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Conserving biodiversity and cultural heritage: the role of sacred forests in the Moribane Forest Reserve, Mozambique

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Sacred Forests (SF) offer vital cultural ecosystem services, providing intangible benefits rooted in spiritual beliefs and traditional practices. This study examines how practices within Sacred Forests (SF) contribute to the conservation of forest species diversity in the Moribane Forest Reserve (MFR), located in Manica Province, Mozambique, through: (i) documenting local cultural meanings and practices linked to sacred forests; (ii) comparing forest structure and species diversity in sacred versus non-sacred areas; and (iii) assessing land-use and land-cover changes in the reserve, focusing on sacred forests. This study contributes to the empirical evidence on how sacred forests support biodiversity conservation and landscape stability under increasing anthropogenic pressures and shifting land-use dynamics. A mixed-methods approach was employed, integrating the Analytic-Deliberative Method (ADM), field surveys, and remote sensing analysis. The ADM included semi-structured interviews with 149 households, 85 of which were headed by women, aiming to identify the cultural values associated with 13 principal SF sites. Field survey involved the establishment of 26 rectangular plots, 18 within SF and 8 in non-SF areas, to compare the composition and structure of woody species. The species accumulation curve indicated higher species richness in SF (41 species) compared to non-SF areas (38 species). Approximately 50–60% of the 10 most ecologically significant species, ranked by Importance Value Index, in both forest types are considered sacred. These include *Newtonia buchananii*, *Millettia stuhlmannii*, *Diplorhynchus condylocarpon*, and *Bridelia micrantha*, most of which are classified as species of least concern on the IUCN Red List. SF are primarily used for ritual ceremonies that seek rain during drought periods, promote agricultural productivity, protect crops, and prevent wildfires. On average, 53.84% of SF were found to be in good conservation condition, while 30.76% were in poor condition, and 15.38% in moderate condition. Remote sensing analysis revealed ongoing cropland expansion and forest loss, predominantly in non-SF areas, with deforestation peaking in 2020. Sacred forests show higher species richness and better conservation status than non-sacred areas. We conclude that SF embodies cultural heritage, fosters conservation, and faces growing deforestation pressures that threaten biodiversity and traditional practices. Therefore, we recommend recognizing SF, integrating cultural values into conservation strategies, promoting sustainable livelihoods, and supporting research to strengthen biodiversity conservation.

KEYWORDS

sacred forests, cultural ecosystem services, cultural practices, biodiversity conservation, livelihood

1 Introduction

Forests rank among the world's most critical ecological assets, supporting human well-being through a broad array of ecosystem services typically classified into four categories: provisioning, regulating, cultural and supporting (Nolander and Lundmark, 2024; You et al., 2024). While provisioning and regulating services are often tangible and quantifiable, cultural ecosystem services (CES) remain less visible but equally influential. CES encompass the non-material benefits that arise from dynamic human–nature interactions, including spiritual enrichment, cultural identity, knowledge transmission, recreation, and inspiration (LCTMTFC, 2025).

The value of CES is deeply rooted in individuals' sensory, emotional, and cognitive relationships with ecosystems and is shaped by broader socio-cultural, economic, and political contexts (Wu et al., 2024). Globally, CES categories include cultural heritage, spiritual values, community identity, education, and recreation. In high-income settings, tourism and aesthetics often dominate public discourse, whereas Indigenous and local communities emphasize kinship ties, ancestral knowledge, and spiritual beliefs as central to ecosystem value (Kirmayer et al., 2012). For many Indigenous societies, forests hold a vital role in collective identity and act as living repositories of oral histories, rituals, and customary practices passed down across generations.

Within this context, Sacred Forests (SF), a form of sacred natural site, emerge as culturally protected landscapes where spiritual meaning and biodiversity conservation converge (Sinthumule, 2024). Since the late 20th century, research has underscored the unique role of SF in preserving species richness, safeguarding rare and endemic taxa, and functioning as ecological refugia that enhance landscape connectivity and resilience. Local communities often derive multiple ecosystem services from these forests as a consequence of long-standing cultural restrictions on resource extraction and land-use transformation. International initiatives such as the Sacred Natural Sites Initiative (SNSI) and the International Union for Conservation of Nature (IUCN) acknowledge the conservation importance of SF and advocate for community-led stewardship to reinforce traditional governance (Undaharta and Wee, 2023).

Despite well-established global relevance, the distribution, ecological function, and cultural significance of sacred forests across Africa remain understudied (Sinthumule, 2024). In Mozambique, for instance, scattered evidence points to the existence of SF in several regions, including Chirindzene, Zongoene, and Chilaulene in the south (Virtanen, 2002; Simbine, 2013). While certain communities still uphold prohibitions against tree felling and hunting within sacred groves (Cavane, 2000), expanding shifting cultivation, weakened customary institutions, and shifting cultural norms have contributed to their degradation. Deforestation, driven primarily by subsistence agriculture, accounts for an estimated 86% of forest loss in the country, amounting to approximately 267,000 hectares annually, posing a significant threat to SF and the biodiversity they harbor (LCTMTFC, 2025; Siteo and Guedes, 2015; IUCN, 2021).

Land-use and land-cover (LULC) changes directly impact both sacred and non-sacred forests, affecting carbon storage, woody species diversity, and local livelihoods (Francisco et al., 2022; Sinthumule, 2024). However, the intangible and place-specific nature of CES continues to challenge conventional valuation approaches, often leading to the exclusion of cultural values in forest policy and

management (Costanza et al., 2017). This is particularly concerning in contexts where CES are deeply embedded within biodiversity, as is the case in many African sacred groves (Simbine, 2013).

In Mozambique, the Moribane Forest Reserve (MFR), a buffer zone to Chimanimani National Park, contains several SF fragments still actively used for ceremonial practices related to rainfall, harvest success, and ancestral reverence (Sinthumule, 2024; ANAC, 2021). Nonetheless, increasing population pressure, land encroachment, and the prevalence of short-cycle shifting cultivation pose growing risks to both ecological integrity and cultural continuity. Local resource management committees within MFR attempt to reconcile conservation objectives with socioeconomic needs; however, empirical data comparing the ecological conditions of sacred and non-sacred forest patches remain scarce.

This study addresses this knowledge gap by integrating socio-cultural surveys with detailed assessments of woody species biodiversity and LULC analysis. This study also used Remote Sensing and Google Earth Pro for precise mapping and temporal tracking of land-use and cover changes. These cost-effective tools offer high-resolution imagery, enable time-based comparisons, and improve spatial analysis reliability in remote or data-poor regions. It explores how cultural beliefs and practices tied to sacred forests influence forest structure, tree species richness, and landscape dynamics. Specifically, the study investigates: (i) What cultural meanings and practices are associated with sacred forests by local communities? (ii) How do forest structure and species diversity differ between sacred and non-sacred areas? (iii) What patterns of land use and cover change have occurred in the MFR, particularly in relation to SF?

By combining ecological fieldwork, community interviews, and spatial analysis, this study aims to inform conservation practice and policy both within Mozambique and more broadly. It underscores the interconnection between cultural identity and biodiversity conservation, offering insights into how Indigenous knowledge and spiritual values can enhance sustainable forest governance, reinforce local stewardship, and contribute to resilient landscapes amid increasing socioeconomic pressures.

2 Materials and methods

2.1 Description of the study area

Moribane Forest Reserve is located in the Sussundenga district (S 19° 45', 33° 22'E) in the center of Manica province in western Mozambique, easily accessible along the Sussundenga-Dombe road (UNEP-WCMC, 2024). It is a natural forest in the buffer zone of Chimanimani National Park, which is situated ~24 km north of Dombe village (UNEP-WCMC, 2024; Dondeyne et al., 2011). The MFR is one of the largest mid-altitude rainforests in southern Africa (Ghiurghi et al., 2010). It was proclaimed a forest reserve in 1957 during the colonial era for both wood production and watershed protection (Siteo and Guedes, 2015). MFR was selected for this study due to its active sacred forest traditions and increasing land-use pressures, providing a unique context to examine the role of cultural practices in biodiversity conservation. According to Ghiurghi et al. (2010), the MFR occupies an area of 162 km² and, historically, it was intensively exploited from the early 20th century onwards, initially for natural rubber derived from rubber vine (*Cryptostegia grandiflora*),

and subsequently for its valuable timber species that include red mahogany (*Khaya anthotheca*), iroko (*Milicia excelsa*), and panga-panga (*Millettia stuhlmannii*).

As the 21st century approached, it was marked by the impact of wildfires and shifting agricultural practices (Ghiurghi et al., 2010). Despite past overexploitation, the widespread occurrence of berry seedlings of different species gave hope for the possibility of natural regeneration (Šerá, 2021). Currently, the management of MFR seeks to respond to environmental, socio-economic, political, and institutional interests with a management centered on the local Natural Resources Management Committee. This committee works with a private investor, the Eco-MICAIA Foundation, with a camp in the Mpunga community (Ndzou Camp) (Micaia Foundation, 2025a). Eco-Micaia's purpose is to enable people to prosper in strong local economies and healthy vibrant communities.

2.1.1 Climate

According to the Köppen climate classification, the climate of the Sussundenga district is characterized as a tropical wet-and-dry climate, featuring two distinct seasons, a hot, humid one from November to March and a cooler, dry one from April to October, with annual maximum and minimum temperatures near 26 and 16°C, respectively, mean annual precipitation of about 1,200 mm, and relative humidity around 74% (FEWS NET, 2024a; World Bank, 2024).

2.1.2 Demographics and economic activities

According to local leadership, the main villages in MFR are Mutoe (200 households), Mucuawao (153), Magaraba (68) and Mpunga (58). Recent studies indicate that shifting (slash-and-burn) cultivation remains a principal driver of deforestation and forest degradation in Mozambique, and smallholder farms in the district remain predominately tiny (around 1–1.5 ha per household); staple crops include bananas, maize, cassava, cowpeas/other pulses, groundnuts, sorghum, sweet potato and rice (UNU-WIDER, 2025; United States Department of Agriculture, Foreign Agricultural Service (USDA/FAS), 2024; FEWS NET, 2024b). In addition, communities commonly raise livestock such as goats, chickens, pigs, and cattle, which serve as sources of food, income, and savings. Tourism activities are developed by the community association Kubatana Moribane in cooperation with the Eco-Micaia Foundation through Ndzou Camp Lodge (Micaia Foundation, 2025b). This Foundation has a set of long-term programs, including work on land use planning and conservation, sustainable agriculture, and local economic development. They also provide business development services and invest in areas such as tourism and natural products (Micaia Foundation, 2025c).

