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Vascular Plants Utilization In Mahimborondro Protected Area, Northern Highland Of Madagascar

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Abstract: This study was conducted among local communities bordering the Mahimborondro Protected Area (PA). This ethnobotanical research aimed to document woody forest resources harvested by local populations. The methodology combined semi-structured surveys using a predefined questionnaire with residents of two villages, Bealanana and Beandrarezona, and a floristic inventory to assess resource availability. Respondents were questioned about their livelihoods, particularly their relationships with forest resources. During floristic inventory, four growth parameters were measured: density, basal area, biovolume, and regeneration rate. The surveys identified 39 useful plant species, including three threatened species: *Breonia madagascariensis*, *Cryptocarya vaccinioides*, and *Prunus africana*. The uses identified were as follows: house construction, utensil manufacturing, transportation and agricultural tools, fuelwood, traditional medicine, and fencing. By applying Lance et al. (1994) formula, we identified eight most frequently used species: *Erythroxylum nitidilum*, *Ocotea laevis*, *Cryptocarya vaccinioides*, *Erythroxylum sphaeranthum*, *Brachylaena merana*, *Eugenia emirnensis*, *Prunus africana*, and *Pittosporum verticillatum*. Analysis of diameter classes revealed a significantly higher density for trees with a diameter]0.20 to 0.30 m], which decreased for larger classes. In contrast, basal area and biovolume showed lower values for diameter]0.10 - 0.40 m], and higher values for trees with a diameter]0.40 m[. However, the stands of these species mostly exhibited a very good state of natural regeneration, indicating active resource renewal. For sustainable use, any conservation plan for the Mahimborondro Protected Area must integrate the needs and traditional knowledge of local populations regarding these forest resources. Its sustainable management is essential to reconcile biodiversity conservation with community well-being.

Keywords: Ethnobotany, Forest Resources, Mahimborondro, Sustainable management, Protected Area.

1. Introduction

Wood is vital to the world economy and human communities everywhere, but the pressures of human development and the growing demand for wood are contributing to the degradation of natural forests worldwide, creating a dilemma over future supplies (Ramage *et al.,* 2017). Although wood is a highly prized commodity, the economics of its production have always been problematic. Unlike conventional agriculture, it is usually cheaper to harvest trees from the wild than to plant for harvest, and this is often accomplished by clear cutting with little regard for the success of regeneration and other environmental consequences.

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Unfortunately, most of the world's wood is still harvested this way, especially in developing countries (Mallik & Rahman, 1994; Ramage *et al.,* 2017, Sarker *et al.,* 2011).

In Madagascar and as in many other developing and/or hotspot countries, secondary forests have become a major feature of many forest landscapes (Chokkalingam *et al*., 2001; Raik, 2007; Schroeder *et al*., 2010; Razafintsalama *et al*., 2014). To help to reduce the harvest pressures within primary forests, it is necessary to bring wood consumption in secondary forests or in corridors between protected areas into line with the level of sustainable supply (Fenning & Gershenzon, 2002; Fredericksen & Penã-Claros, 2007; Wilde *et al*., 2012). This can be achieved by either increasing production, or by reducing consumption, or both. However, in Madagascar, given the increasing demand for wood, the implications of trying to reduce it need to be considered carefully.

Confronted with rapid forest degradation, Madagascar has adopted approaches aimed at reconciling biodiversity conservation, the use of natural resources, and local development. This entails the empowerment of local communities. One of the most significant of these approaches is the Contractual Management of State Forests (Gestion Contractualisée des Forêts de l'État - GCF), established by Decree No. 2001-122, which enables the transfer of management rights to Local Communities (COBAs). This system is founded on a contract between the state, represented by the forestry administration, and the local community.

Specifically, the majority of the bordering population is heavily dependent on woody forest products for their daily subsistence and socio-economic activities. On one part, the selective harvesting of the highest-quality timber is believed to be the cause of the rapid depletion of certain resources compared to others (Ramamonjison *et al.,* 2003). On the other hand, illegal logging also persists in the area (Association Reniala, 2014).

