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Importance value index and conservation trends of tree species in Okalma Natural Forest Reserve, Sudan

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ABSTRACT

Species richness and diversity are key indicators of ecosystem resilience and sustainability. However, identifying vulnerable and rare tree species in a particular environment can effectively guide its sustainable management and restoration plans. Therefore, this study explored the conservation trends of tree species in Okalma Natural Reserved Forest based on their importance value index and regeneration status. The study used a systematic sampling design, by which the Okalma forest was divided into 11 transects and each transect was further subdivided into sample plots. The seedlings, saplings, and mature trees were identified and measured in 84 sample plots of 1000 m², which were systematically distributed across the study area. Based on the species regeneration pattern and importance value index, the study classified the tree species of Okalma forest into rare, vulnerable, in-between, subdominant, and dominant species. The mean density of dominant tree seedlings was six times equal to vulnerable ones with significant differences ($F_{4,83}$ = 144.7 and $P < 0.01$). While 10% of the identified tree species displayed a good regeneration pattern, 55% and 20% showed none and poor regeneration, respectively. However, the conservation trends show that 60% of Okalma tree species were rare, with no regeneration and limited relative frequency. These results highlighted the signs of biodiversity decline due to anthropogenic pressure and high consumption rates, which calls for conservation measures and restoration plans. The study recommends the introduction of community forests outside the reserve and intensive extension programs.

KEYWORDS

Conservation trends; Natural forest; Rare species; Restoration; Sustainability

ARTICLE HISTORY

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Introduction

The Importance Value Index (IVI) is an ecological index that measures how a specific species is dominant in a particular ecosystem [1]. It is an integrative value of species relative frequency, dominance, and abundance articulated in percentages ranging from 0 to 300 [1,2]. While tree species with IVI values close to 0 display no significance, the ones with values near 300 exhibit a high prominence and dominance in their habitat and ecosystem range [1,3]. This index illustrates the ecological significance of a given tree species in a community and niche [4]. Therefore, for conservation purposes, yield regulation, and sustainable management of forest trees, understanding the IVI of each species in hotspots and frequently disturbed sites is significant, particularly for naturally regenerated forests and rangelands.

Naturally regenerated forests and rangelands play significant ecological functions in Savanna ecosystems by supporting human livelihoods, various wild animals, livestock, and ecosystem resilience [5-8]. They facilitate nutrient cycling, weather acclimatization, soil protection, and conservation of biological diversity [1,9-11]. These functions and services are essential for rural communities, urban environments, agroforestry parklands, protected areas, and watershed sites [12-21]. So, the integrative management of such functions and roles is a key approach for sustainable satisfaction of local community needs, mitigating climate change, and enhancing ecosystem resilience, especially for mixed-natural forests in Sudan and other dryland areas.

One of the unique mixed-natural forests in Sudan is the Okalma Natural Forest Reserve (ONFR). The forest is located in Sinnar State southeastern Sudan near Lakandi locality, Hegeir village, and Dinder Biosphere Reserve. It hosts various tree and shrub species with considerable bird populations and Hussar monkeys (*Cercopithecus aethiops*) [1,22]. Besides timber and honey, the reserve products include Gum Arabic, Baobab fruits (fruits of *Adansonia digitata*), Laloab fruits (fruits of *Balanites aegyptiaca*), Sidir fruits (fruits of *Ziziphus spina-christi*), Aradeib fruits (fruits of *Tamarindus indica*), and medicinal extracts [10,23,24]. Despite these mufillous functions and services supported by ONFR, little is documented about the conservation status of its tree species and which ones vigorously regenerating versus those need interventions.

This study analyzed the conservation trends of tree species in ONFR based on their IVI and regeneration status. Due to the ongoing war crisis and climatic variability, the study hypothesized that broadleaf species such as *Adansonia digitata* are severely affected and its frequency was dramatically reduced.

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Furthermore, fast-growing and drought-tolerant species like *Acacia senegal* and *Acacia seyal* dominate large areas of ONFR. Moreover, as ecological monitoring and dynamic prediction models require updated information and data, the study findings will initiate a concrete baseline for further studies of tree population dynamics and long-term monitoring towards the sustainable management of forest resources and biodiversity conservation in Sudan and similar ecosystems in the continent.