2.1.3 Vegetation

In Moribane Forest Reserve, two vegetation types were described, namely moist evergreen forest and (ii) transitional forest (Dondyene et al., 2011), and the landscape supports a mosaic of several woodland and forest types co-dominated by deciduous tree species, such as *Newtonia buchananii* (Baker) Gilbert and Boutique (Leguminosae), *Pteleopsis myrtifolia* (M. A. Lawson) Engl. and Diels (Combretaceae), *Millettia stuhlmannii* Taub. (Leguminosae), *Albizia gummifera* (J. F. Gmel.) C. A. Sm. (Leguminosae), *Khaya anthotheca* (Welw.) C. DC., among others (Marzoli, 2007). See details including the MFR's vegetation in Figure 1.

2.2 Data collection

The data collection process consisted of two stages and employed a combination of methods. The first was the survey-based methods that included interviews (semi-structured interviews), and analytic-deliberative methods (Young, 2024), and took place between September 22nd and October 5th, 2019; the second was a field survey that took place between February 21st and March 21st, 2020. Spatial data analyses of baseline digital datasets were also used. See the methodological diagram (Figure 2).

2.2.1 Semi-structured interviews (SSI)

The study drew on previous work (Francisco et al., 2022) and employed semi-structured interviews (SSI) to collect data on the cultural values and rituals associated with sacred forests, following the approach of Angarita-Báez et al. (2017). According to the population distribution data, the study area is concentrated along the N260 national road, with approximately 479 households. Interviews were conducted with 149 households (30% of the total), surpassing the 20% recommended by Adhikari and Adhikari (2004). The four most populated villages along the road were covered using exponential non-discriminative snowball sampling (Naderifar et al., 2017). In this method, the first participant refers to others, and the process continues until a sufficient sample is reached. Both male and female heads of households were interviewed, depending on who was available, as described by (Subedi, 2021). Table 1 below shows the distribution of the respondents:

2.2.2 Analytic-deliberative method (ADM)

The ADM aimed to validate the biophysical and social aspects reported by households and explore deep community attitudes and beliefs (Sherrouse et al., 2022). This method, based on universal well-being domains (Amir et al., 2024), involved citizens' juries, deliberative polls, and choice experiments (Schoon and Chi, 2022). Group discussions (four to six participants per village) included diverse male and female participants from various wealth and forest-use profiles. Meetings involved local leaders, elders, traditional healers, and practitioners of ancestor worship, focusing on both biophysical and social changes, as well as their cultural impacts (Kalaba et al., 2013). Data from local leaders, when triangulated and carefully facilitated, provide reliable insights into community practices (Amir et al., 2024). Discussions, held in the local language, adhered to the ethical principles of voluntary participation, confidentiality, and informed consent (Guillemin and Gillam, 2004). Prior to participation, all respondents were provided with clear explanations of the study's objectives, procedures, potential risks, and benefits. Participants were informed of their right to withdraw from the study at any time without any negative consequences. Formal authorization to conduct the research in the communities was obtained from local leadership, ensuring adherence to both institutional and community ethical requirements. The researcher's local university affiliation and language proficiency facilitated trust and engagement. Data was collected through participant observation and semi-structured interviews, including photos and notes (Simbine, 2013).

2.2.3 Field survey

The field survey was preceded by traditional ceremonies (*mutoto*) in each sacred area to obtain spiritual permission. Ceremonies

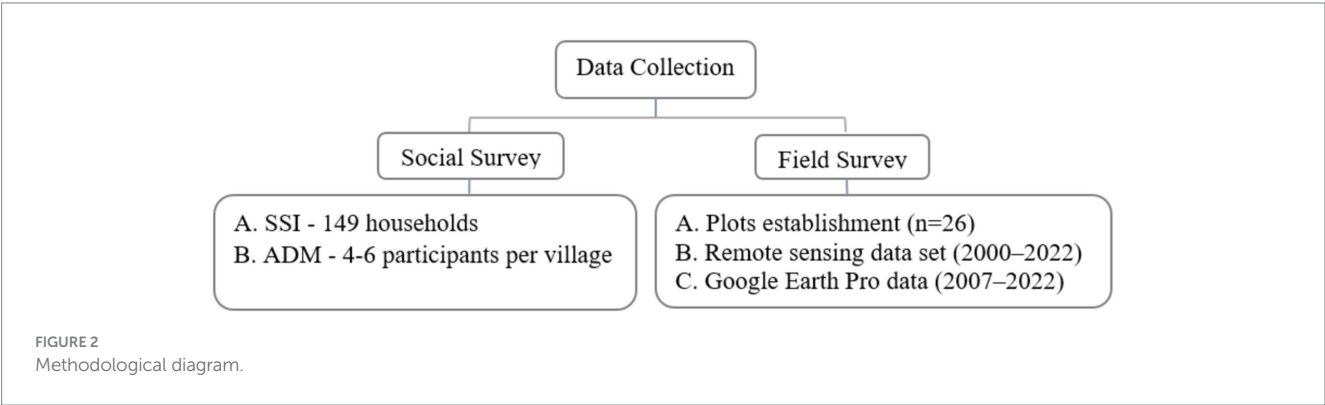
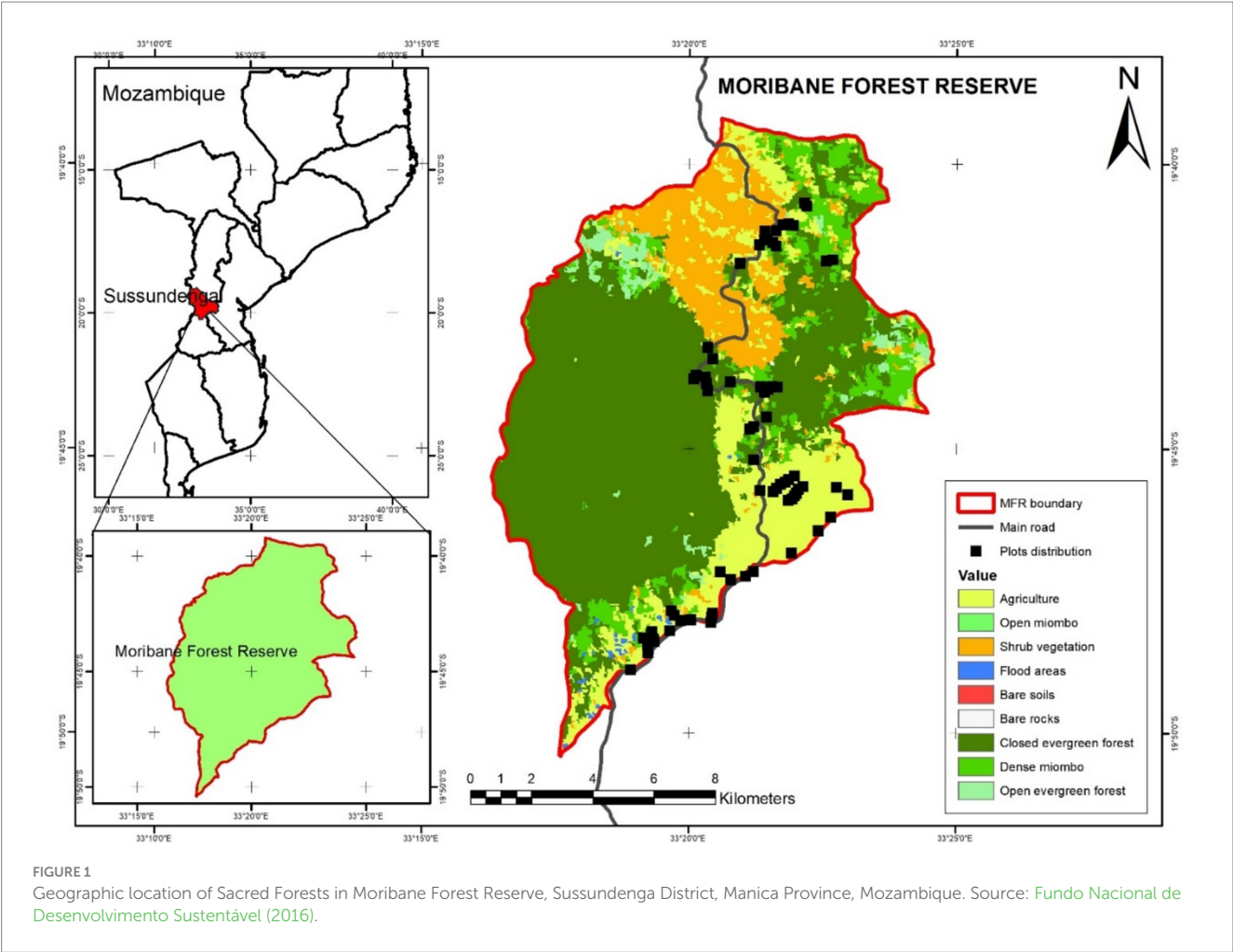


TABLE 1 Sample (HH) distribution by village.

Village	Total HH number	Sampling number (≥ 30%)
Mucuawaio	153	46
Mutoe	200	64
Magaraba	68	21
Mpunga	58	18

involved village leaders, two family members, and two elders per village, totaling 15 participants. Conducted by a master of ceremonies, each 15-min ritual involved ancestor worship, ceremonial drink offerings, and hand clapping to show respect (Afriklens, 2024). A brief explanation of the site’s cultural significance followed.

Field surveys assessed species composition and structure in sacred and non-sacred forests (MFR). A total of 26 plots were established: 18 in sacred forests and 8 in non-sacred patches. This sample size met criteria for forest variance assessment (Westfall, 2022), with an average

forest patch area of 10,000 m² and a minimum 200 m plot spacing. Purposeful sampling, based on researcher judgment (Showkat and Parveen, 2017; Kalaba et al., 2013), was used to ensure coverage of culturally and ecologically significant forest fragments (Marshall, 2024; Table 2).

The selected top villages within the reserve had plots measuring 50 × 20 m (0.1 ha), oriented north–south, with 25 × 20 m subplots. Data were collected on adult woody stems (dbh > 10 cm) in main plots and natural regeneration (5 cm ≤ dbh < 10 cm) in subplots, following Macave et al. (2022). See the Figure 3 the plot outline:

DBH of adult individuals and regenerating individuals was measured, identified scientifically by a UEM Herbarium botanist (Macave et al., 2022), and locally by a knowledgeable guide. Unidentified species were sampled and later identified at the herbarium using field guides (Macave et al., 2022). In SF plots, notes were made on surrounding land use, proximity to villages, access rights, conservation state, and anthropic interference. Ecological condition was assessed using an adaptation of Francisco et al. (2022) with indicators: (i) surrounding land use (cropland, fallow, forest), (ii) distance to settlements (≤500 m, 500–1,000 m, ≥1,000 m), and (iii) conservation state over 10 years.