Actually, The Peregrine Fund and 4 local communities, which are co-manager of MPA in Beandrarezona, are wondering about the sustainability of wood resources within their part of Mahimborondro forest and are planning to restore the most vulnerable species. However, the most vulnerable plant species aren't yet identified. In order to elaborate and implement a management plan for these resources, the current study focused on "The Use of Woody Resources within the Mahimborondro Protected Area" was conducted. Its main objective is to provide a tool and data for establishing a sustainable management plan for the site's woody resources. The specific objectives are to (1) determine the vascular plants existed therein and used by the neighboring communities for their daily life, (2) evaluate the current stock of wood within the forest. These basic data will be used as tools for a more sustainable use, better conservation and valorization of this part of Mahimborondro forest.

2. Methods

2.1. Study area

Mahimborondro forest is located in northern highland of Madagascar, in Sofia region, between Bealanana and Ambanja districts. It is between latitudes S14°10' and S14°30' and longitudes E048°35' and E049°00' (Figure 1). Historically, this area was part of the Classified Forest of Sandrakota (Arrêté N°1555/MAER/DG/PRO/FOR of 14/ April, 14th 1967). However, Mahimborondro obtained its definitive status as a Protected Area through Decree No. 2015-782 on April, 28th 2015.This decree classified it as a Natural Resources Reserve (Réserve des Ressources Naturelles - RRN), equivalent to IUCN Category VI. According to the World Database on Protected Areas (WDPA), the Mahimborondro Protected Area has the WDPA ID 55569705.

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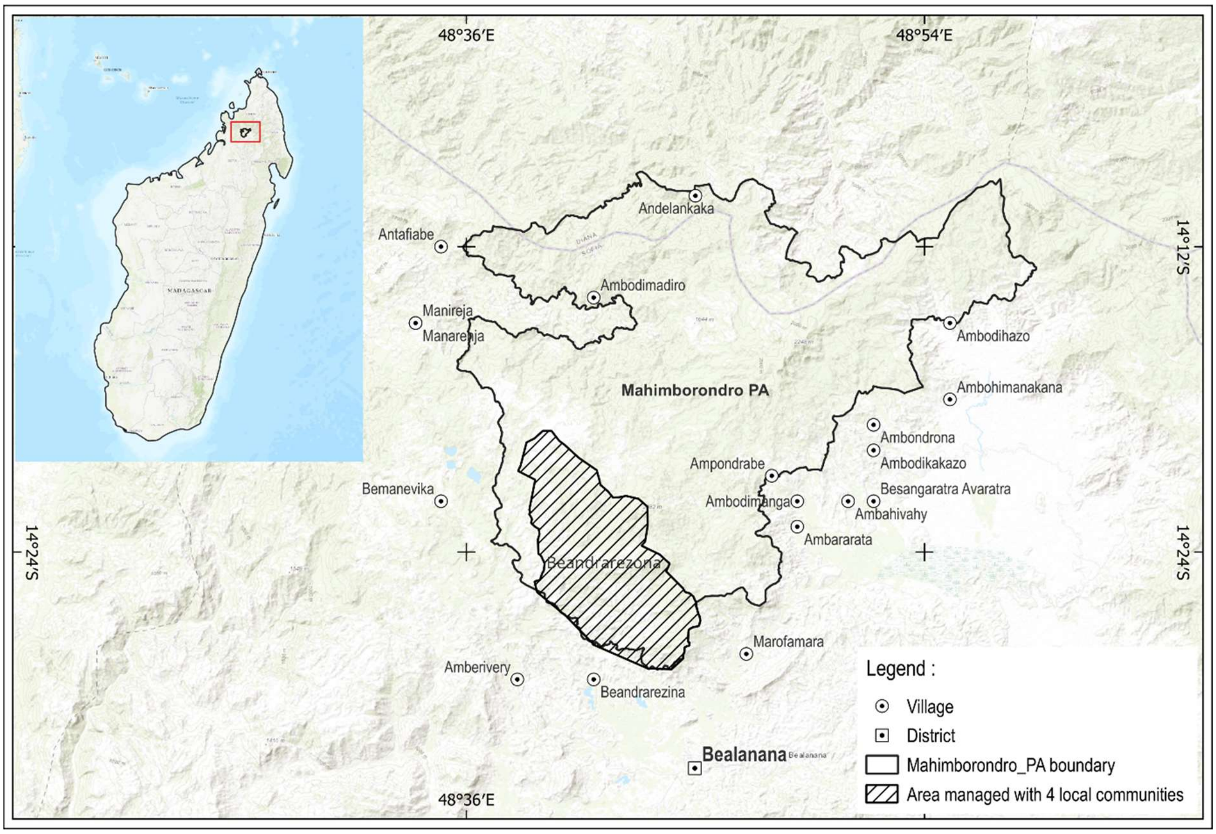

