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Ceriops tagal (Perr.) C.B. Robinson is the most pressured species by natural and human causes in Macuse mangrove (Mozambique)

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A B S T R A C T

The mangrove ecosystem is an important source of resources and services that meet human needs. Despite their relevance, mangroves in southern Zambezia remain poorly known, especially about diversity, distribution, and conservation status. We assessed mangroves' composition, diversity, and conservation status in Macuse, in southern Zambezia, Mozambique. For the floristic survey, 300 m linear transects were laid out. Five sampling points were established on each transect, where 20 x 20 m plots were marked out, where the plants were identified, quantified, and grouped into cutting level categories: intact (no cutting), partial cutting (25% of branches cut), deep cutting (75% of branches cut), complete cutting (stump) and death by natural causes. We recorded 14,116 individuals belonging to eight species, namely: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba*, *Xylocarpus granatum*, with *C. tagal* being the most abundant species. The rarefaction curve reached an asymptote, indicating a low probability of recording new species even with increased sampling effort. We recorded 69% of the individuals intact, 2.8% with partial cuts, 2.2% with deep cuts, 9.3% with the trunk completely cut, and 16.7% dead due to natural causes. *C. tagal* was the species most pressured by natural and human causes. These results provide a good level of conservation of the studied mangroves; however, there is a need to strengthen actions aimed at greater conservation, thus reducing human pressure on mangroves.

Keywords: Composition; mangroves; extraction; rarefaction curve; Mozambique.

Ceriops tagal (Perr.) C.B. Robinson é a espécie mais pressionada por causas naturais e humanas no mangal de Macuse (Moçambique)

R E S U M O

O ecossistema de mangal é uma importante fonte de recursos e serviços que atendem às necessidades humanas. Apesar de sua relevância, os mangais no sul de Zambézia permanecem pouco conhecidos, especialmente em relação à diversidade, distribuição e estado de conservação. Avaliamos a composição, diversidade e estado de conservação dos mangais em Macuse, no sul de Zambézia, Moçambique. Para o levantamento florístico, foram alocados transectos lineares de 300 m. Em cada transecto foram estabelecidos cinco pontos de amostragem, nos quais foram delimitadas parcelas de 20 x 20 m, onde as plantas foram identificadas, quantificadas e agrupadas em categorias de níveis de corte: intactas (sem corte), corte parcial (25% dos ramos cortados), corte profundo (75% dos ramos cortados), corte completo (toco) e morte por causas naturais. Registramos 14.116 indivíduos pertencentes a oito espécies, a saber: *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Heritiera littoralis, Lumnitzera racemosa, Rhizophora mucronata, Sonneratia alba, Xylocarpus granatum*, com *C. tagal* sendo a espécie mais abundante. A curva de rarefação atingiu uma assíntota, indicando uma baixa probabilidade de registrar novas espécies mesmo com o aumento do esforço amostral. Registramos 69% dos indivíduos intactos, 2,8% com cortes parciais, 2,2% com cortes profundos, 9,3% com o tronco completamente cortado e 16,7% mortos devido a causas naturais. *C. tagal* foi a espécie mais pressionada por causas naturais e humanas. Esses resultados proporcionam um

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bom nível de conservação dos mangais estudados; no entanto, há necessidade de fortalecer ações voltadas para uma maior conservação, reduzindo assim a pressão humana sobre os mangais.

Palavras-chave: Conservação; mangais; extração; curva de rarefação; Moçambique.

Ceriops tagal (Perr.) C.B. Robinson es la especie más presionada por causas naturales y humanas en el manglar de Macuse (Mozambique)