2.2.4 Remote sensing data set for land use and land cover assessment

Landsat satellite images (2000–2022) were obtained from Google Earth Engine (USGS (U.S. Geological Survey), 2013), filtered by CLOUD_COVER (<0.001) and covering the MFR. Dry-season scenes were used for consistent phenological conditions (Venkatappa et al., 2020). Pre-processing included topographic, radiometric, and geometric corrections at a 30x30m resolution (Feigl et al., 2025).

Sample polygons for four land-use classes (Forest, Cropland, Grassland, Wetland) were collected in QGIS (3.30.3), 30 samples/class/year (Silva et al., 2025). Classification was performed in R Studio using the Random Forest algorithm (Feigl et al., 2025), with 70% of the samples allocated for training and 30% for validation. Accuracy (Equation 1) was assessed, with 70% as the acceptable level (Ursu et al., 2025).

$$AG = \frac{\sum AG}{\sum AT} \quad (1)$$

See Figure 4 for a summary of the land use classification flowchart:

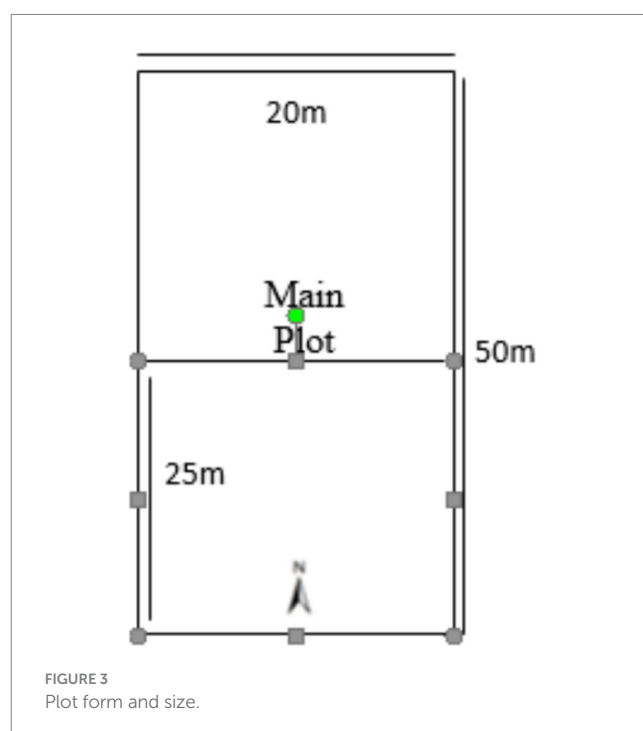
Post-classification used Sieve and Clump filters in QGIS to remove isolated pixel clusters (salt and pepper noise) by aggregating small groups into the dominant class in each window (Silva et al., 2025).

2.2.5 Google earth pro satellite data for LULC assessment of sacred and non-sacred forests

Changes in forest cover (Sacred and non-SF) were analyzed by superimposing polygons on historical satellite images using Google Earth Pro (version 7.3.6.9345) (Blaga et al., 2023). This approach, following Lynam et al. (2004), helped interpret 15-year imagery to understand local landscape valuation. The tool's capabilities, georeferenced data import/export, 2D/3D measurements, and high-resolution thematic cartography (Silva and d., 2024), enabled digitization of forest patch polygons based on survey data (Lea, 2024).

TABLE 2 Sample (plots) distribution by area by village.

Village	Sampling		Not SF	Nr of plots
	SF	Nr of plots		
Mutoe	5	5	1	1
Mpunga	5	5	3	3
Magaraba	1	6	0	0
Mucuawaio	2	2	4	4
Total	13	18	8	8



Polygons were created for each forest patch in GEP, and their area in hectares was determined using the measurement tool. Changes in forest patch area were assessed for 2007, 2011/12, 2016, and 2022 using historical imagery, selected for clarity and availability (Zhao et al., 2023). This allowed analysis of vegetation cover dynamics before, during, and after the EN2016 road asphaltting, reflecting land use pressures and demographic changes (Duan et al., 2025). See the example of the procedure in Figure 5.

2.3 Data analysis

The main SF of the MFR were identified by counting and describing their occurrence through SSI, ADM, and field surveys, with cultural significance validated in community assemblies.

For the ecological status of general woody species concerning sacred species in sacred and non-sacred forests, first, sample standardization was performed through rarefaction and extrapolation analysis. Then, species composition and diversity in sacred and non-SF were analyzed using rarefaction and extrapolation (Hsieh

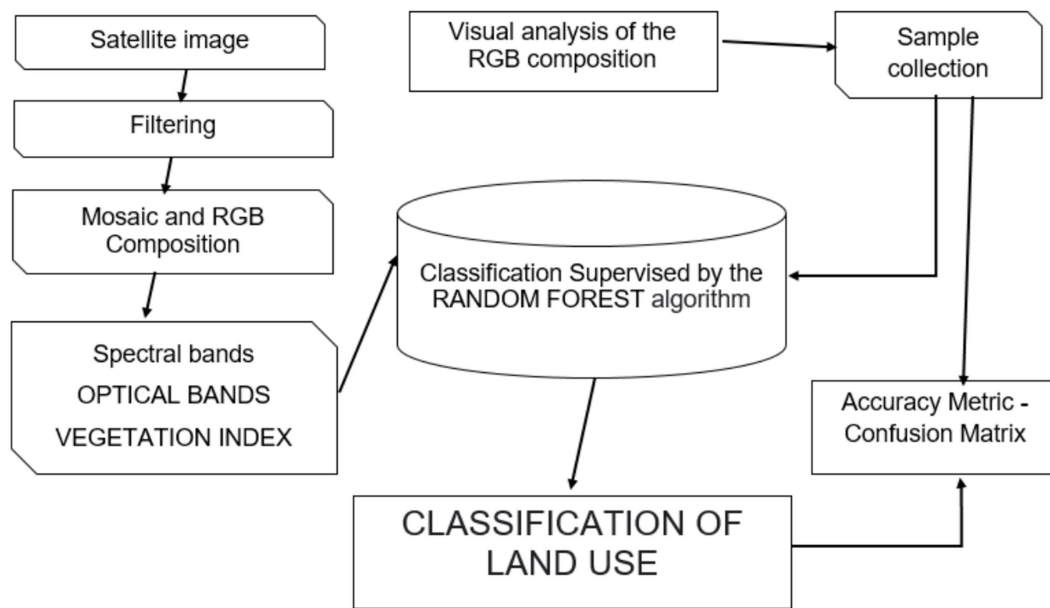


FIGURE 4
Flow chart of land use classification. Source: Recreated from Silva et al. (2025).

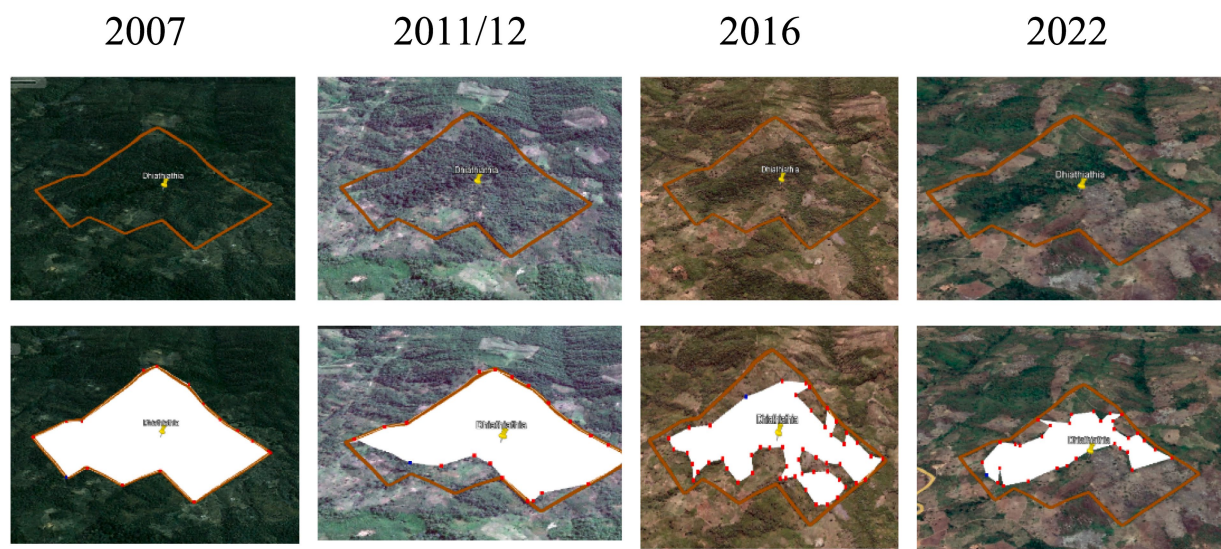


FIGURE 5
Forest area changes in sacred and non-sacred patches of the Moribane Forest Reserve evaluated using Google Earth Pro and true-color satellite images (dark green: dense vegetation, light green: sparse, gray: rocky outcrops).

et al., 2016; Chao et al., 2014). The *iNEXT* function in R estimates expected species richness and diversity (Shannon, Simpson indices), accounting for unequal sampling effort (Chao et al., 2014). Diversity estimates were plotted against sample coverage, and 95% confidence intervals applied (Chao and Jost, 2012).

The Hill diversity index (Equation 2) was used to quantify species richness and evenness (Ricotta, 2024).

Hill diversity indices quantify relative species abundances, requiring only relative abundances as input. The three primary forms used, species richness, Hill–Shannon, and Hill–Simpson—differ in

how they weight rare versus common species. Species richness emphasizes rare species and is calculated as SSS, the total number of species in the sample. Hill–Simpson diversity down weights rare species, reflecting dominance by common species. Hill–Shannon diversity, calculated using the exponential of Shannon entropy, balances sensitivity between rare and common species (Equation 3).

Hill–Shannon diversity uses a logarithmic scale, balancing sensitivity to rare and common species. Communities with many rare species exhibit high diversity, while those with few common species show low diversity (Equation 4).

A highly biodiverse and stable environment will have a high D value. This also indicates that the particular environment has “good biological health.” In contrast, an unstable and non-biodiverse environment will have a low D value. This also indicates that the particular environment has “poor biological health” (Sokolow et al., 2022). See all the equations in Table 3.

The ecological importance of species was assessed using the Importance Value Index (IVI), calculated as the sum of relative dominance, relative frequency, and relative density (basal area). IVI values range from 0 to 300 (Ali, 2024). Table 4 presents the equations for these phytosociological parameters.