Materials and Methods

Study area

The study occurs in ONFR that present at 12° 30' 00" N and 12° 40' 00" N, and 34° 16' 00" E and 34° 24' 00" E, covering an area of 42,000 feddans (Figure 1). The gum-producing trees like *Acacia senegal* and *Acacia seyal* are common, mixed with *Adansonia digitata*, *Balanites aegyptiaca*, and *Ziziphus spina-christi* [22]. The average minimum and maximum temperature degrees in the forest vary from < 20˚C in December and January to > 40˚C in April and May with total annual rainfall of > 900 mm (Figure 2). While sandy and mixed soil types dominate mountainous areas, the cracky clay ones frequently observed in flatland sites of the reserve [22,25].

Based on their income sources and life style, the local communities around the ONFR are classified into farmers (traditional and mechanized), pastoralists (rearing grazers and browsers), agro-pastoralists (practice farming and keeping livestock), timber producers and traders (round and sawn timbers), Non-timber Forest Products (NTFPs) collectors and traders (fruits, gum, honey, and medicine), and charcoal producers [24,26]. The farmers cultivate Dura (*Sorghum bicolor*), cooking oil producing crops like *Sesamum indicum*, *Arachis hypogaea*, and *Helianthus annuus* L, and vegetables [24,27,28].

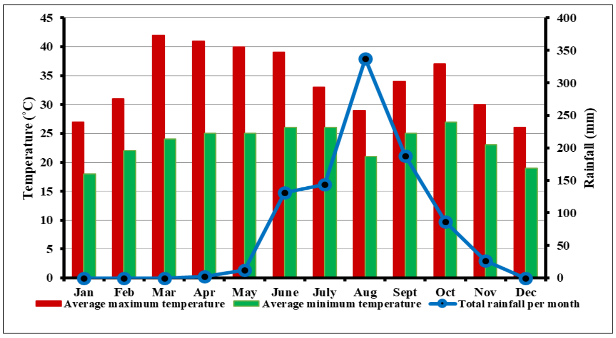

Figure 2. The average minimum and maximum temperature degrees and total rainfall per month for Okalma Natural Forest Reserve (2023), calculated utilizing the meteorological data requested from SMA (Sudan Meteorological Authority).

Data collection

The study used a systematic sampling design, by which the Okalma forest was divided into 11 transects and each transect was further subdivided into sample plots of 1000m2 area (Figure 1). The total number of sample plots was 84, and the completely sampling layout was performed using ArcMap 10.5. In each 1000m2 sample plot, the diameter and height of seedlings, saplings, and adult trees were measured using diameter tape, caliper, and Suunto Clinometer, respectively. While the tree diameter was measured at breast height (at 1.3 m above ground level), the seedling and sapling diameters were cruised at core level as recommended by [24,29]. The woody plants with < 3cm core diameters were considered as seedlings, and those in range from ≥ 3cm to < 7cm were saplings [5,30]. Moreover, adult trees had diameter at breast height of ≥ 7 cm [24,31]. The regeneration patterns, human disturbances, and the frequently observed livestock were recorded and clustered for further analysis.