Figure 1: Map showing the location of Mahimborondro Protected Area

Mahimborondro PA is managed by The Peregrine Fund and local communities. It is a terrestrial protected area covering a total surface area of 751.62 km². As the manager mentioned, the main threat is the forest products exploitation for commercial and domestic purposes (Goodman *et al*., 2018). The present investigation was conducted in the relatively intact forest of Ambalatanihely and the degraded forest of Andohan'Amberivery. This area is co-managed with 4 local associations in Beandrarezona to ensure the sustainable supply of wood for local people and involve them in managing their natural resources (Hernandez, 2019).

2.2. Interviews

Semi-structured oral interviews (Adams, 2015) were performed with local people living in Bealanana and and Beandrarezona in order to identify all vascular plants collected from Mahimborondro Protected Area for: (1) House construction, (2) utensil, transportation and agricultural tools, (3) source of Fuel/Energy (as charcoal and dead wood), (4) carpentering, (5) medicinal use and (6) fence. Bealanana district was selected as the primary survey site due to its role as a commercial hub for forest products. Beandrarezona was also chosen as the study area because it is the estimated forest source for approximately 80% of the wood traded in the Bealanana market (Hernandez, 2019). We adopted a semi-structured interview, which is a type of interview conducting with few predetermined questions while the rest of the questions are not planned in advance (Adams, 2015; Albuquerque *et al*., 2019). Adults over 18-year-old were selected for the survey. Interviews specifically targeted households that reported using woody forest products from Mahimborondro, encompassing professions such as carpenters and sawyers, as well as other resource users, local authorities and traditional authorities.

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2.3. Target plant species selection

To evaluate the current stock of woody plants in the Beandrarezona forest area, a forest inventory was conducted, focusing on species which have a high socio-economic and ecological relevance. The selection of these target species was guided by the following two criteria:

- *Utilization Frequency:* Plant species exhibiting a high frequency of use, as quantified by the established formula of Lance *et al.* (1994), were designated as target species. This criterion ensures the assessment focuses on resources critical for local livelihoods.
- *Conservation Status*: Following taxonomic identification, the conservation status of all utilized species was verified against the IUCN Red List. Any species categorized as threatened was immediately classified as a priority for preservation actions within the management framework.

2.4. Forest inventory

Systematic sampling design (systematic line transect) was adopted to facilitate the census of target plants. The species inventory was conducted within a 5-meter-wide belt on either side of the transect line. Target species with a Diameter at Breast Height (DBH) of less than 10 cm were recorded, while those with a DBH greater than or equal to 10 cm were measured to determine their height and DBH (Christopher & Chuckran, 2017). A total of 21 transects were established in the study area.

The floristic parameters considered in this study are as follows:

- Number of stems per individual of each target species
- Diameter at Breast Height (DBH) and maximum height (Hm) for individuals with DBH ≥ 10 cm
- Vernacular name and scientific name

2.5. Evaluation of recorded species

We evaluated each cited species based on its utilization frequency by applying the formula established by Lance *et al.* (1994). This formula is calculated as the ratio between the number of informants who cited a given species and the total number of informants. A species is classified as having a *High Utilization Frequency* when its frequency is greater than 75%, indicating that the species is widely known and used by the local population. Conversely, a species is classified as having a *Low Utilization Frequency* when its frequency is less than 25%, reflecting its lesser importance in local practices.

2.6. Quantitative and ecological data analysis

This analysis was mainly based on the estimation of four ecological parameters as stand density index, biovolume, basal area and regeneration rate of target species.