R E S U M E N

El ecosistema de manglar es una fuente importante de recursos y servicios que satisfacen las necesidades humanas. A pesar de su relevancia, los manglares en el sur de Zambezia siguen siendo poco conocidos, especialmente en lo que respecta a su diversidad, distribución y estado de conservación. Evaluamos la composición, diversidad y estado de conservación de los manglares en Macuse, en el sur de Zambezia, Mozambique. Para el estudio florístico se trazaron transectos lineales de 300 m. Se establecieron cinco puntos de muestreo en cada transecto, en los que se delimitaron parcelas de 20 x 20 m, donde se identificaron las plantas, se cuantificaron y se agruparon en categorías de nivel de corte: intactas (sin corte), corte parcial (25% de las ramas cortadas), corte profundo (75% de las ramas cortadas), corte completo (tocón) y muerte por causas naturales. Registramos 14.116 individuos pertenecientes a ocho especies, a saber: *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Heritiera littoralis, Lumnitzera racemosa, Rhizophora mucronata, Sonneratia alba, Xylocarpus granatum*, siendo *C. tagal* la especie más abundante. La curva de rarefacción alcanzó una asíntota, lo que indica una baja probabilidad de registrar nuevas especies incluso con un mayor esfuerzo de muestreo. Registramos el 69% de los individuos intactos, el 2,8% con cortes parciales, el 2,2% con cortes profundos, el 9,3% con el tronco completamente cortado y el 16,7% muertos debido a causas naturales. *C. tagal* fue la especie más presionada por causas naturales y humanas. Estos resultados proporcionan un buen nivel de conservación de los manglares estudiados; sin embargo, es necesario fortalecer las acciones destinadas a una mayor conservación, reduciendo así la presión humana sobre manglares.

Palabras clave: Composición; manglares; extracción; curva de rarefacción; Mozambique.

1. Introduction

The mangrove is a coastal ecosystem located in tropical and subtropical regions, occurring near the mouths of rivers, estuaries, and coastal lagoons, even where there is influence of tides (Schaeffer-Novelli, 1989). This plant formation covers a global area estimated at 13.776,000 ha, with Asia being the continent with the largest area (Giri et al., 2011), followed by Africa (2.935.120 ha) with 20% of global mangroves, 74% on the west coast and 26% on the east coast (Bunting et al., 2022; Naidoo, 2023). In Africa, Mozambique has the second largest mangrove area on the continent (second to Nigeria with 844,200 ha), and the largest in the eastern region of Africa, with an estimated coverage of just over 300.000 ha, corresponding to approximately 2.3% and 10.2% of the mangrove forest area in the world and Africa (Giri et al., 2011; Fatoyinbo & Simard, 2013; Bunting et al., 2022), with the central coastal zone of the country having the largest area, followed by the north and south coast (Barbosa, Cuambe & Bandeira, 2001; Macamo et al., 2016b).

In Mozambique, mangroves remain poorly documented, and one of the causes that may explain this scenario is their inaccessibility in some regions, especially during the rainy season. Despite this, at least eight species of mangroves have been documented or are expected to occur in Mozambique, namely: *Avicennia marina* (Forssk.) Vierh., *Bruguiera gymnorrhiza* (L.) Lam., *Ceriops tagal* (Perr.) C.B. Robinson, *Heritiera littoralis* Dryand. ex Aiton, *Lumnitzera racemosa* Willd., *Rhizophora mucronata* Lam., *Sonneratia alba* J. Smith, and *Xylocarpus granatum* J. Koenig, representing about 19% of global true mangrove diversity (Bentjee & Bandeira, 2007; Spalding, Kainuma & Collins, 2010). However, despite the country's relatively considerable richness, there are still few regions where inventories have been carried out.

As in many parts of the world, in Mozambique, the mangrove ecosystem is an important source of resources and services that satisfy human needs in the social, economic, and ecological dimensions (Taylor, Ravilious & Green, 2003; Walters et al., 2008; Giri et al., 2011). However, despite this notable importance, in

Mozambique, the pressure on this ecosystem is relatively high, through the unrestrained extraction of vegetable fuel, construction material, wood for furniture production, construction of salt pans, and subsistence agriculture (Saket & Matusse, 1994), land use, and land cover changes, as well as global climate change (Francisco, Ribeiro & Sitoe, 2008). The fact that this ecosystem is frequently degraded by various human activities makes baseline biodiversity surveys even more urgent.