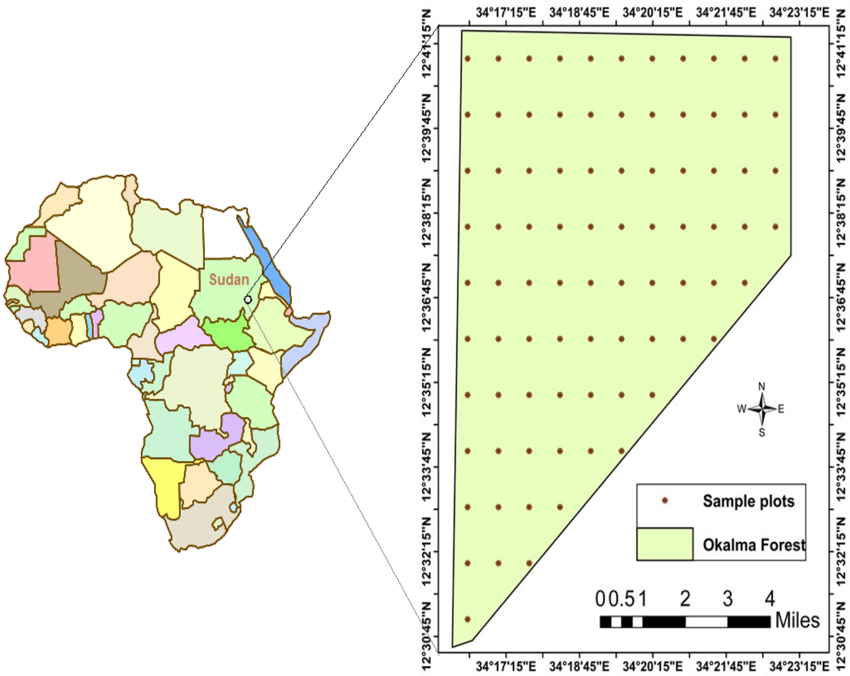

Figure 1. The study area map showing the sample plots sites and the boundary of Okalma Natural Forest Reserve.

Data analysis

The density of seedlings, saplings, and adult trees was calculated as a number of stem per area sampled [24]. The tree basal area (m2) and IVI (%) were calculated using equations described in Table 1 [1,29,32]. The species regeneration patterns were distinguished into good (seedling density > sapling density > adult tree density), fair (seedling density > sapling density < adult density), poor (no seedlings), and none (only adult) [1,2,33]. Based on the species regeneration pattern and IVI, the tree species of ONFR were classified into rare, vulnerable, in-between, subdominant, and dominant species. The dominant species are those with good regeneration status and IVI of ≥ 60, while subdominant, in-between, and vulnerable ones have good, fair, and poor regeneration with IVI of ≥ 45 to < 60, ≥ 30 to < 45, and ≥15 to < 30, respectively. However, rare species are only adults with IVI of < 15. The descriptive statistics and analysis of variance (ANOVA) were performed in JAMOVI (Ver. 1.1.7).

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Table 1. The tree basal area, relative frequency, dominance, abundance and IVI equations.

Equation	Reference
Tree basal area (g) = $\frac{\pi * (Diameter\ at\ Breast\ Height)^2}{4}$	[5]
Frequency (F) = Presence or absence of the species per site	[1]
Relative frequency (RF) = $\left(\frac{Tree\ species\ frequency}{Total\ frequency\ for\ all\ species}\right) * 100$	[1]
Dominance (D) = Total basal area of the species	[2]
Relative dominance (RD) = $\left(\frac{Species\ dominance}{Total\ dominance\ for\ all\ species}\right) * 100$	[2]
Abundance (A) = Number of trees per area measured	[31]
Relative abundance (RA) = $\left(\frac{Tree\ species\ abundance}{Total\ abundance\ for\ all\ species}\right) * 100$	[31]
IVI = Relative frequency + Relative dominance + Relative abundance	[31]

Results

Tree species diversity, diameter class distribution and density

The forest hosts twenty tree species distributed between ten families dominated by Fabaceae (40%) followed by Combretaceae (15%) and Malvaceae (10%), with 5% to each of the remaining families (Table 2). While 85% of the identified tree species were trees with single stems, 15% were shrubs with limited regeneration and growing stock (Table 2). The dominant and codominant tree populations have more juvenile and young generations compared to vulnerable and rare ones (Figure 3). However, the mean density of dominant tree seedlings was six times equal to vulnerable ones with significant differences ($F_{4,\,83}$ = 144.7 and P <0.01, Figure 4). Similar pattern was observed for dominant and rare saplings density ($F_{4,\,83}$ = 162.3 and P <0.01, Figure 4).

Table 2. Tree species, habit, and regeneration patterns.

