range of commensal organisms and ecological functions. The threats they face, primarily from external interference, underscore the urgent need for comprehensive conservation strategies.
2. The authors recommend a multifaceted approach that includes establishing protected areas, implementing sustainable land-use practices, engaging the community in conservation efforts, and integrating traditional ecological knowledge. By focusing on preserving the forest ecosystems that accommodate the large old trees, the ecological balance can be maintained, ensuring the long-term sustainability of the holistic natural endowments in rural China.
3. This study contributes to the growing body of evidence supporting the critical role of large old trees in nature and socio-cultural conservation.

ACKNOWLEDGMENTS

This research was funded by the National Natural Science Foundation of China (grant number: 32360417), Hainan Provincial Natural Science Foundation of China (Grant number: 423MS061), and the Education Department of Hainan Province (grant number: Hnky2023ZD-17). The authors express their gratitude to Mr. Erlin Tian from Qiongtai Normal University for the invaluable assistance rendered during the field surveys.

Data Availability Statement

The data presented in this study are available on request from the first author.

Author Contributions

XC and CYJ conceived and designed the research; XC, LD and JS performed research; XC, LD and JS curated the data; XC Wrote the original draft; CYJ reviewed and edited. All authors had read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES CITED

Aluri, J. S. R., Palathoti, S. R., Banisetti, D. K., and Samareddy, S. K. (2019). "Pollination ecology characteristics of *Barringtonia racemosa* (L.) Spreng. (Lecythidaceae)," *Transylvanian Review of Systematical and Ecological Research* 21(3), 27-34. DOI: 10.2478/trser-2019-0017

Awono, A., Somorin, O. A., Eba'a Atyi, R., and Levang, P. (2014). "Tenure and participation in local REDD+ projects: Insights from southern Cameroon," *Environmental Science & Policy* 35, 76-86. DOI: 10.1016/j.envsci.2013.01.017

Belote, R. T., Dietz, M. S., Jenkins, C. N., McKinley, P. S., Irwin, G. H., Fullman, T. J., Leppi, J. C., and Aplet, G. H. (2017). "Wild, connected, and diverse: Building a more resilient system of protected areas," *Ecological Applications* 27(4), 1050-1056. DOI: 10.1002/eap.1527

Benvenuti, S., and Mazzoncini, M. (2019). "Soil physics involvement in the germination ecology of buried weed seeds," *Plants* 8(1), 7. DOI: 10.3390/plants8010007

Blicharska, M., and Mikusiński, G. (2014). "Incorporating social and cultural significance of large old trees in conservation policy," *Conservation Biology* 28(6), 1558-1567. DOI: 10.1111/cobi.12341

Boafo, Y. A., Saito, O., Kato, S., Kamiyama, C., Takeuchi, K., and Nakahara, M. (2016). "The role of traditional ecological knowledge in ecosystem services management: The case of four rural communities in Northern Ghana," *International Journal of Biodiversity Science, Ecosystem Services & Management* 12(1-2), 24-38. DOI: 10.1080/21513732.2015.1124454

Bruner, A. G., Gullison, R. E., Rice, R. E., and da Fonseca, G. A. B. (2001). "Effectiveness of parks in protecting tropical biodiversity," *Science* 291(5501), 125-128. DOI: 10.1126/science.291.5501.125

Cambi, M., Mariotti, B., Fabiano, F., Maltoni, A., Tani, A., Foderi, C., Laschi, A., and Marchi, E. (2018). "Early response of seedlings to soil compaction following germination," *Land Degradation & Development* 29(4), 916-925. DOI: 10.1002/ldr.2912

Chan, E. W. C., Baba, S., Chan, H. T., Kainuma, M., Inoue, T., and Wong, S. K. (2017). "Ulam herbs: A review on the medicinal properties of *Anacardium occidentale* and *Barringtonia racemosa*," *Journal of Applied Pharmaceutical Science* 7(2), 241-247. DOI: 10.7324/JAPS.2017.70235.

Couceiro, D., Hristova, I.R., Tassone, V., Wals, A., and Gómez, C. (2023). "Exploring environmental stewardship among youth from a high-biodiverse region in Colombia," *The Journal of Environmental Education* 54(5), 306-324. DOI: 10.1080/00958964.2023.2238649

Dean, C., Kirkpatrick, J. B., Doyle, R. B., Osborn, J., Fitzgerald, N. B., and Roxburgh, S.H. (2020). "The overlooked soil carbon under large, old trees," *Geoderma* 376, article 114541. DOI: 10.1016/j.geoderma.2020.114541.