The current conservation status of sacred forests (SF) between 2007 and 2022, was assessed by scoring each sample area (SF) relative to a reference control plot with the highest score. The ecological condition scale followed van Elst (2013), using statistical criteria (amplitude, classes, and limits) to define condition intervals, as there were no existing metrics for this area (Sullivan et al., 2024) See Equations 9–12 below:

Amplitude = (Difference between%of reference
which is 100% – minimum%in relation to reference) / 3

(9)

Amplitude (A) = 20.68.

Good = %of ref. – A

(10)

Medium = min.%in relation to ref.
+ A to min.%in relation to ref. + 2* A

(11)

Bad = min.%in relation to the ref.(37.96)
up to min.%in relation to the ref. + A

(12)

3 = Number of classes (Good, Medium, and Bad).
min. = minimum; ref. = reference.

According to Van Elst (2013), the number of interval classes (often calculated using Sturges’ method) was adjusted by rounding down decimal values (Table 5).

The conservation condition map of forest patches, showing changes between 2007 and 2022, was validated by induction, a process of confirming hypotheses through field observations (Alves-Mazzotti

TABLE 3 Equations for determining the diversity index:

Equations		Meaning
$D = (\sum_{i=1}^S p_i(r_i))^{\frac{1}{1-\ell}}$	(2)	Where D is diversity, S is the number of species, p_i is the proportion of all individuals that belong to species i , r_i is the rarity of species i , defined as $1/p_i$, and ℓ is the exponent that determines the rarity scale on which the mean is taken.
$e^{-\sum_{i=1}^S p_i \ln(p_i)}$	(3)	
$1/\sum_{i=1}^S (p_i)^2$	(4)	

TABLE 4 Equations for phytosociological parameter estimation.

Equations		Meaning
$IVI_i (\%) = RA_i + RDm_i + RF_i$	(5)	IVI _i = Importance Value Index
$RA_i = [(n_i / ha) / (N / ha)] * 100$	(6)	RA _i = Relative abundance; n _i /ha-number of individuals of the species i by unit of area; N/ha-Total number of individuals of all species by unit area
$RDm_i = [(g_i / ha) / (G / ha)] * 100$	(7)	RDm _i = Relative dominance; g _i /ha = basal area of species i by unit of area (ha); G/ha = basal area of all species by unit area (ha)
$RF_i = (AF_i / \sum AF_i) * 100$	(8)	RF _i = Relative frequency; AF _i = Absolute frequency

TABLE 5 Decision on the ecological condition of the sacred forests of the Moribane Forest Reserve (Centro de Estudos de Agricultura e Gestão de Recursos Naturais (CEAGRE), 2023, adapted from Ribeiro et al., 2020).

Ecological condition	Description	Overall percentage of indicators (%)
Good	The tree component is in good condition compared to the vegetation type references	79.22–100
Medium	The tree component is in reasonable condition compared to the vegetation type references	58.54–79.21
Bad	The tree component is in bad condition compared to the vegetation type references	37.96–58.53

and Gewandsznajder, 2002), with ADM members adjusting trends and correcting biases in the preliminary model.

Multivariate beta diversity analysis (hierarchical clustering with UPGMA and Jaccard index, JCI) was conducted to assess species similarities across land cover gradients (LUT) (Iritani et al., 2025). The 1I (Equation 13) quantifies shared species proportions between communities (Scherting et al., 2025):

JCI = a / a + b + C

(13)

Where: a = Number of species common to both areas; b = Number of species found in sample “A” and not in sample “B”; c = Number of species found in sample “B” and not in sample “A.”

JCI = 1 when all species are common; JCI = 0 when none are shared. Values between 0.5 and 1 indicate high species overlapSimilarity measures how alike two samples are (Diserud and Ødegaard, 2007).

Land use/cover changes in MFR (2000–2022) were mapped via image classification. Accuracy was assessed using producer/user accuracy, overall accuracy, and kappa coefficient from confusion matrices. Validation required >70% accuracy; similar studies report acceptable accuracy between 84.7 and 91.75% (Silva et al., 2025).

Changes in sacred and non-sacred forests were assessed through spatial data analysis (2007, 2011/12, 2016, and 2022), following the approach of Yohannes and Soromessa (2018), in which losses and gains were calculated as follows:

- Remain (%) = (Coverage year X * 100)/Coverage reference year
- Lost (%) = 100 – Remain (%)

Changes interpreted alongside social-economic factors from SSI and ADM.

3 Results

3.1 Local cultural meanings and practices linked to sacred forests

The documentation of local cultural meanings and practices associated with sacred forests comprised the identification of

cultural values attributed to sacred forests by local communities, the main cultural practices conducted within these forests, and the materials required for the performance of related ceremonies:

Cultural values represented by sacred forests to local communities

MFR Sacred Forests represent local cultural heritage. Access is restricted, requiring traditional ceremonial protocol led by the régulo. Ritual services celebrate reference tree species. Based on myths passed down through generations and the historical contribution of each Sacred Forest to maintaining cultural identity, connection, and heritage, and continuing to serve as a source of inspiration and problem-solving for local communities, some remain highly respected ceremonial sites, while others have become mere places of worship. Therefore, all these sites are protected and preserved, ensuring the conservation of their biodiversity (Table 6).

Main local cultural practices in sacred forests

Cultural values are preserved through practices encompassing the behaviors, beliefs, and spiritual and material values of MFR local communities (Table 7).

Cults typically involve requests, followed by thanksgiving ceremonies when successful. While generally community-focused, some services address individual needs.

TABLE 6 Sacred forests in the Moribane Forest Reserve and their cultural significance for local communities.

Community	Biophysical-social elements	Type	Cultural Significance	Tree species used for Ceremony	
				Scientific name	Local name
Mutoe	Tchimana	Forest	Burial site for Mutoe leaders	<i>Newtonia buchananii</i>	Mufomoti
	Pamapofu	Forest	Places of worship	<i>Albizia adianthifolia</i>	Mudjerenge
	Machorwhana	Forest	One of the ceremonial sites in Mutoe	<i>Newtonia buchananii</i>	Mufomoti
	Dhiathiathia	Forest	Places of worship	<i>Khaya anthotheca</i>	Muwawa
	Tchihungwe	Forest	Most respected ceremonial site in Mutoe	<i>Macaranga capensis</i>	Mufucuchamacaia
Mpugna	Ponte de Deus	River	Most respected ceremonial site in Mpunga	<i>Newtonia buchananii</i>	Mufomoti
	Chirita	Mountain	Places of worship	<i>Millettia stuhlmannii</i>	Mussara
	Bhuerokhamba	Rock	Places of worship	<i>Erythrophleum suaveolens</i>	Mussandha
	Mataca Okuswipa	Place	Places of worship	<i>Inhambanella henriquesii</i>	Mutswandzwua
Magaraba	Txabhutu	Forest	Main ceremonial site in Magaraba	<i>Vitex payos</i>	Mucuvu
Mucuawaio	Gubvunhi	Place	Respected place	<i>Erythrophleum suaveolens</i>	Mussandha
	Pa dzya	River	Respected place	<i>Diplorhynchus condylocarpon</i>	Mutoa
	Rhunde	Place	Respected place	<i>Khaya anthotheca</i>	Muwawa

TABLE 7 Main cultural practices and frequency of ceremonies in sacred forests in MFR.

General interest	%	Individual interest	%
Request for rainfall in cases of prolonged drought	91.9	Crop losses due to avoidance by wild animals recurrently and exclusively in the production field of the household in question	89.3
Request for good production in agricultural campaigns	86.5	Frequent fires in their huts	81.8
Request for the protection of crops against devastation by wild animals, especially elephants and monkeys	89.3	Among other particular cases	80.5
Occasionally cults against the frequency of wildfires	78.5	-----	

Necessary material for the celebration of ceremonies in sacred forests

Ceremonies require sorghum, a native black chicken, and two *capulanas*¹ (one red, one black), essential offerings to ancestral spirits (SSI and ADM).

3.2 Comparing forest structure and species diversity in sacred versus non-sacred areas

The comparison of forest structure and species diversity between sacred and non-sacred areas involved: assessing the ecological status of woody species, evaluating species and botanical family richness and overall abundance, calculating the Importance Value Index (IVI), determining the conservation status of species listed on the IUCN Red List, and examining the current conservation conditions of sacred forests in relation to changes observed over the past 15 years:

Ecological status of woody species in sacred and not sacred forests

Through rarefaction and extrapolation analysis, relative to the same number of individuals sampled (A), the collector curve indicates a greater richness of species accumulated in SF (41 species) compared to non-sacred (38 species) (A-1).

It was verified that the collector curve (Sample completeness curve) reaches the asymptote (stability) from the last individual found per area in the interpolation path (A-2). This stability

prevails along the extrapolation route, meaning that sufficient proportions of the total number of individuals in the studied assemblages were achieved in the species expected to be found (A-1).

The collector curve (A-3) emphasizes the result described in B, showing the true total relative abundance of individuals of all expected species represented in the sample. This trend is repeated for the Hill-Shannon (B-1, B2, and B-3) and Hill-Simpson (C-1, C-2, and C-3) diversity indices. Therefore, the SF proved to be the ecosystem with the greatest diversity of species (Figure 6).

Species richness and global abundance

Seventy-five woody plant species from 31 botanical families were identified in the Sacred and non-Sacred Forests of Moribane Forest Reserve (Figure 7). Twenty-one species are considered sacred by local communities, notably *Newtonia buchananii*, *Millettia stuhlmannii*, *Inhambanella henriquesii*, *Diplorhynchus condylocarpon*, and *Cola mossambicensis*, the most abundant. Find the complete list of species in the Supporting information in the end.

Botanical family richness

Fabaceae, Apocynaceae, and Euphorbiaceae Families were the ones that found the highest number of species (Figure 8).

Importance value index (IVI)

Half (50%) and 60% of the species that occupy the list of the 10 species with the highest IVI in non-sacred (Figure 9A) and sacred (Figure 9B) areas, respectively, are species considered sacred at the community level, namely, *Newtonia buchananii*, *Millettia stuhlmannii*, *Diplorhynchus condylocarpon*, *Inhambanella henriquesii*, *Tabernaemontana elegans*, and *Bridelia micrantha*.

IUCN conservation status of plant species in sacred and non-sacred forests of MFR

More than half (65%) of species identified in SF are of low concern. In non-SF, this category represents 27.5% of the species identified therein. The number of near-threatened and vulnerable species represents 4.3 and 1.3% in SF and 7.5 and 2.5% in not SF as shown in Figure 10.

Regarding similarity, no similarity was found between sacred and non-Sacred Forests (JC = 0.45).