Local name	Scientific name	Family name	Habit	Regeneration patterns
Kiter	*Acacia mellifera*	Fabaceae	Shrub	Poor
Kakamot	*Acacia polyacantha*	Fabaceae	Tree	None
Hashab	*Acacia senegal*	Fabaceae	Tree	Good
Talha	*Acacia seyal*	Fabaceae	Tree	Good
Baobab	*Adansonia digitata*	Malvaceae	Tree	None
Seilak	*Anogeissus leiocarpus*	Combretaceae	Tree	Poor
Hegleig	*Balanites aegyptiaca*	Balanitaceae	Tree	Fair
Tragtrag	*Boswellia papyrifera*	Burseraceae	Tree	Poor
Habeil	*Combretum hartmannianum*	Combretaceae	Tree	Fair
Abanous	*Dalbergia melanoxylon*	Fabaceae	Tree	None
Kadad	*Dichrostachys cinerea*	Fabaceae	Shrub	None
Abu Gawi	*Gardenia lutea*	Rubiaceae	Tree	None
Doom	*Hyphaena thebiaca*	Palmae	Tree	None
Sarah	*Maerua angolensis*	Capparaceae	Shrub	None
Kharoub	*Piliostigma reticulatum*	Fabaceae	Tree	None
Homeid	*Sclerocarya birrea*	Anacardiaceae	Tree	None
Tartar	*Sterculia setigera*	Malvaceae	Tree	Poor
Aradeib	*Tamarindus indica*	Fabaceae	Tree	None
Darout	*Terminalia laxiflora*	Combretaceae	Tree	None
Sidir	*Ziziphus spina-christi*	Rhamnaceae	Tree	Fair

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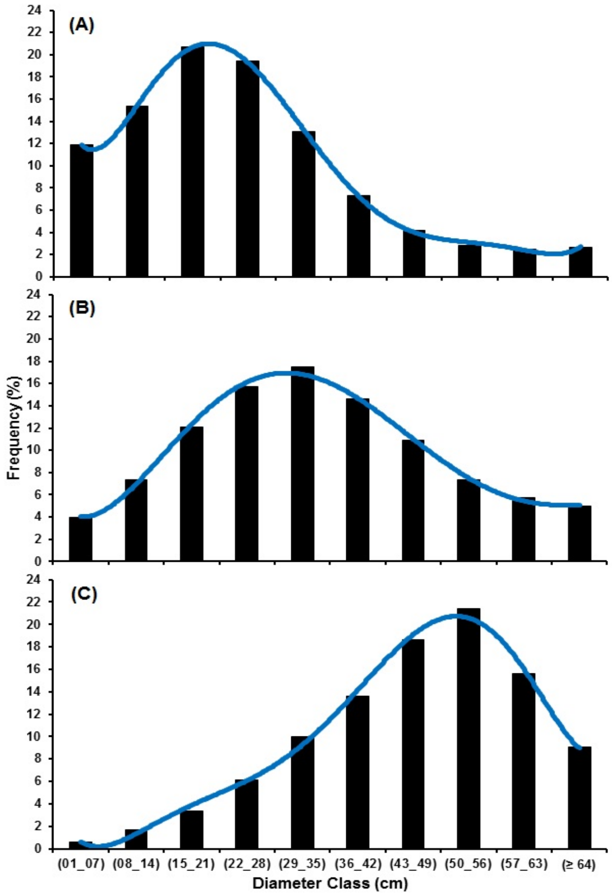

Figure 3. Weibull distribution for (A) Dominant and subdominant, (B) In-between, and (C) Vulnerable and rare tree species identified in Okalma Natural Forest Reserve.

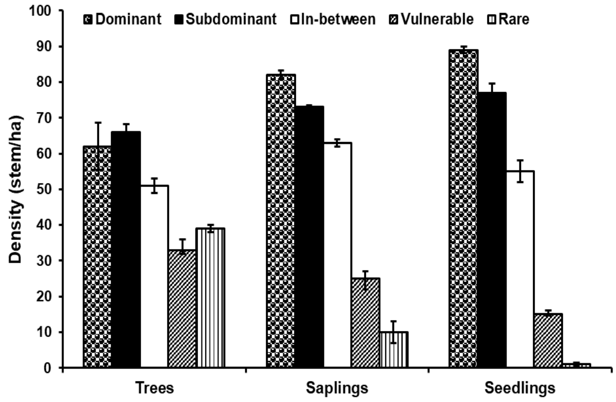

Figure 4. Mean density of trees, saplings and seedlings for dominant, subdominant, in-between, vulnerable and rare tree species identified in Okalma Natural Forest Reserve.