Finlayson, C. M., Lowry, J., Bellio, M. G., Nou, S., Pidgeon, R., Walden, D., Humphrey, C., and Fox, G. (2006). "Biodiversity of the wetlands of the Kakadu Region, Northern Australia," *Aquatic Sciences* 68(3), 374-399. DOI: 10.1007/s00027-006-0852-3

Fisher, J. B. (1982). "A survey of buttresses and aerial roots of tropical trees for presence of reaction wood," *Biotropica* 14(1), 56-61. DOI: 10.2307/2387760

Gendreau-Berthiaume, B., Macdonald, S. E., and Stadt, J. J. (2016). "Extended density-dependent mortality in mature conifer forests: Causes and implications for ecosystem management," *Ecological Applications* 26(5), 1486-1502. DOI: 10.1890/15-0887

Gilhen-Baker, M., Roviello, V., Beresford-Kroeger, D., and Roviello, G. N. (2022). "Old growth forests and large old trees as critical organisms connecting ecosystems and human health. A review," *Environmental Chemistry Letters* 20(2), 1529-1538. DOI: 10.1007/s10311-021-01372-y

Goessen, R., Isabel, N., Wehenkel, C., Pavy, N., Tischenko, L., Touchette, L., Giguère, I., Gros-Louis, M.-C., Laroche, J., Boyle, B., *et al*. (2022). "Coping with environmental constraints: Geographically divergent adaptive evolution and germination plasticity in the transcontinental *Populus tremuloides*," *Plants, People, Planet* 4(6), 638-654. DOI: 10.1002/ppp3.10297

Guo, C., Chen, Q., Xu, S., Chen, H., Li, W., and Pan, T. (2019). "The disturbance mechanism and potential ecological loss of the *Barringtonia racemosa* community on the east coast of Leizhou Peninsula," *Journal of South China Normal University (Natural Science Edition)* 51(4), 67-75. DOI: 10.6054/j.jscnun.2019068

Hu, J., Deng, X., Bai, C., Li, L., Yang, X., Lan, C., Zhong, H., Tan, X., and Liang, F. (2024). "Mechanism of salt tolerance in the endangered semi-mangrove plant *Barringtonia racemosa*: Anatomical structure and photosynthetic and fluorescence characteristics," *3 Biotech* 14(4), article 103. DOI: 10.1007/s13205-024-03943-6

Huang, L., Tian, L., Zhou, L., Jin, C., Qian, S., Jim, C. Y., Lin, D., Zhao, L., Minor, J., Coggins, C., *et al*. (2020). "Local cultural beliefs and practices promote conservation of large old trees in an ethnic minority region in southwestern China," *Urban Forestry & Urban Greening* 49, article 126584. DOI: 10.1016/j.ufug.2020.126584

Kawa, N. C., Painter, B., and Murray, C. E. (2015). "Trail trees: Living artifacts (vivifacts) of eastern North America," *Ethnobiology Letters* 6(1), 183-188. DOI: 10.14237/ebl.6.1.2015.410

Kebrle, D., Zasadil, P., Hošek, J., Barták, V., and Šťastný, K. (2021). "Large trees as a key factor for bird diversity in spruce-dominated production forests: Implications for conservation management," *Forest Ecology and Management* 496, 119460. DOI:

10.1016/j.foreco.2021.119460

Kong, K. W., Mat Junit, S., Aminudin, N., and Abdul Aziz, A. (2020). "Phytochemicals in Barringtonia species: Linking their traditional uses as food and medicine with current research," *Journal of Herbal Medicine* 19, article 100299. DOI: 10.1016/j.hermed.2019.100299

Krebs, P., Koutsias, N., and Conedera, M. (2012). "Modelling the eco-cultural niche of giant chestnut trees: New insights into land use history in southern Switzerland through distribution analysis of a living heritage," *Journal of Historical Geography* 38(4), 372-386. DOI: 10.1016/j.jhg.2012.01.018.

Li, Z., Chen, Y., Hong, X., H.an, W., and Li, X. (2015). "Age structure and point pattern analysis of *Dacrydium pectinatum* in Bawangling, Hainan Island," *Chinese Journal of Ecology* 34(6), 1507-1515.