This stand density index (SDI), based on the ratio between number of trees per unit area and their average diameter, is premised on the characteristic distribution of tree sizes in even-aged stands (Reineke, 1933; Dean *et al*., 2020). As such, for this study, the living trees with dbh ≥ 10 cm in all plots were classified into five intervals by 0.10 m: [0.10 – 0.20 m],]0.20 – 0.30 m],]0.30 – 0.40 m] and > 0.40 m and the average density was extrapolated for a hectare, according to the formula $D = n/S$ where D: density (in trees/ha); n: number of trees present on the surface considered and S: sampled area (m^2) (Richard *et al*., 2016). Therefore, this SDI can be used to define the degree of crowding within stocked areas, using various growing space ratios based on crown length or diameter, tree height or diameter, and spacing (Reineke, 1933). It is usually correlated with stand volume and growth (Avery & Harold, 2002).

Biovolume is a cubic measure of the amount of wood present in an individual tree, group of trees, or stand within unit area (Adekunle & Olagoke, 2008). It makes it possible to estimate the wood potential of the specific forest (Dawkins, 1959). In this study, as in the stand density index, the biovolume in all plots was classified into five dbh intervals by 0.10 m, from 0.10 m to > 0.40 m and was expressed in m^3/ha. In the humid forests of Madagascar, Eduard *et al.* (2000) classified this biovolume into three categories:

High : Biovolume > 250 m^3/ha

Average: Biovolume 50 m^3/ha to 250 m^3/ha

Low : Biovolume < 50 m^3/ha

Basal area (m^3/ha) of a tree corresponds to the area occupied by the tree trunk at the level of the DBH. It is given by the formula: Basal area = dbh^2 x 0.25 x 9 (Dawkins, 1959). It can be calculated at the stand level as at the species level. In this study, the basal area was calculated at the species level according to the dbh interval by ever 0.05 m [0.10 – 0.20 m],]0.20 – 0.25 m],]0.25 – 0.30 m] or 0.10 m]0.30 – 0.40 m] and > 0.40 m.

Regeneration rate is fundamental for determining whether current harvesting levels are sustainable or if specific conservation measures (such as assisted natural regeneration or enrichment planting) are needed for vulnerable species. It is expressed as the ratio of the number of regenerated individuals (i.e., those with a Diameter at Breast Height, DBH, less than 10 cm) to the number of seed-bearing individuals (those with a DBH equal to or greater than 10 cm). We also adopted the scale of Rothe (1964) to visualize the overall regeneration status of the target species' stands:

- TR < 100% : poor regeneration;
- 100% < TR < 300% : moderate regeneration;
- 300% < TR < 900% : good regeneration;
- TR ≥ 900% : very good regeneration.

3. Results

3.1. Profile of vascular plant users at Mahimborondro

Interviews are consisted of a total of 53 individuals. All were direct users of the natural resources within the Mahimborondro Protected Area. The cohort was predominantly male, representing 94% (n = 50) of the sample. The ages of the informants ranged from 25 to 65 years, with the 35-45 age group constituting the majority (n = 33). Furthermore, most participants were farmers (n = 35) and belonged to *Tsimihety* ethnic group.

3.2. Species utilization and their conservation status

This study documented 39 vascular plant species used by local communities surrounding the Mahimborondro Protected Area for construction and domestic purposes. Interviews revealed that house construction (24 species) and furniture making (18 species) accounted for the highest diversity of species used, while medicinal applications utilized the fewest (4 species) (Annex 1). The number of species used for other purposes—including tools (utensils, transportation, and agricultural implements; 7 species), fuelwood and charcoal production (9 species), and fencing (5 species)—was comparatively similar.

The survey results indicated a considerable variation in the frequency of use for useful species, ranging from 9% to 75%. Among these, *Pittosporum verticillatum* was identified as the most widely recognized and preferred species, while *Suregada* sp. was the least utilized. By applying Lance *et al*. (1994) formula, the eight most frequently used species are listed below (Table 1).