Importance value index and conservation trends

Findings illustrated that *Acacia senegal* trees dominate the Okalma forest with an importance value index of 67.1, followed by *Acacia seyal*, *Balanites aegyptiaca*, *Combretum hartmannianum*, and *Ziziphus spina-christi* (Table 3). While 10% of the identified tree species displayed a good regeneration pattern, 55% and 20% showed none and poor regeneration, respectively (Table 3). However, the conservation trends show that 60% of Okalma tree species were rare with none regeneration patterns and limited relative frequency (Table 3). The relative abundance and frequency of *Acacia senegal* were respectively ten and nine times equal to that of *Adansonia digitata* and *Acacia mellifera* (Table 3). The relative dominance of *Combretum hartmannianum* was double that of *Anogeissus leiocarpus* and *Sterculia setigera*, with significant variation in relative frequency and importance value index (Table 3).

Table 3. Importance Value Index, regeneration patterns, and conservation trends.

Species	RA	RD	RF	IVI	Regeneration patterns	Conservation trends
Acacia mellifera	2.15	1.2	2.2	5.55	Poor	Rare
Acacia polyacantha	1.54	0.34	1.22	3.1	None	Rare
Acacia senegal	21.96	26.8	18.34	67.1	Good	Dominant
Acacia seyal	15.91	19.97	12.71	48.59	Good	Subdominant
Adansonia digitata	1.76	0.96	1.96	4.68	None	Rare
Anogeissus leiocarpus	6.44	5.03	5.87	17.34	Poor	Vulnerable
Balanites aegyptiaca	9.33	11.18	10.27	30.78	Fair	In-between
Boswellia papyrifera	5.35	4.5	7.33	17.18	Poor	Vulnerable
Combretum hartmannianum	11.31	11.69	7.33	30.33	Fair	In-between
Dalbergia melanoxylon	1.35	0.3	1.96	3.61	None	Rare
Dichrostachys cinerea	1.28	0.38	1.71	3.37	None	Rare
Gardenia lutea	1.15	0.27	2.21	3.63	None	Rare
Hyphaena thebiaca	0.61	0.71	0.73	2.05	None	Rare
Maerua angolensis	0.96	0.27	1.22	2.45	None	Rare
Piliostigma reticulatum	0.64	0.28	0.98	1.9	None	Rare
Sclerocarya birrea	1.54	1.18	1.96	4.68	None	Rare
Sterculia setigera	3.46	5.14	6.6	15.2	Poor	Vulnerable
Tamarindus indica	1.12	0.78	1.71	3.61	None	Rare
Terminalia laxiflora	1.63	0.92	1.71	4.26	None	Rare
Ziziphus spina-christi	10.51	8.1	11.98	30.59	Fair	In-between

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Discussion

While the study results documented that the ONFR accommodates diversified tree species, most are rare with low frequency and importance value index. This trend illustrates an unbalanced distribution of tree species in the reserve with selective utilization and intensive competition. The inter-specific competition between vigorously regenerating trees like *Acacia senegal* and *Acacia seyal*, and the poorly regenerating ones including *Adansonia digitata* and *Sterculia setigera* affects the species abundance, distribution, and population dynamics. Competition usually disturbs seed germination, seedling growth, sapling recruitment, and tree fitness [34–37].

Furthermore, over-harvesting of timber by local communities neighboring the reserve can reduce the number of adult trees and consequently, the seed production and seedling recruitments. A study conducted in Sudan at Dinder Biosphere Reserve concluded that illegal harvesting of crown branches for livestock feeding and adult trees for charcoal production dramatically minimized the seedlings of *Balanites aegyptiaca* and disturbed its population composition [38]. Likewise, similar trends were observed in Benin, Burkina Faso, Ethiopia, Niger, and Nigeria [2,29,39-46]. The unmanaged utilization of forest resources increases the number of vulnerable species and diminishes forest diversity [47,48]. Therefore, the high number of rare and vulnerable tree species in the Okalma forest can be directly referred to the intensive illegal harvesting of forest trees, particularly *Anogeissus leiocarpus*, *Combretum hartmannianum*, and *Dalbergia melanoxylon* for building purposes and *Adansonia digitata*, *Hyphaena thebaica*, and *Tamarindus indica* for domestic and commercial uses.