Current conservation conditions of sacred forests in light of the changes in the last 15 years

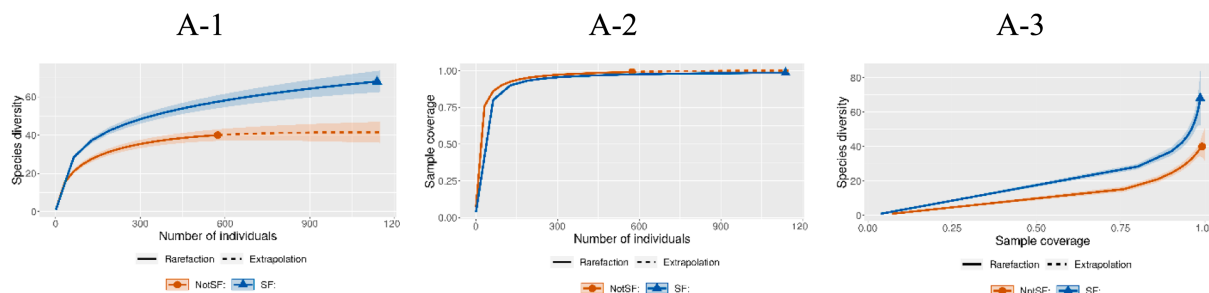
Based on SSI and ADM field observations, 53.84% of Sacred Forests (SF) are in good conservation condition, 30.76% in poor condition, and 15.38% in moderate condition. Most SF are adjacent to small forest fragments, fallow land, and croplands, located 500–1,000 m from communities. Local houses use poles sourced nearby (Figure 11).

3.3 Assess land-use and cover changes in the reserve, focusing on sacred forests

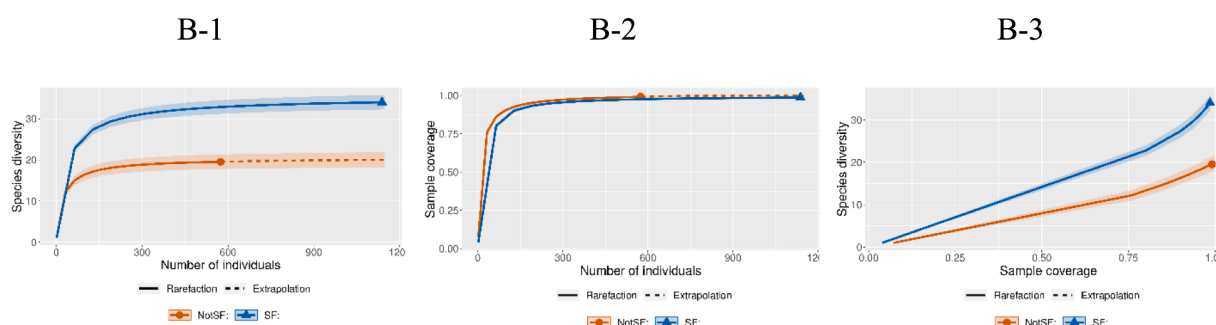
The assessment of land-use and land-cover changes in the reserve comprised the mapping of land-use and land-cover dynamics across

¹ "capulana" is a type of sarong, specifically a vibrant and colourful fabric often worn by women in Mozambique.

A. Species richness ($q=0$)



B. Shannon diversity ($q=1$)



C. Simpson diversity ($q=2$)

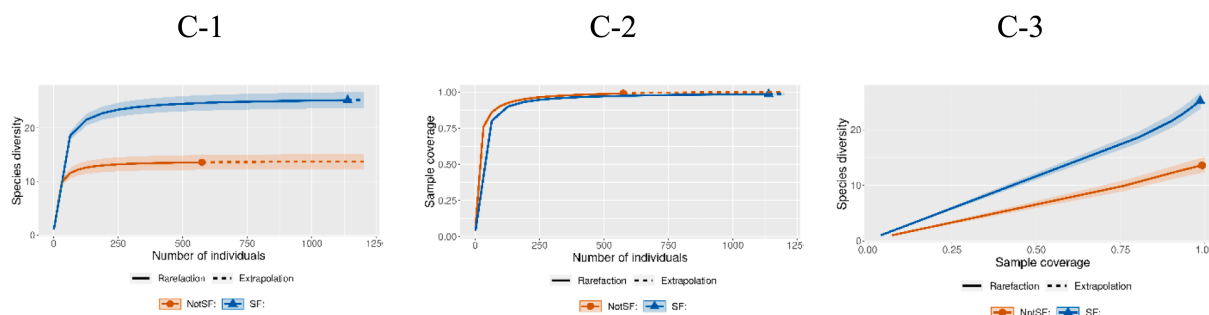


FIGURE 6

Comparison of Sample-size-based interpolation/rarefaction (A-1, B-1, C-1), Sample completeness curve (A-2, B-2, C-2), Coverage-based interpolation (A-2, B-2, C-2) (solid curve) and extrapolation sampling curve (dashed curve) for species richness, Shannon diversity and Simpson diversity.

the ecosystems of the Moribane Forest Reserve, as well as the evaluation of changes in sacred and non-sacred forests:

Mapping of land use and land cover changes in the ecosystems of the Moribane Forest reserve

There was a gradual increase in cropland and a consequent reduction in forest areas, mainly affecting the northern zones and part of the central zone of the Reserve, with a peak being reached in 2020.

Assessment of changes in sacred and non-sacred forests

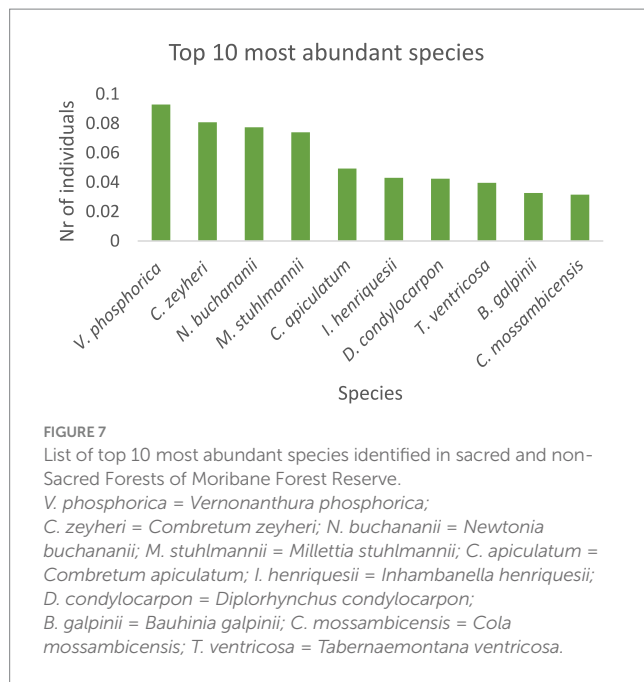
Comparing changes in use and coverage between sacred and non-Sacred Forests regarding the year 2007, a progressive reduction in their proportion was verified. However, non-Sacred Forests were

the ones that recorded the most significant losses in 2011/2, 2016, and 2022 as illustrated in Figure 12. A considerable proportion of the degraded forest fragments are invaded by the invasive species *Vernonanthura phosporica*.

4 Discussion

4.1 Cultural values represented by sacred forests to local communities

Belief in ancestor cults within the Moribane Forest Reserve (MFR) fosters a profound human–nature relationship in which Sacred Forests (SF) serve not only as spiritual sanctuaries but also as vital refuges



supporting local biodiversity (Table 6) (Sullivan et al., 2024). These areas embody both tangible and intangible values, spiritual, cultural, and physical that necessitate protection, thereby contributing directly to the maintenance of habitat integrity and species richness (ICOMOS et al., 2010). This dual role of SF has been corroborated by studies in other African contexts, reinforcing the idea that cultural beliefs can effectively underpin local conservation strategies (Sinthumule, 2024).

The cultural beliefs associated with SF continue to guide community-based conservation practices. In Mpunga, for example, the myth of the “Bridge of God (ponte de Deus),” revitalized during road construction in 2011, reaffirmed ancestral mandates to protect forests from encroachment. Similarly, sacred caves such as those in Chirita SF, historically used as defensive refuges, remain intact due to their sacred status, thus acting as inadvertent sanctuaries for biodiversity (Sullivan et al., 2024). Local legends, such as the Bhuerokhamba tale of a leopard perceived as an ancestral guardian, extend this protective ethic to plant and animal life alike, embedding conservation values within spiritual beliefs and emotional attachments to nature (Sullivan et al., 2024). These findings align with global research indicating that spiritual and cultural frameworks can produce measurable ecological outcomes, including species preservation and forest structure maintenance (Santilli, 2015; Dudley, 2008).

This value-driven conservation approach illustrates how cultural worldviews reinforce ecological outcomes, offering a locally grounded knowledge system that complements science-based resource management while deepening understanding of community-landscape relations. By documenting these practices, the study contributes to science by providing empirical evidence of the role of cultural norms in ecosystem management and offers insights for integrating traditional knowledge into global conservation strategies. Similar dynamics are observed among the Bakonzo people of Uganda, who believe that mountains and their ecosystems are inhabited by spirits, with traditional leaders restricting access to preserve ecological integrity (Sinthumule, 2024). Historically, many resource-rich sites were also spiritually revered, with customary rules ensuring ecological