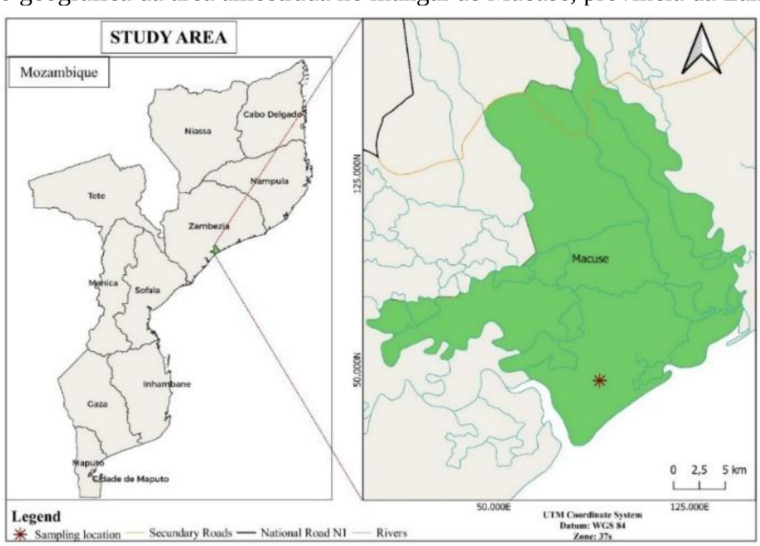
Among the notable works published for the country are: species surveys (e.g., Barbosa, Cuambe & Bandeira, 2001; Mandlate, 2013; Cuamba, Vieira & Morgado, 2019), structure and biomass (Bandeira et al., 2009; Trettin, Stringer & Zarnoch, 2016; Machava António et al., 2022), carbon estimation (Mandlate, 2013; Sitoe, Mandlate & Guedes, 2014), cover change (Francisco, Ribeiro & Sitoe, 2008), genetic diversity (Amade, Oosthuizen and Chirwa, 2021), spatial dynamics (Macamo et al., 2018), cut levels (Balidy et al., 2005; Cuamba, Vieira & Morgado, 2019; Miguel, Armazia & Miguel, 2024), rehabilitation (Bandeira & Balidy, 2016), reproduction and phenology (Amade et al., 2019), species decomposition (Fernando & Bandeira, 2010), and mangrove responses to the effects of climate change (Macamo et al., 2016) and anthropogenic activities (Charrua et al., 2020; Lacerda & Andrade, 2022; Come et al., 2023).

However, even with these laudable efforts, mangroves in southern Zambezia remain poorly known, especially about diversity, distribution, and conservation status. It is in this context that we focus on this important biotope and evaluate the mangrove that occurs in the administrative post of Macuse, in terms of composition, diversity, and conservation status. This work is an important contribution to expanding knowledge about the distribution of mangrove species in Mozambique and, particularly, in the southern Zambezia province, where studies with this plant formation are rare. Furthermore, this work constitutes a starting point to guide the development of actions that enhance the conservation and monitoring of this important ecosystem, considering the reduction in the mangrove area due to anthropogenic factors.

2. Material and methods

The study was conducted in the administrative post of Macuse, district of Namacurra, province of Zambezia, coastal area of Mozambique, between the parallels 17.7977S and 37.1827E, during the dry season, from July 31 to August 5, 2021 (Figure 1).

Figure 1. Geographic location of the sampled area in the Macuse mangrove, Zambezia province, Mozambique.
Figura 1. Localização geográfica da área amostrada no mangal de Macuse, província da Zambézia, Moçambique.



2.1. *Data collection*

For data collection, five sampling points were selected based on random sampling, from which transects were established perpendicular to the coastline with a separation of 100 meters from each other, where plots measuring 20 m x 20 were demarcated, distanced from each other to another for 50 m (Adapted from Cuamba, Vieira & Morgado, 2019).

The species and number of individuals were recognized and recorded in each plot. Species composition was determined using identification guides (Beentje & Bandeira, 2007), with support from the local community. The assessment of the conservation status of the mangrove consisted of quantifying and grouping individuals and tree species into categories of cutting levels: intact (uncut), partial cutting (25% of branches cut), deep cutting (75% of branches cut), completely cut (stump) and death from natural causes (Macamo et al., 2008; Cuamba, Vieira & Morgado, 2019).

We list their common names in Portuguese (the official language of Mozambique), and Echuwabo (the local language spoken in the Macuse, in that order). We primarily used the Portuguese names listed by Bentjee & Bandeira (2007). When the name is not available, it is indicated as unknown.

2.2. *Data analysis*

The Relative abundance (AR) was calculated based on the following equation: $AR = Aabs/Ntpha * 100\%$; where: AR = relative abundance of the ith species; Ntpha = total number of individuals found in the sampled area; Aabs = absolute abundance as described above (Mueller-Dombois & Ellenberg, 1974).