Table 1: The eight tree species with the highest frequency of use by local people

Family	Scientific name	Malagasy name	IUCN Status	Utilization frequency
ERYTHROXYLACEAE	*Erythroxylum nitidilum*	Nofotrakoho		62%
LAURACEAE	*Ocotea laevis*	Tafononana	NT	62%
LAURACEAE	*Cryptocarya vaccinioides*	Tavolo	EN	63%
ERYTHROXYLACEAE	*Erythroxylum sphaeranthum*	Menahihy	LC	65%
ASTERACEAE	*Brachylaena merana*	Piro		67%
MYRTACEAE	*Eugenia emirnensis*	Rotry	LC	74%
ROSACEAE	*Prunus africana*	Hoditra	VU	74%
PITTOSPORACEAE	*Pittosporum verticillatum*	Maimbovitsika	LC	75%

Of particular conservation concern, we recorded three threatened plant species: *Breonia tsaratananensis* (EN), *Cryptocarya vaccinioides* (EN), and *Prunus africana* (VU) (IUCN, 2025-1). The interview results shows that two of these species, *Breonia tsaratananensis* and *Cryptocarya vaccinioides*, are collected as materiel to building house and making furniture. The third, *Prunus africana*, is exploited for phytotherapeutic purposes.

3.3. Density, basal area and biovolume of target trees

The growth parameters, density, basal area, and biovolume at our study site exhibited distinct distribution patterns. Density was significantly higher for trees with a DBH between 0.20 and 0.30 m, then decreased for larger diameter classes (Figure 1a). In contrast, basal area and biovolume displayed much lower values for DBH classes between 0.10 m and 0.40 m, and higher values for larger trees (DBH > 0.40 m) (Figures 2b, 2c).