On the other hand, the poor and low regeneration status of various tree species identified in the Okalma reserve may result from the rigorous collection of forest fruit for income generation and daily needs satisfaction. The species like *Adansonia digitata*, *Balanites aegyptiaca*, *Grewia bicolor*, *Grewia flavescens*, *Grewia molle*, T*amarindus indica*, and *Ziziphus spina-christi* are of high demand in the non-timber forest products markets and intensively gathered from different natural forests [26,49–51]. Moreover, the fast germination of *Acacia sengal* and *Acacia seyal* gives them more advantage and can rapidly encroach on the illegally harvested sites and establish pure stands. Such a scenario was reported in Southern Tanzania where *Pinus patula* areas in Sao hill forest plantation were invaded and encroached on by *Acacia mearnsii* [52].

The study findings underlined the significance of long-term monitoring programs that will oversee the forest trees through permanent monitoring plots and remotely sensed maps. However, based on the study results and for conservation purposes, categorizing the study area into highly, moderately, slightly, and non-disturbed sites can be easy. Further population dynamics and spatial distribution studies are recommended to protect vulnerable and rare tree species and the sustainable management of the Okalma forest reserve. Additionally, some supporting literature and former studies were reported and highlighted in table 4. These studies were conducted in various sites ranging from natural forests to national parks and savanna woodlands.

Table 4. Some supporting literature and former studies.

	Title	Published	Reference
1	Riverine forest as a significant habitat to harbor a wide range of bird species	2024	[53]
2	Intensive harvesting menaces trees producing fodder, edible fruit, and gum in Abu Gadaf natural reserved forest, Sudan	2023	[24]
3	Importance value index (IVI) of tree species and diversity of Baturiya Hadejia Wetland National Park, Jigawa State, Nigeria	2022	[4]
4	The stocking density and regeneration status of *Balanites aegyptiaca*in Dinder Biosphere Reserve, Sudan	2022	[5]
5	Anthropogenic pressure on tree species diversity, composition, and growth of *B. aegyptiaca* in Dinder Biosphere Reserve, Sudan	2021	[1]
6	Tree population structure, diversity, regeneration status, and potential disturbances in Abu Gadaf natural reserved forest, Sudan	2021	[54]
7	Population structure and regeneration status of woody plants in relation to human Interventions, Arasbaran Biosphere Reserve, Iran	2021	[32]
8	Population structure and regeneration status of woody species in a remnant tropical forest: A case study of South Nandi forest, Kenya	2020	[55]
9	Agroforestry parkland profiles in three climatic zones of Burkina Faso	2019	[42]
10	Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, Ethiopia	2019	[29]
11	Tree diversity and its ecological importance value in organic and conventional cocoa agroforests in Ghana	2019	[16]
12	Trend and Structure of Populations of *Balanites aegyptiaca* in Parkland Agroforests in Western Niger	2018	[2]
13	Structure, richness and diversity of tree species in a tropical deciduous forest of Morelos	2018	[3]
14	Implication of forest zonation on tree species composition, diversity and structure in Mabira Forest, Uganda	2017	[56]
15	Analysis of the structure and diversity of *Prosopis africana* (G. et Perr.) Taub. Tree stands in the Southeastern Niger	2016	[44]
16	Analysis of structure and diversity of the Kilengwe forest in the Morogoro region, Tanzania	2014	[57]

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Conclusions

The study out-listed twenty tree species belonging to ten families in the Okalma forest with different regeneration patterns and conservation trends. The study findings illustrated that 60% of the reserve tree species are rare with no regeneration or juvenile populations. These results show the influence of high anthropogenic pressure on forest resources and species diversity, which calls for urgent intervention and conservation measures. To reduce the ongoing pressure, a community forest must be introduced in areas neighboring the villages and outside the reserve. The community forest can regularly satisfy the locals' needs and help the reserve to recover naturally. Moreover, awareness-raising and nature-conservation education are necessary for long-term sustainability and ecosystem resilience.

The future research must focus on the site conditions that governing the tree seeds distribution, seedlings germination, saplings establishment, and tree maturity. Such research directions, assisted with community-based monitoring and conservation, can guide the integrative management plan of the reserve and its vulnerable and rare tree species.

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Data Availability Statement

The data will be available on request.

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