Species richness was based on rarefaction curves (interpolation and extrapolation method). Rarefaction curves represented standardized abundances of individuals (standardized sample size estimates) and measures of sample coverage (sample completeness; Chao & Jost, 2012). The confidence intervals (95%) associated with the curves were estimated based on the bootstrap method (1000 randomizations). Analyses were performed in iNEXT online (iNterpolation and Extrapolation) (Chao, Ma & Hsieh, 2016).

The diversity was calculated based on the Shannon-Weaver index (H') and Pielou's evenness index (C):

$$H' = -\sum p_i \ln(p_i) \, ; C = \frac{H'}{ln\,(S)};$$

where: H' is the Shannon-Weaver diversity index; pi is the proportion of the number of individuals of species i in relation to the total number of individuals; ln is the natural logarithm; C is Pielou's evenness index, and S is the number of sampled species (Pielou, 1977).

The Shannon-Weaver diversity index is a relative index used to compare diversity between different forest types, being the most used because it incorporates both richness and evenness. The higher the index value, the greater the floristic diversity. The average value of this index is between 1.5 and 3.5; below 1.5 can be considered low and above 3.5 as high, although it is rarely greater than 4.5 (Nascimento, 2001) and is sensitive to the presence of species with poor coverage. Marangon et al. (2007) warn that, in addition to the floristic dissimilarities of different communities, the variation in the values of diversity indices may be mainly related to differences in succession stages added to discrepancies in sampling methodologies, inclusion levels, taxonomic effort. Pielou's index measures uniformity between communities (Pielou, 1977).

The index value ranges between zero (0) and one (1), where one (1) represents maximum diversity, that is, all species are equally abundant. Low evenness can be attributed to few species that occurred with a high number of individuals. According to Uhl & Murphy (1981), equability is directly proportional to diversity and antagonistic to dominance. The conservation status of the forest is considered good when the percentage of intact and partially cut individuals corresponds to 50% of the total, acceptable if both levels of cutting correspond to between 40 and 50%, intermediate when the sum of intact and partially cut individuals corresponds between 30 to 40%, and bad when the number of intact individuals is below 30% of the total number of individuals (Cuamba, Vieira & Morgado, 2019).

3. Results

A total of 14.116 individuals belonging to eight species, eight genera, and six families were recorded in 76 plots (Table 1).

Table 1. List of mangrove species recorded in Macuse, coastal Mozambique, with common names in Portuguese and the local language (Echuwabo), provided when possible.
Tabela 1. Lista de espécies de mangais registadas em Macuse, costa de Moçambique, com nomes comuns em português e na língua local (Echuwabo), fornecida quando possível.

Taxon	Common name	Local name	Nr of individuals
Avicenniaceae			
Avicennia marina (Forssk.) Vierh.	Mangal branco	Inveve	6.331
Rhizophoraceae			
Bruguiera gymnorrhiza (L.) Lam.	Mangal vermelho	Mukamuchena	28
Ceriops tagal (Perr.) C.B. Robinson	Mangal branco	Laka-laka	6.647
Rhizophora mucronata Lam.	Mangal vermelho	Impizi	545
Sterculiaceae			
Heritiera littoralis Dryand. ex Aiton	Mangal Moçambique	Mologo	16
Combretaceae			
Lumnitzera racemosa Willd.	Mangal preto	Unknown	12
Sonneratiaceae			
Sonneratia alba J. Smith	Mangal maçã	Mukata	83
Meliaceae			
Xylocarpus granatum J. Koenig	Mangal bola-de-canhão	Mutalamada	454
Total number of individuals (N)			14.116

Table 1 highlights the following: Rhizophoraceae (3 species), Avicenniaceae (1), Sterculiaceae (1), Combretaceae (1), Sonneratiaceae (1), and Meliaceae (1). *Ceriops tagal* (47%) and *Avicennia marina* (44.8%) were the most abundant species, while *Heritiera littoralis* (0.11%) and *Lumnitzera racemosa* (0.9%) were the least abundant.

3.1. *Diversity*

The rarefaction curve reached an asymptote, indicating a low probability of recording new species even with additional sampling effort (Figure 2). The coverage analysis of compiled data suggests that these eight species records represent 100% of the mangroves for the sampled conditions (Bootstraps = 1000; confidence level = 95%, Figure 3).

Figure 2. Species richness for mangroves recorded in Macuse, coastal of Mozambique, using the rarefaction (interpolation and extrapolation) method based on the abundance of individuals. We used 1000 bootstrap replicates and a 95% confidence level.