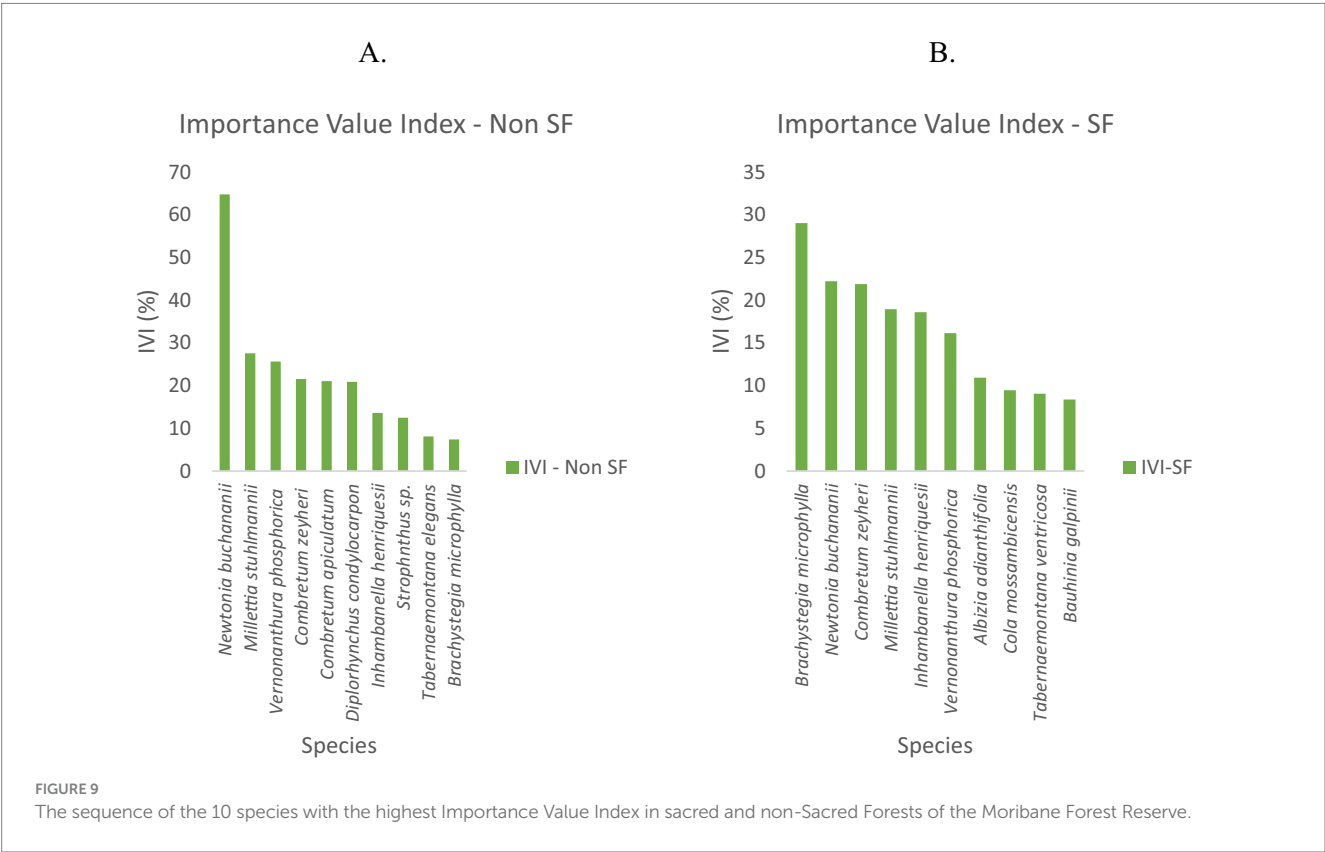
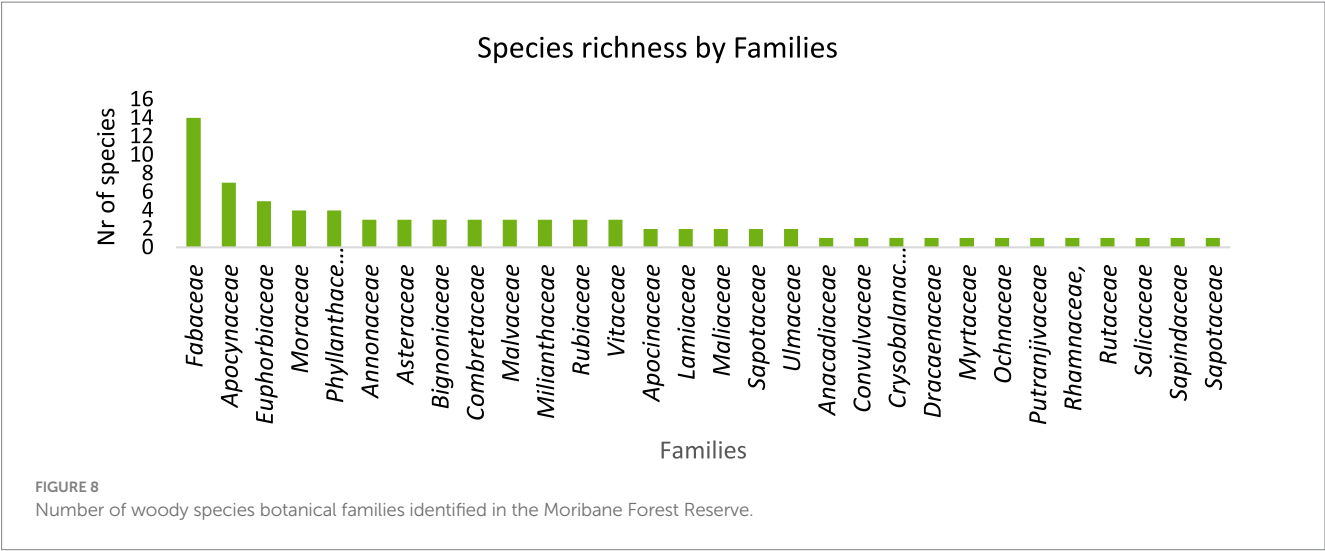
balance and the sustainability of vital resources (Rathoure, 2024). Such intangible heritage, shaped by continuous human–environment interaction, strengthens both cultural identity and reverence for biological diversity (Santilli, 2015).

These place-based belief systems foster environmentally responsible behaviors and reinforce norms of environmental stewardship (Dudley, 2008). For example, in Mucuawao, the sustainable extraction of clay for pottery and fishing is governed by community-based restrictions that express ancestral gratitude while protecting local species. By highlighting these practices, the research demonstrates the potential for local communities to serve as active stewards of biodiversity, thereby informing conservation policies and practices worldwide. The cultural significance communities assign to places and practices arises from collective meaning-making rather than inherent characteristics (Banda et al., 2024). Recognizing this duality supports the development of robust heritage conservation frameworks that link cultural values with biodiversity protection (ICOMOS et al., 2010; UNESCO, 2017).

Ritual practices, such as the sacrifice of a black chicken and the offering of its blood to ancestral spirits during the main cultural events, reinforce taboos and customary rules that restrict extractive activities, helping to preserve forest structure (Table 7) (Ye’Tsunam, 2023). These culturally mediated conservation actions provide a living model for integrating traditional ecological knowledge into modern biodiversity management, with implications for global conservation programs seeking to balance human use and ecological integrity. The deep reverence that communities express for SF is sustained through myths that interweave historical memory with sacred narratives, ensuring that fear and respect translate into long-term conservation practices (Hidalgo and Sánchez, 2020). These myths function as socio-cultural frameworks that not only explain natural phenomena but also shape land-use norms that protect forested areas and the species they harbor (Simbine, 2013).

Local belief systems actively promote sustainable land-use practices, including rotational agriculture, selective access, controlled resource extraction, and the protection of particular species. Such practices demonstrate the practical application of cultural norms in resource management and highlight pathways for community-driven conservation interventions, contributing to the global discourse on participatory and culturally informed biodiversity strategies (Rathoure, 2024). Notable ecological outcomes include enhanced rainfall, improved agricultural yields, and a reduction in wildfire incidence, all ecosystem-level benefits that stem from forest cover preserved through spiritual reverence for SF (Lopes et al., 2025).

Despite these cultural safeguards, signs of ecological disruption have emerged in recent decades. Many practitioners have noted that traditional ceremonies, once believed to summon rainfall, are becoming less effective. According to Yang et al. (2024), natural features such as mountain elevation and dense forest historically contributed to fog formation and stable rainfall patterns in the MFR. These microclimates depended on extensive canopy cover. However, in the absence of formal scientific knowledge, local communities did not initially associate deforestation caused by burning, agriculture, or resource extraction with the microclimatic changes that now threaten both ecosystem integrity and ritual efficacy (Akaliibey et al., 2024). This underscores the complementary role of scientific monitoring in reinforcing traditional conservation practices,



providing actionable data to support both community livelihoods and global biodiversity objectives.

Between 2007 and 2022, the Sacred Forests experienced a 67.5% decline in forest cover (Figure 12), compromising the ecological foundation for practices and rituals that have historically been based on these areas (Cambaza, 2025). Overall, in the period under analysis, the MFR as a whole lost 4.35% of its forest cover (Figure 13), and alters streamflow patterns, posing threats to species dependent on stable water regimes (Langhammer and Bernsteinová, 2024). Current scientific consensus affirms that the loss of just 20–30% of forest cover can significantly alter regional microclimates (De Frenne et al., 2021). Consequently, the climate shifts currently observed across the MFR reflect broader deforestation trends in the surrounding Chimanimani landscape, an area that in recent decades has faced acute climatic variability, including cyclones such as *Idai* in 2019, and alterations in rainfall and temperature regimes (Munsaka et al., 2021).

4.2 Ecological status of woody species in sacred and non-sacred forests

Sacred Forests (SF) exhibit the highest species richness ($q = 0$) and sacred species richness. These results corroborate findings from other tropical forest studies showing that culturally protected forests often harbor higher biodiversity than non-protected areas (Sullivan et al., 2024). Rarefaction and sample completeness curves (Figure 6) (Sullivan et al., 2024) indicate species richness approaches an asymptote, implying that further sampling would yield minimal new species. Coverage-based interpolation confirms that maximum richness can be effectively captured through comprehensive habitat sampling, providing a reliable baseline for both ecological research and conservation planning.

Hill-Shannon diversity ($q = 1$) is greater in SF, with collector curves stabilizing at large sample sizes, reflecting species equitability (Sullivan et al., 2024). Hill-Simpson diversity exhibits similar trends, highlighting the relative abundances of common species (Chandel, 2022). These diversity patterns emphasize the role of SF as critical reservoirs of both common and rare species, reinforcing the notion that culturally protected areas contribute to maintaining ecological balance and resilience in forest ecosystems.

SF thus represents key habitats supporting high floristic richness and diversity, serving as refuges and ecological corridors (Chandel, 2022). From a conservation perspective, these findings demonstrate that integrating traditional cultural practices into biodiversity management can enhance species protection, inform adaptive forest management strategies, and guide global conservation efforts. Furthermore, by documenting the ecological significance of SF, this study provides empirical evidence that can strengthen community engagement in conservation initiatives, support local livelihoods through sustainable resource use, and contribute to worldwide discussions on the value of culturally managed forests for biodiversity preservation.

4.2.1 Species richness and global abundance

Approximately 28% of species identified are sacred, with half of these among the 10 most abundant species in the MFR, including *Newtonia buchananii*, *Millettia stuhlmannii*, and *Combretum apiculatum*, consistent with patterns observed in other culturally protected forests in East Africa (Zannini et al.,

2021; Adanma and Ogunbiyi, 2024). Notably, 33% of sacred species are exclusive to SF, highlighting their unique conservation role as refugia for species not found elsewhere (Sokolow et al., 2022). However, the invasive *Vernonanthura phosphorica* dominates abundance, indicating ongoing anthropogenic pressures that threaten native biodiversity (Centro de Estudos de Agricultura e Gestão de Recursos Naturais (CEAGRE), 2023). At the family level, 35.7% of families occur only in SF (Figure 8), further reinforcing the importance of SF for preserving native taxonomic diversity and maintaining ecosystem resilience (Sokolow et al., 2022; Gamfeldt et al., 2013).