Liang, F., Hu, J., Liu, B., Li, L., Yang, X., Bai, C., and Tan, X. (2022). "New evidence of semi-Mangrove plant *Barringtonia racemosa* in soil clean-up: Tolerance and absorption of lead and cadmium," *International Journal of Environmental Research and Public Health* 19(19), article 12947. DOI: 10.3390/ijerph191912947

Lindenmayer, D. B. (2017). "Conserving large old trees as small natural features," *Biological Conservation* 211, 51-59. DOI: 10.1016/j.biocon.2016.11.012

Lindenmayer, D. B., and Laurance, W. F. (2017). "The ecology, distribution, conservation and management of large old trees," *Biological Reviews* 92(3), 1434-1458. DOI: 10.1111/brv.12290

Liu, D., Guo, Z., Cui, X., and Fan, C. (2023a). "Estimation of the population dynamics of *Taxus cuspidata* by using a static life table for its conservation," *Forests* 14(11), article 2194. DOI: 10.3390/f14112194

Liu, W., Zhang, J., and Liu, Q. (2023b). "Dominant population structure and dynamic characteristics of *Betula platyphylla* and *Larix olgensis* forest on the eastern slope of Changbai Mountain Northeast China," *Acta Ecologica Sinica* 43(18), 7462-7473. DOI: 10.20103/j.stxb.202209272747

Moomaw, W. R., Masino, S. A., and Faison, E. K. (2019). "Intact forests in the United States: Proforestation mitigates climate change and serves the greatest good," *Frontiers in Forests and Global Change* 2, article 449206. DOI: 10.3389/ffgc.2019.00027

Morgenroth, J., Nowak, D. J., and Koeser, A. K. (2020). "DBH distributions in America's urban forests—An overview of structural diversity," *Forests* 11(2), article 135. DOI: 10.3390/f11020135

Mutillod, C., Buisson, É., Mahy, G., Jaunatre, R., Bullock, J.M., Tatin, L., and Dutoit, T. (2024). "Ecological restoration and re-wilding: Two approaches with complementary goals?," *Biological Reviews* 99(3), 820-836. DOI: 10.1111/brv.13046

Nik Mohamed Sukri, N. A., Ismail, Z., Wan Ariffin, W. T., and Mohd Nordin, R. (2023). "Categorising the tree protection legislative provisions implemented by local planning authorities globally," *International Journal of Sustainable Construction Engineering and Technology* 14(5), 355-363. DOI: 10.30880/ijscet.2023.14.05.029.

O'Brien, S. T., Hubbell, S. P., Spiro, P., Condit, R., and Foster, R. B. (1995). "Diameter, height, crown, and age relationship in eight neotropical tree species," *Ecology* 76(6), 1926-1939. DOI: 10.2307/1940724

Orzack, S. H., and Tuljapurkar, S. (1989). "Population dynamics in variable environments. VII. The demography and evolution of iteroparity," *The American Naturalist* 133(6), 901-923. DOI: 10.1086/284959

Poorter, L., and Markesteijn, L. (2008). “Seedling traits determine drought tolerance of tropical tree species,” 40(3), 321-331. DOI: 10.1111/j.1744-7429.2007.00380.x

Prósperi, J., Caballé, G., and Caraglio, Y. (2001). “Lianas and hemiepiphytes: Distribution, development, and adaptations,” *Selbyana* 22(2), 197-212.

Putz, F. E., and Holbrook, N. M. (1986). “Notes on the natural history of hemiepiphytes,” *Selbyana* 9(1), 61-69.

Qin, H., Yang, Y., Dong, S., He, Q., Jia, Y., Zhao, L., Yu, S., Liu, H., Liu, B., Yan, Y., *et al*. (2017). “Threatened species list of China’s higher plants,” *Biodiversity Science* 25(7), 696-744. DOI: 10.17520/biods.2017144

Rao, M., Nagendra, H., Shahabuddin, G., and Carrasco, L. R. (2016). "Integrating community-managed areas into protected area systems," in: *Protected Areas: Are They Safeguarding Biodiversity?*, L. N. Joppa, J. E. M. Baillie, and J. G. Robinson (eds.), Wiley, London, pp. 169-189. DOI: 10.1002/9781118338117.ch10

Saddhe, A. A., Manuka, R., Nikalje, G. C., and Penna, S. (2020). "Halophytes as a potential resource for phytodesalination," in *Handbook of Halophytes: From Molecules to Ecosystems towards Biosaline Agriculture*, M.-N. Grigore (ed.), Springer International Publishing, Cham, Switzerland, pp. 1-21.