Figura 2. Riqueza de espécies para mangais registrados em Macuse, litoral de Moçambique, utilizando o método de rarefação (interpolação e extrapolação) baseado na abundância de indivíduos. Usamos 1000 réplicas de bootstrap e um nível de confiança de 95%.

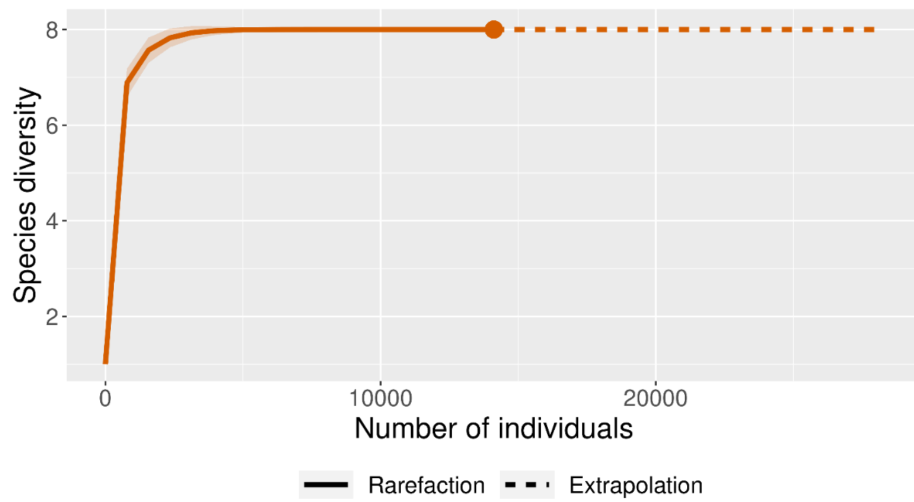
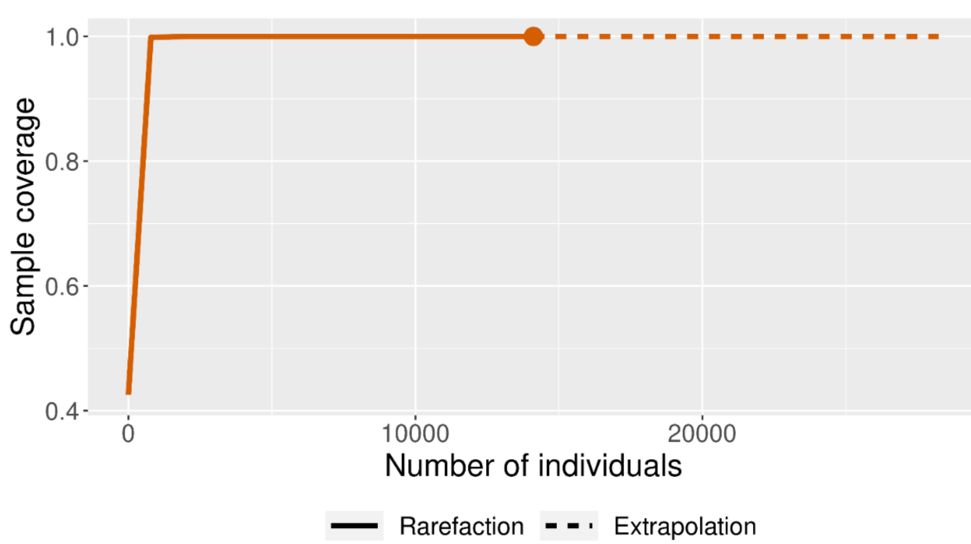


Figure 3. Sampling coverage level of mangrove species recorded in Macuse, Mozambique's coast, using the rarefaction method (interpolation and extrapolation) based on the abundance of individuals. We used 1000 bootstrap replicates with a 95% confidence level.

Figura 3. Nível de cobertura amostral das espécies de mangais registradas em Macuse, litoral de Moçambique, utilizando o método de rarefação (interpolação e extrapolação) com base na abundância de indivíduos. Foram utilizadas 1000 réplicas de bootstrap com um nível de confiança de 95%.