The Importance Value Index (IVI) shows similar proportional representation of sacred species in SF and non-sacred forests (NSF), suggesting shared environmental drivers such as edaphoclimatic and topographical factors. This finding underscores the need for integrated conservation strategies that protect habitat quality across the landscape to sustain ecosystem services and local livelihoods (Verkerk et al., 2019).

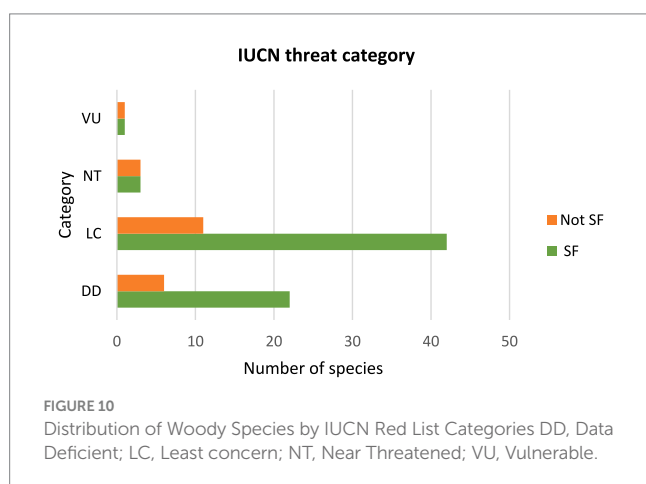
Regarding IUCN conservation status (Figure 8), Near-threatened species such as *Cola mossambicensis*, *Milicia excelsa*, and *Brachylaena huillensis* occur mainly in SF, while *Khaya anthotheca* is Vulnerable and restricted to SF. These results demonstrate that SF function as critical reservoirs for globally threatened species, reinforcing their role in both local and international biodiversity conservation efforts (IUCN, 2025). Jaccard similarity indices reveal low species overlap ($JC < 0.5$) between SF and NSF, indicating high beta diversity, habitat specialization, and landscape heterogeneity. This high uniqueness justifies the conservation of both habitats to preserve species assemblages, support ecological research, and inform community-based management strategies that integrate traditional knowledge with scientific approaches.

Overall, these findings provide empirical evidence that culturally protected forests contribute significantly to biodiversity preservation, enhance ecosystem service provision, and offer a model for globally relevant conservation practices that harmonize local cultural values with scientific management objectives.

4.2.2 Current conservation conditions of sacred forests considering the changes between 2007 and 2022

Between 2007 and 2022, 53.84% of SF were in good condition, with 30.78 and 15.38% in bad and medium conditions, respectively (Figure 11). These findings are consistent with other studies in African tropical forests showing that culturally protected areas generally maintain higher ecological integrity than non-protected sites, although pressures from human activities remain significant (Timberlake et al., 2016; Siteo and Guedes, 2015). Land conversion for agriculture, urbanization, and resource extraction threatens SF integrity, notably in the Mutoe community, which experienced severe deforestation from 2000 to 2022. This highlights the vulnerability of SF under increasing demographic and economic pressures, reinforcing the need for integrating traditional knowledge with formal conservation strategies.

Conversely, Mpunga's SF remain mostly well-conserved due to effective local management and adherence to customary rules. Such locally driven conservation demonstrates the potential of community-based governance to sustain ecosystem services, preserve biodiversity, and provide replicable models for forest management in other regions worldwide. Areas in poor condition often suffer from shifting



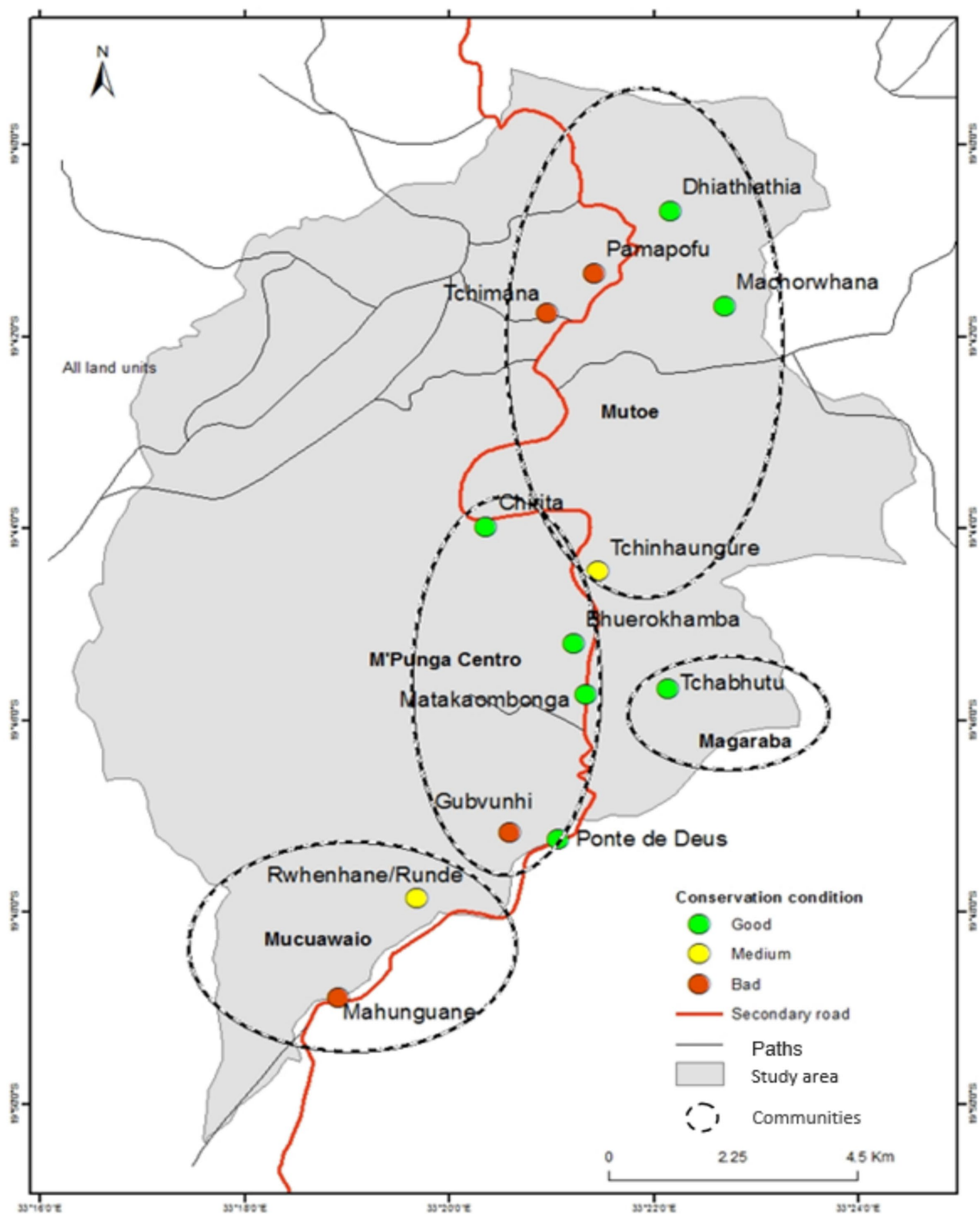


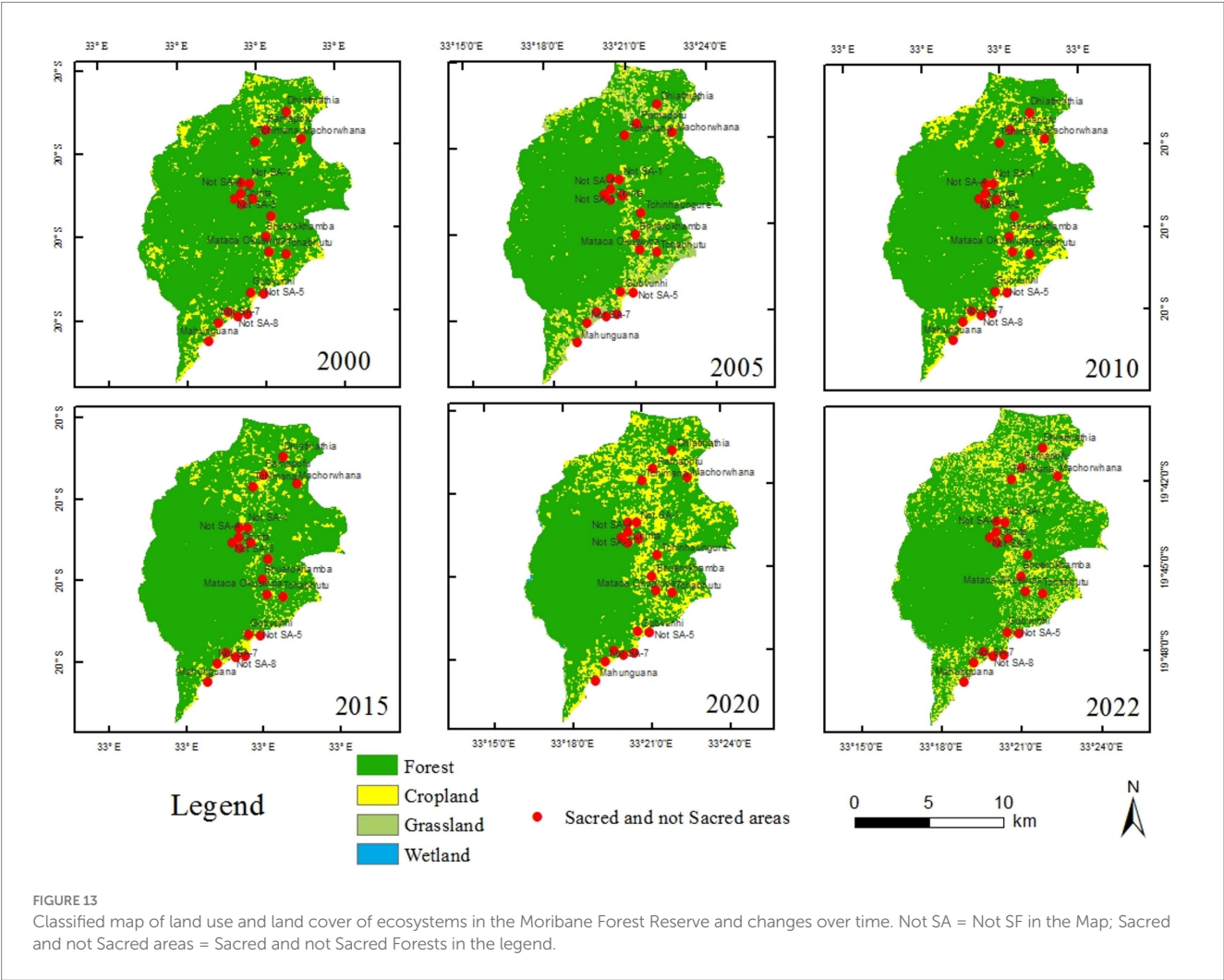
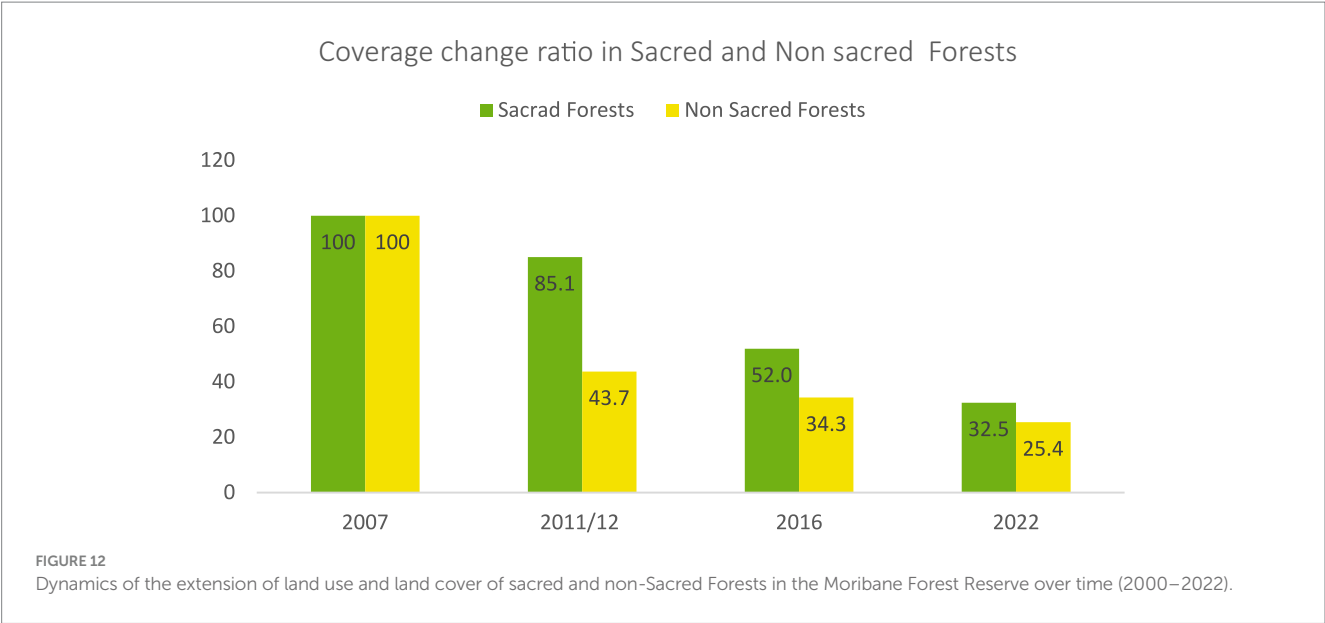
FIGURE 11
Map showing differences in conservation conditions of Sacred Forests in Moribane Forest Reserve.