Sam, K., Zabbey, N., Gbaa, N. D., Ezurike, J. C., and Okoro, C. M. (2023). “Towards a framework for mangrove restoration and conservation in Nigeria,” *Regional Studies in Marine Science* 66, article 103154. DOI: 10.1016/j.rsma.2023.103154

Shaheb, M. R., Venkatesh, R., and Shearer, S. A. (2021). “A review on the effect of soil compaction and its management for sustainable crop production,” *Journal of Biosystems Engineering* 46(4), 417-439. DOI: 10.1007/s42853-021-00117-7

Singh, A. (2022). “Soil salinity: A global threat to sustainable development,” *Soil Use and Management* 38(1), 39-67. DOI: 10.1111/sum.12772

Thomas, G., and Fernandez, T. V. (1997). “Incidence of heavy metals in the mangrove flora and sediments in Kerala, India,” *Hydrobiologia* 352, 77-87. DOI: 10.1023/A:1003061524716

Turreira-García, N., Meilby, H., Brofeldt, S., Argyriou, D., and Theilade, I. (2018). “Who wants to save the forest? Characterizing community-led monitoring in Prey Lang, Cambodia,” *Environmental Management* 61(6), 1019-1030. DOI: 10.1007/s00267-018-1039-0

Venter, S. M., and Witkowski, E. T. F. (2010). “Baobab (*Adansonia digitata* L.) density, size-class distribution and population trends between four land-use types in northern Venda, South Africa,” *Forest Ecology and Management* 259(3), 294-300. DOI: 10.1016/j.foreco.2009.10.016

Wang, W., Li, X., and Wang, M. (2019). “Propagule dispersal determines mangrove zonation at intertidal and estuarine scales,” *Forests* 10(3), 245. DOI: 10.3390/f10030245

Whyte, K. P. (2013). “On the role of traditional ecological knowledge as a collaborative concept: A philosophical study,” *Ecological Processes* 2(1), article 7. DOI: 10.1186/2192-1709-2-7

Wratten, S. D., and Fry, G. L. A. (1980). *Field and Laboratory Exercises in Ecology*, Edward Arnold Publishers, London.

Xie, C., Fang, Y., and Fang, Y. (2010). “Analysis of the population dynamics of *Quercus phillyraeoides*,” *Journal of Sichuan Agricultural University* 28(4), 438-448. DOI: 10.3969/j.issn.1000-2650.2010.04.009

Xie, X., Pang, X., Deng, X., Hu, J., Chen, W., Yang, Y., Liang, F., and Tan, X. (2023).

"Salicylic acid alleviates tidal flooding and salinity toxicity on *Barringtonia racemosa* seedlings by activating the stress defense mechanism," *Brazilian Journal of Botany*. DOI: 10.1007/s40415-023-00947-z

Yang, L. R., Zhang, Z. L., Yun, Y., Yan, W. P., Chen, X., Zhang, L., Zheng, D., and Chen, J. (2018). "The population structure and dynamics of *Dracaena cambodiana*, an endangered tree on Hainan Island," *Acta Ecologica Sinica* 38(8), 2802-2815. DOI: 10.5846/stxb201708071415

Yao, N., Gu, C., Qi, J., Shen, S., Nan, B., and Wang, H. (2024). "Protecting rural large old trees with multi-scale strategies: Integrating spatial analysis and the contingent valuation method (CVM) for socio-cultural value assessment," *Forests* 15(1), article 18. DOI: 10.3390/f15010018

Zhong, J. D, Cheng, X. L., Mo, Y. X., Li, H. L., Chen, Y. C., Chen, Y. (2018). "Dynamic of *Barringtonia racemosa* population in Jiulongshan Mangrove National Wetland Park, Leizhou," *Wetland Science* 16(2), 231-237. DOI: 10.13248/j.cnki.wetlandsci.2018.02.018.

Zhu, S., Li, D., and Li, J. (2008). "Study on the population structure and life table of the endangered population of *Juniperus rigida* in Fugu nature reserve in Shaanxi province," *Journal of Sichuan University (Natural Science Edition)* 45(1), 176-180. DOI: 10.3969/j.issn.0490-6756.2008.01.034

Zimmermann, M. H., Wardrop, A. B., and Tomlinson, P. B. (1968). "Tension wood in aerial roots of *Ficus benjamina* L.," *Wood Science and Technology* 2(2), 95-104. DOI: 10.1007/BF00394958

Article submitted: August 20, 2024; Peer review completed: September 21, 2024; Revised version received: December 8, 2024; Accepted: December 10, 20204; Published: December 19, 2024.
DOI: 10.15376/biores.20.1.1584-1599