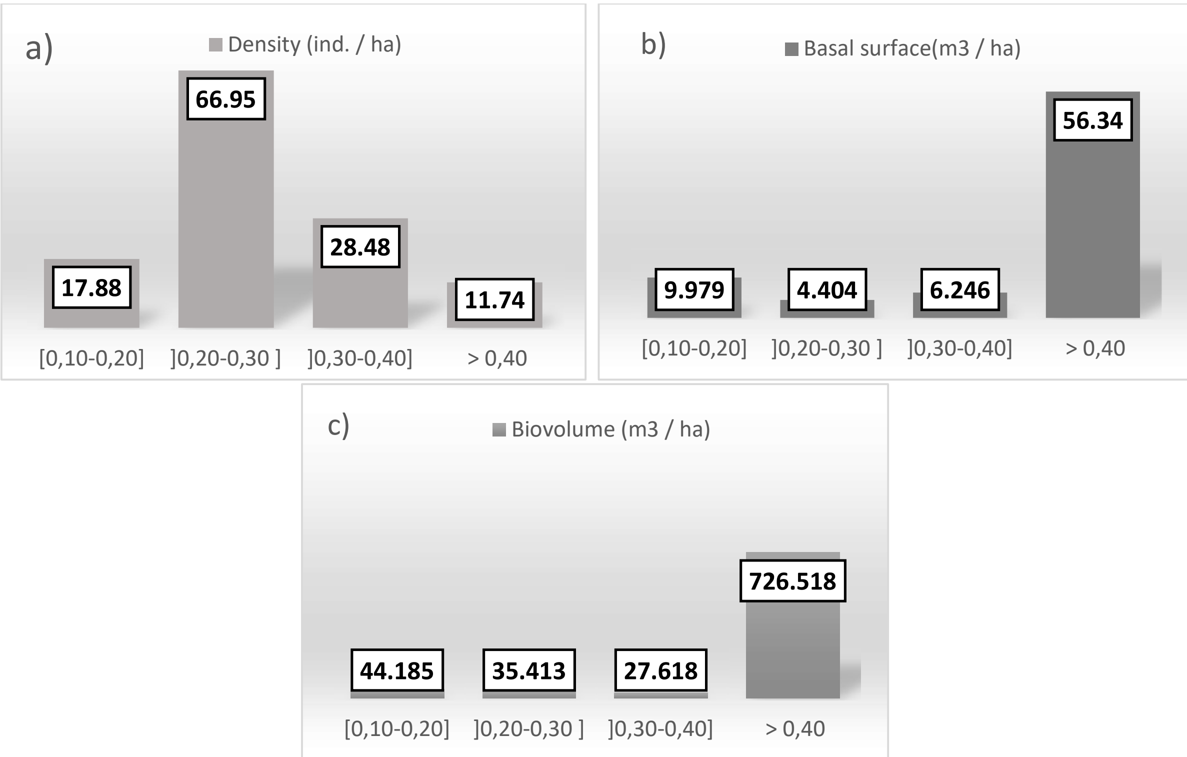

Figure 2. Distribution of tree parameters across diameter classes

3.4. Regeneration of target trees

Table 2 below shows the regeneration rates for the eight target species. Following the conducted floristic census, the regeneration rates vary among species, with values ranging from 14.44% for *Prunus africana*, indicating very poor recruitment of young plants, up to 1373.63% for *Pittosporum verticillatum*, which reflects very good regeneration. From an overall perspective, most species exhibit very good regeneration.

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Table 2: Overview of stand regeneration status for the target species.

Scientific name	TR (%)	Regeneration status
Erythroxylum nitidilum	1050.72	Very good regeneration
Ocotea laevis	101.43	Moderate regeneration
Cryptocarya vaccinioides	1023.33	Very good regeneration
Erythroxylum sphaeranthum	1210.92	Very good regeneration
Brachylaena merana	294.23	Moderate regeneration
Eugenia emirnensis	82.47	Low regeneration
Prunus africana	14.44	Low regeneration
Pittosporum verticillatum	1373.63	Very good regeneration

4. Discussion

4.1. *Sustainable uses of plant species in Mahimborondro*

Timber for construction is one of the many forest products used around the world (Ramage *et al*., 2017). In Mahimborondro, as in many other tropical forests (Van *et al*., 2018), the increasing demand for timber as building materials made the highest rate of tree species used for house construction and furniture-making. As confirmed Hernandez (2019), some timbers collected from Mahimborondro were also transported to and frequently used to supply the neighboring town located at about 120 km from Bealanana such as Antsohihy.

Worldwide, about 80 % of people in developing countries are totally dependent on herbal drugs for their primary healthcare (Chen *et al*., 2016; Van Wyk & Prinsloo, 2018) and the use of medicinal plants can be considered as threat to biodiversity in many tropics (Van Wyk & Prinsloo, 2018). Yet, in many regions of Madagascar, contrarily to the deforestation (Vieilledent *et al*., 2018), the impacts of this traditional use of medicinal plants are not a big concern to forest ecosystems (Norscia & Borgognini-Tarli, 2006; Onjalalaina *et al*., 2021). In this study, amongst others plant species utilizations, medicinal uses were less recorded. However, further study will be required to get more exhaustive results, especially for those medicinal species (as *Prunus africana*) that are internationally traded (Neimark, 2010; Cunningham *et al*., 2016).

While the other uses of vascular plants such as for charcoal making (Vezina *et al*., 2020), utensil, transportation and agricultural tools and fence (Randrianarivony *et al*., 2016) can make a non-neglecting environmental effects, this study would suggest that the impacts of these uses in Mahimborondro might probably be less severe. The continuous technical supports to the members of the local association "*Zalahibe*" in community-based forest management by The Peregrine Fund may have a significant positive conservation impact. The record of seven threatened species within very limited survey period and surface (from only ten transects) would support this hypothesis. The peregrine Fund has several year experiences in the community-based capacity strengthening for the sustainable management of natural resources (Rabearivony *et al*., 2008).

4.2. Density and biovolume as growth parameters

In Mahimborondro, according to Hernandez (2019), the low density and biovolume at the dbh [0.10 – 0.20 m] and > 0.40 m may reflect the level of tree species utilization within those intervals. Accordingly, in this study, most of vascular plant species used for house construction fall within dbh [0.10 – 0.20 m] and made up a total to 20 species, while those used for furniture-making within dbh > 0.40 m and in total 17 species. For these dbh intervals, management of growth parameters such as density and biovolume is required to ensure that studied stands have several individuals of future to ensure the regeneration. This can be achieved by setting much appropriate harvesting quotas for each extracted species and investing in low-impact harvest methods (Torres-Rojo *et al*., 2016). However, in Madagascar as worldwide, these slow-growing natural forests are unable to meet current demand (Fenning & Gershenzon, 2002); and planting fast growing exotic species in the peripheral zone of protected area is needed to supply the bulk of humanity's wood needs on a long-term basis. For this purpose, reforestation undertaken by The Peregrine Fund - Madagascar Project has involved in peripheral zone of Mahimborondro Protected Area.