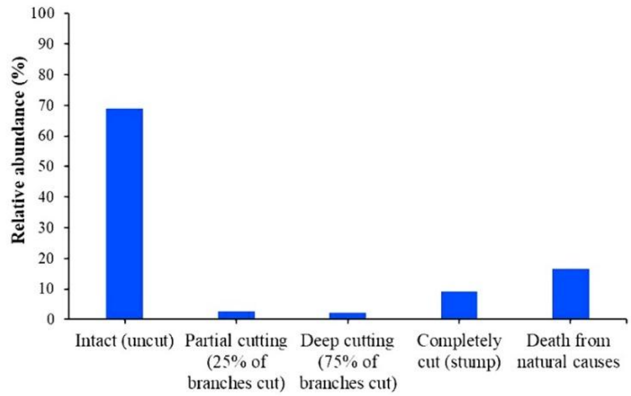


Our results also indicated that the Shannon-Wiener diversity for the Macuse mangrove was 1.0, and evenness was 0.5 for eight (8) species and 14.116 observed individuals.

3.2. *Conservation status*

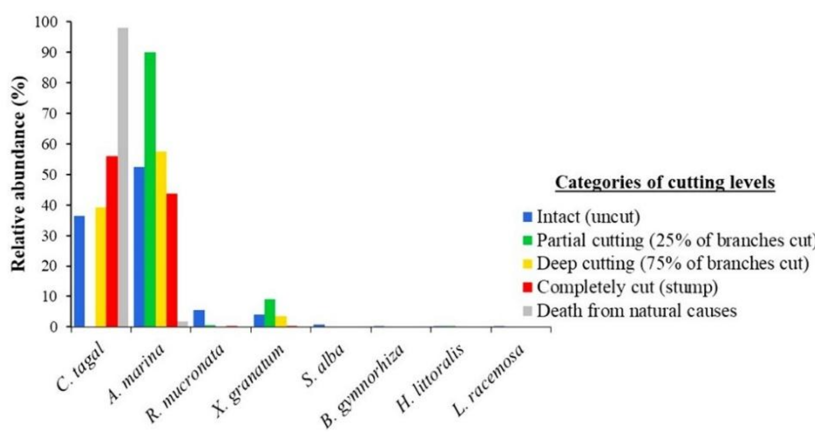
We recorded 69% of the individuals intact, 2.8% with partial cuts, 2.2% with deep cuts, 9.3% with the trunk completely cut, and 16.7% dead due to natural causes (Figure 4).

Figure 4. Conservation status by mangrove cutting levels in Macuse, coastal of Mozambique.
Figura 4. Estado de conservação por níveis de corte de mangais em Macuse, costa de Moçambique.



Regarding species, *A. marina* (52.6%) and *C. tagal* (36.4%) were those with the highest percentages of intact individuals. *A. marina* (90.1%) was the species with the highest percentage of individuals with partial cuts. *A. marina* (57.4%) and *C. tagal* (39.1%) were the species that presented the highest number of individuals with deep cuts, and they were also the species that presented the highest number of individuals with completely cut trunks, with 55.9% and 43.6%, respectively. Additionally, *C. tagal* (98.2%) was the species with the highest number of individuals dead due to natural causes (Figure 5).

Figure 5. Conservation status by mangrove species, in Macuse, coastal of Mozambique, from which *C. tagal* and *A. marima* stand out, as the species that suffered the most cutting pressure.
Figura 5. Estado de conservação por espécies de mangal, em Macuse, litoral de Moçambique, das quais se destacam *C. tagal* e *A. marima*, como as espécies que mais sofreram pressão de corte.



4. Discussion

Knowledge about mangroves in southern Zambezia remains insufficient and requires further research. The recorded number of species (eight species) indicates a high diversity for the area, representing the total number of species estimated for Mozambique (n = 8) and 47% for Africa (Beentje & Bandeira, 2007; Bunting et al., 2022; Naidoo, 2023). Most species have a wide distribution along the Mozambican coast (Barbosa, Cuambe & Bandeira, 2001; Alves & Sousa, 2007; Francisco, Ribeiro & Sitoe, 2008; Trettin, Stringer & Zarnoch, 2016; Macamo et al., 2018; Cuamba, Vieira & Morgado, 2019) and in some countries on the East African Coast (Kirui, 2013; Mangora et al., 2015). The prevalence of the Rhizophoraceae family in terms of composition is a common result in several other locations in Mozambique (Barbosa, Cuambe & Bandeira, 2001; CEAGRE, 2015; Trettin, Stringer & Zarnoch, 2016). All recorded species in this study are classified as Least Concern - LC (IUCN, 2024).