cultivation and population pressure, underscoring the importance of targeted restoration programs that combine ecological science with culturally sensitive approaches.

Overall, this findings provides critical data for monitoring SF health, informs adaptive management strategies, and emphasizes the global relevance of sacred forests as reservoirs of biodiversity, sources of ecosystem services, and living laboratories for understanding the interaction between cultural practices and forest conservation.

4.3 Mapping of land use and land cover changes in the ecosystems of the Moribane Forest reserve

The spatial patterns of land use and land-cover change within the MFR illustrate a gradual yet persistent transformation of the landscape's ecological condition. In the reference year 2000, the reserve was predominantly covered by the Forest class, with fragmented patches of



cropland dispersed throughout, including in the reserve's core (Figure 13). Croplands were most concentrated in the northern zone, thinning out progressively southward along the corridor of road N216 (highlighted by the red dotted line in Figure 11) that bisects the reserve's forest matrix. These patterns are consistent with other studies of tropical forest landscapes, showing that roads and settlement corridors are primary drivers of fragmentation and biodiversity loss (FAO, 2020; Timberlake et al., 2016).

Historically, as Ghiurghi et al. (2010) note, prior to Mozambique's independence in 1975, human settlement within forest reserves was permitted, with land clearing for cultivation being the main limitation. Consequently, banana cultivation became widespread in Moribane, especially in Mpunga village, while staple crops like sorghum, maize, millet, beans, tomatoes, cassava, sweet potatoes, and sesame were grown on small plots across the reserve. However, such cultivation historically reduced native forest cover, particularly in fertile valley bottoms, echoing findings from other East African forest systems where agricultural expansion directly threatened forest integrity (Alule et al., 2023).

Embedded within this changing mosaic are SF, which act as critical ecological refuges that moderate the pace and impact of landscape transformation. Their persistence highlights the importance of culturally protected forests in maintaining biodiversity and ecological services under anthropogenic pressures, reinforcing the role of traditional knowledge in contemporary conservation frameworks (Zannini et al., 2021).

The Chimanimani National Park (CNP), part of the broader Chimanimani Transfrontier Conservation Area (TBCA) established jointly by Mozambique and Zimbabwe in 1999 (Ghiurghi et al., 2010), was conceived to manage such forests across borders. However, despite a 2004 bilateral agreement, practical cross-border ecosystem governance remains limited (ANAC, 2021). Early management frameworks outlined by Bell (1999) were never formally adopted, and initial implementation proved weak. These governance challenges reflect global trends in transboundary conservation areas, where legal agreements often lag behind enforcement and community engagement, highlighting the need for adaptive co-management strategies (Adanma and Ogunbiyi, 2024).

Renewed efforts through Mozbio I and II (2006–2023) have since strengthened resource allocation and improved on-ground management. Yet, challenges persist: chronic funding shortages, inadequate infrastructure, expanding agriculture, illegal mining, and fragile local governance continue to drive unsustainable exploitation patterns that erode the forest ecosystem's resilience (ANAC, 2021). This underscores the importance of integrating local communities, traditional knowledge, and scientific monitoring to sustain ecosystem services, protect biodiversity, and provide replicable lessons for tropical forest conservation worldwide.

Between 2015 and 2022, agricultural encroachment intensified, particularly around Mucuawaio and the Mpunga community, where land clearance for banana plantations and settlement growth accelerated forest loss, directly affecting SF situated along key access roads (Figure 12). Comparative analysis of land-cover maps from 2000 to 2022, each with over 86% global accuracy, confirms these intensifying trends and provides robust data for evidence-based conservation planning. These findings contribute to science by quantifying landscape-level change, inform local conservation priorities, and offer globally relevant insights into the interplay between cultural protection, land-use dynamics, and forest resilience.

4.3.1 Assessment of changes in sacred and non-sacred forests

Critical comparative assessments reveal that SF play a measurable role in sustaining local biodiversity within the MFR ecosystem. While both SF and non-sacred forests (NSF) have experienced significant deforestation, SF have consistently suffered lower proportional losses. From 2007 to 2011/12, SF lost 14.9% of cover compared to 56.3% in NSF; between 2011/12 and 2016, SF declined by 48.0% against NSF's 65.7%; and by 2016–2022, SF recorded a 67.5% loss compared to 74.6% in NSF (Figure 12). These trends align with previous research showing that culturally protected forests generally experience lower rates of deforestation than non-protected areas, highlighting the measurable conservation value of traditional stewardship practices (Zannini et al., 2021).

This persistent differential suggests that communities, guided by cultural beliefs and taboos, maintain higher levels of stewardship over SF than over other forest patches. Such culturally mediated protection demonstrates that local knowledge systems and spiritual values can function as effective conservation tools, supporting both the maintenance of biodiversity and the continuity of traditional ecological knowledge (Adanma and Ogunbiyi, 2024).

Ecologically, this difference is reflected in vegetation structure and species composition. Whereas NSF areas have become dominated by the invasive shrub *Vernonanthura phosphorica*, which suppresses native plant regeneration, SF patches retain native species as the dominant flora and display minimal invasive presence (Timberlake et al., 2016; ANAC, 2021). This illustrates that cultural protection of SF directly supports native biodiversity conservation by providing stable refuges that resist biological invasion, a finding consistent with global studies highlighting the role of community-managed sacred forests in buffering ecosystems against anthropogenic pressures (Boon et al., 2023). Such resilience is increasingly critical given projections that invasive species, combined with demographic pressures, may drive African forest loss by an additional 9.3 million hectares between 2010 and 2060 (Boon et al., 2023).

Differences in forest structure, canopy complexity, and the degree of disturbance between SF and NSF underscore how the embedded cultural reverence for SF functions as a tangible conservation mechanism, buffering against ecological degradation typically associated with land-use change. This protective function provides a model for integrating traditional and scientific approaches to forest management, illustrating the synergistic benefits of combining local stewardship with formal conservation interventions.

Therefore, reinforcing community stewardship of SF holds strategic potential for sustaining the ecological integrity of the MFR and the wider CNP landscape. By formally recognizing and integrating these cultural sanctuaries into conservation policy, local belief systems can be aligned with modern biodiversity governance, ensuring that the cultural values safeguarding SF continue to deliver tangible ecological benefits, support community livelihoods, and provide globally relevant lessons for conservation in tropical forests.

5 Conclusion

We concluded that:

- The SF, more than being mere forest fragments attached to a buffer zone (MFR) of a conservation area (PNC), constitute a symbolic heritage of attachment between current generations of

residents and their ancestors, making them places of spiritual contact and a source of blessing through the practice of cults;

- Cultural practices in SF, whether implicitly or explicitly, lead to attitudes of protection and conservation, which, in a certain way, safeguard the composition and structure of its biodiversity, as well as its biophysical environment. 60% of the species that occupy the list of the 10 species with the highest IVI in SF are species considered sacred at the community level;
- Changes in use and land cover have intensified in recent years, as population growth and the construction of development projects, particularly the N260 road, have accelerated pressure on forest resources. These changes have primarily converted forests into cropland and grassland. This ongoing pressure has reduced forest cover across the reserve, including the Sacred Forests, thereby compromising the communities' cultural heritage and the conservation of local biodiversity. Still, the average difference in forest area loss between Sacred and non-sacred areas is 63.2%.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The questionnaires were approved by the ethics committee of Eduardo Mondlane University after obtaining authorization to conduct the research at the district government level of Sussundenga. Informed consent was considered before the interview was conducted, and for the integrity of the participants, the maintenance of anonymity.

Author contributions

FF: Formal analysis, Writing – review & editing, Data curation, Methodology, Investigation, Writing – original draft, Conceptualization. EC: Writing – original draft, Validation, Writing – review & editing, Supervision. AS: Writing – original draft, Writing – review & editing, Validation, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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