4.3. Basal area as a tool for estimating site productivity

Despite harvesting impacts in some dbh classes, Mahimborondro forest still had a high potentiality in wooden plants, as showed its total basal area of 102 m^2 / ha. This value is much higher than those of other humid forests in Madagascar, as in Amber Forest of 51 – 60 m² / ha, northern Madagascar (Randimbiarison, 2014).

In each dbh class, the high basal area of tree species commonly used by local population supported the site productivity in Mahimborondro: *Erythroxylum sphaeranthum* and *Erythroxylum nitidilum* for the dbh [0.10 – 0.20 m], *Garcinia verrucosa* and *Macaranga* sp. for the dbh]0.20 – 0.25 m], *Eugenia emirnensis* for the dbh]0.25 – 0.30 m], *Eugenia* sp. and *Ocotea laevis* for the dbh]0.30 – 0.40 m] and *Cryptocarya vaccinoides* for the dbh > 0.40 m. Furthermore, the presence of threatened species confirmed the conservation value of the Mahimborondro site.

5. Conclusion

This study on the use of vascular plants in the Mahimborondro zone represents pioneering ethnobotanical research in this remote area of Madagascar. The investigations identified the diverse uses of vascular plants for the local communities of the Mahimborondro Protected Area, which are integrated into numerous aspects of their daily lives. These uses include house construction, tool and utensil fabrication, transportation and agricultural implements, firewood and supplies, as well as needs for traditional medicine and fence building. This finding suggests that any conservation plan for the Mahimborondro Protected Area must incorporate the needs and knowledge of local populations regarding these resources. The sustainable management of these resources is essential to reconcile biodiversity conservation with community well-being.

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Annex 1. List of vascular plants utilization, Mahimborondro Protected Area

Scientific name	Malagasy name	IUCN Status (2025-1)	Vascular plant use					
			House construction	Utensils, transportation and agricultural tools	Fuelwood (charcoal, dead wood)	Furniture making	Medicine	Fence
Abrahamia grandidieri	Nanto					x		
Albizia gummifera	Sambalahy	LC	x		x	x	x	
Aphloia theiformis	Kirandrambaiavy	LC	x		x		x	
Bathiorhamnus louvelii	Telotritry	NT	x			x		
Brachylaena merana	Piro		x	x		x		
Breonia tsaratananensis	Valotra	EN				x		
Bridelia tulasneana	Kitata	LC	x			x		
Calophyllum parviflorum			x					
Commiphora orbicularis	Matambelona		x					
Cryptocarya vaccinioides	Tavolo	EN	x			x		
Diospyros haplostylis	Maintipototra	LC	x	x				
Erythroxylum nitidilum	Nofotrakoho		x			x		
Erythroxylum sphaeranthum	Menahihy	LC		x		x		
Eucalyptus sp.			x			x		
Eugenia sp.	Levakivaky		x			x		
Psidium guajava		LC			x			
Garcinia verrucosa	Vongo	LC	x					
Harungana madagascariensis		LC	x					x
Kaliphora madagascariensis	Kimpantrozona	LC					x	x
Macaranga madagascariensis	Mankaranga				x			x
Mangifera sp.					x			
Mundulea laxiflora		LC	x			x		
Ocotea laevis	Tafononana	NT	x	x				
Eugenia emirnensis	Rotry	LC	x			x		x
Phyllarthron madagascariense	Antohiravina	LC	x					
Phylloxylon xylophylloides		NT	x	x		x		
Pinus sp.						x		
Pittosporum verticillatum	Maimbovitsika	LC			x			
Polycardia orientalis				x	x			
Prunus africana	Hoditra	VU					x	
Psidium guajava	Goavy	LC			x			

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Psorospermum revolutum	Harongampanihy		x			x		
Suregada sp.					x			
Symphonia urophylla	Hazina	LC	x					
Tamarindus indica		LC			x			
Trema orientalis		LC						x
Weinmannia rutenbergii	Lalogno	LC	x			x		
Zanthoxylum tsihanimposa	Tsiagnaniamposa	NT	x					