Analysing the rarefaction curve suggests that the sampling carried out in this study was sufficient to record most of the diversity of species present in the area. The species richness recorded in this study is relatively significant when compared to other inventories carried out in the north (Alves & Sousa, 2007 and Macamo et al., 2018, n = 5; Bandeira et al, 2009, n = 7; Cuamba, Vieira & Morgado , 2019, n = 6; Nicolau, 2016, n = 6), the centre (Mandlate, 2013; Sitoe, Mandlate & Guedes, 2014, n = 6; Anjos, 2011, n = 7) and southern Mozambique (Machava-António et al, 2022, n = 6; Zide & Rajkaran, 2015, n = 7); and similar richness was observed by Barbosa, Cuambe & Bandeira (2001) and CEAGRE (2015), n = 8 throughout the country and Trettin, Stringer & Zarnoch (2016), n = 8 in the Zambezi delta (centre of the country), indicating a high biological diversity at the site. It is important to emphasise that the lack of calculation of richness estimators and rarefaction curves in some previous studies limits the possibility of more precise comparisons. In addition, these differences in species richness between different regions can be attributed to variations in physical-chemical and environmental conditions, such as soil type and nutrient availability (Deshmukh, 1986; Lamprecht, 1990). Furthermore, the distribution and abundance of species are influenced by geographical and topographical characteristics, with the north and south of the country having sandy, coralline, and less diverse soils; and in the centre, richer and more varied soils, due to the influence of several nutrient-rich rivers and estuaries (Fatoyinbo et al., 2008), as is the case with the Macuse mangrove, which is essentially distributed throughout the Macuse River estuary and the Licungo River delta (MAE, 2005).

Regarding the conservation status, although it is considered relatively good (69% of intact individuals), several signs of human activities were observed, such as salt mines, the felling of trees for the production of vegetable fuel, and the construction of housing and furniture. These activities, if not controlled, can lead to the destruction of the few existing microhabitats for fauna species that use these environments for reproduction, feeding, nesting, and shelter (Schaeffer-Novelli, 1995) and cause a reduction in the diversity of plant species in the ecosystem itself, as well as the fauna that exists there and consequently lead to the disappearance of species of both flora and fauna before they are even recorded, along with all others already recorded. Furthermore, regardless of the scale, mangrove cutting can negatively affect the state of the forest, stimulating the growth of propagules and consequently reducing their production (Macamo et al., 2008).

Our results indicate that both *A. marina* and *C. tagal* are essential species in the Macuse mangrove, but also that these species are subject to different levels of human and natural impact. The cutting trend for *A. marina* and *C. tagal* is a result that was also observed by Lacerda & Andrade (2022) in the same ecosystem, although these authors used qualitative approaches. However, according to Kairo et al. (2002), this selectivity largely depends on abundance, availability, consistency, and cutting objectives. Therefore, *A. marina* and *C. tagal* are considered species with more applications in the different daily activities of the community in Macuse. In addition to providing wood for the production of furniture, they are used in the construction of houses, boats and as vegetable fuel (Lacerda & Andrade, 2022). Based on our results, to conserve Macuse's mangrove ecosystem, it is essential to strengthen the regulations that control logging, salt extraction, and construction in the area. Promoting sustainable alternatives for fuels and materials can reduce dependence on *Avicennia marina* and *Ceriops tagal*. Reforestation programs, with the active participation of the community, should prioritize these and other essential species. In addition, awareness campaigns and continuous monitoring are indispensable. Community involvement is central in drawing up plans that meet local needs. Implementing these actions is essential to preserve biodiversity and ecological services for future generations.

5. Conclusion

This work provides records that significantly expand knowledge about mangroves in Mozambique, particularly regarding their geographic distribution and conservation status. Both *A. marina* and *C. tagal* are essential species in the Macuse mangrove, but they are subject to different levels of human and natural impact. *C. tagal* was the species most pressured by these causes.

Additionally, this research can offer valuable information for mangrove conservation and sustainable management programs, ensuring their continued importance for local communities and the environment. However, while it provides relevant data, more research is needed to obtain more robust information on species richness and abundance, as well as to investigate further aspects of biology, ecology, and the possible occurrence of new records.

6. Acknowledgments

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