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A socio-ecological survey in Inhambane Bay mangrove ecosystems: Biodiversity, livelihoods, and conservation

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ABSTRACT

Mangroves are highly productive ecosystems that provide a variety of ecosystem services to local communities. Mangrove ecosystems are important blue carbon ecosystems that support unique fauna, flora, and livelihoods. The decline and degradation of mangrove populations, mostly due to anthropogenic impacts and climate change, necessitate protection worldwide. There is limited research on the conservation and management of these ecosystems in Mozambique. A combination of six biodiversity surveys, thirty-one semi-structured interviews and participant observation at six sites was used to describe and understand mangrove ecosystems in Inhambane Bay. This study is among the first to involve local community leaders as academic co-authors, thus highlighting the value of local ecological knowledge and community involvement, both of which are necessary for a comprehensive understanding of mangrove ecosystems. Social and ecological approaches were integrated to describe mangrove ecosystems, perceived ecosystem services and benefits to local communities. This study has identified areas of increased mangrove cover and areas with disturbance. Out of the seven mangrove species that occur in Inhambane Bay, *Avicennia marina* was the most abundant mangrove species in at least three sites, and *Xylocarpus granatum* the least abundant mangrove species, present only in two sites. Perceived benefits include provisioning, supporting and regulating services. Community initiatives to protect mangroves include enforcing environmental laws, prohibiting cutting mangrove trees, and replanting. This study shows that community initiatives for law enforcement and mangrove restoration play an important role in raising awareness and actively protecting mangroves.

1. Introduction

Local communities benefit from a wide range of ecosystem services offered by mangrove ecosystems (Millennium Ecosystem Assessment 2005). These ecosystems host a variety of fauna and flora that are critical for livelihoods, including invertebrates such as crabs, juvenile shrimps, juvenile and adult fish (Ewel et al., 1998; Dahdouh-Guebas et al., 2020). Additionally, several studies have highlighted the capacity of mangroves to store carbon (Alongi 2012) and the linkages of carbon processing in mangrove ecosystems with the ecosystem services they provide (Alongi 2012; Rogers et al., 2019).

Currently, mangroves are declining worldwide, with approximately 0.4% of losses per year, mostly due to anthropogenic pressures (Taillardat et al., 2018; Friess et al., 2019; Goldberg et al., 2020) and climate change impacts (Godoy and de Lacerda 2015; de Lacerda et al., 2022). Increased temperatures, changes in rainfall, sea level rise and increased

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frequency and severity of storms, negatively impact mangrove distribution and survival (Ward et al., 2016; Friess et al., 2020), and contribute to mangrove decline (Duke et al., 2007; Bandeira et al., 2009). Increased population growth in coastal areas, poverty, economic drivers, and increased unsustainable harvesting have also put these ecosystems at risk (Maina et al., 2021). The loss of mangroves threatens the ecosystem's ability to sustain several terrestrial and marine food webs, protection from sea-level rise and storm surges, fisheries, and the livelihoods of local communities (Ewel et al., 1998; Polidoro et al., 2010; Malik et al., 2017).

In recent years, mangroves have been considered a high-priority ecosystem in several major international conservation initiatives such as the Global Mangrove Alliance and the International Blue Carbon Initiative (Friess et al., 2020). Mangrove ecosystems occur in the tropics and subtropics and extend into the temperate zones (Bayen, 2012; Charrua et al., 2020). Around 20% of the world's mangrove area is found in Africa (Giri et al., 2011), while Mozambique has eight species of mangroves across approximately 3054 km^2 (Bandeira et al., 2009; Charrua et al., 2020). Here mangroves exist at the land-water interface, often in intertidal areas, including protected shorelines, deltas and estuaries (Barbosa et al., 2001). However, large mangrove stands, such as at Inhambane Bay which covers approximately 58 km^2, remain understudied despite their social, ecological and economic value. Local communities depend upon this habitat and have sought to establish, manage, and enforce nine no-take areas for harvest and fishing activities to protect the mangrove fauna and the juvenile reef fish that use the bay as a nursery habitat. The local Fisheries Council enforces these rules in cooperation with the Ministry of Fisheries (*Instituto Oceanográfico de Moçambique*) and the police (Polícia da República de Moçambique – PRM). Each community governs its designated area and has established no-take zones based on local ecological knowledge. Local ecological knowledge is generally described as "knowledge held by a specific group of people about their local ecosystems" (Olsson and Folke, 2001 p.87). Although conservation measures are in place and strict monitoring takes place, the effectiveness of these zones has not yet been quantified.

Ecological gaps in knowledge further exist regarding the marine ecosystems of Inhambane Bay. Day (1974) provided an extensive biodiversity list of the Morrumbene Estuary which feeds into the bay. In general, the lack of data related to the global impact of mangrove loss or change on local communities, including their livelihoods and well-being, poses unseen risks in policy decisions (Adhikari et al., 2019; Nyangoko et al., 2022). More recently, seagrass surveys have mapped biodiversity and change over time, linking ecology to social use and perceptions of communities (Barbosa et al., 2001; Chitará-Nhandimo et al., 2022).

Understanding local communities' perceptions of mangrove ecosystem services is critical for determining their role in conserving these ecosystems and incorporating their priorities and preferences into decision-making processes (Nyangoko et al., 2020). It is also necessary to understand communities' perspectives on mangrove cover change, their perceived benefits from mangrove ecosystem services, and underlying drivers (Quevedo et al., 2020). This paper aimed to explore the relationships between social and ecological perspectives of mangroves in Inhambane Bay. Thus, the objectives of this study were to (1) describe the mangrove ecosystems around Inhambane Bay, (2) understand community interactions and perceptions of these mangroves, and (3) identify future research areas based on community needs.

2. Materials and methods

2.1. Study area

The Bay of Inhambane is located in the province of Inhambane, in southern Mozambique, on the east coast of Africa. The bay is situated in the Western Indian Ocean (WIO) region and covers an area of 25,000 hectares, distributed in four of the 12 districts of the Inhambane Province (Table 1, Fig. 1). Of the eight mangrove species occurring in Mozambique (Bandeira et al., 2009), *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Rhizohora mucronata*, and *Sonneratia alba* are the most dominant species (Barbosa et al., 2001). The other, less common species are *Heritiera littoralis*, *Xylocarpus granatum,* and *Luminitzera racemosa*. A study conducted in Mozambique found that *Heritiera littoralis*, *Xylocarpus granatum*, and *Luminitzera racemosa* are declining in Inhambane Province (Barbosa et al., 2001).

The current Mozambican legislation on mangroves envisages community participation in the protection of natural resources through responsible, multi-sectoral, and multi-disciplinary management that includes actions by local communities, civil society organizations and local government (MIMAIP et al., 2020). The study was conducted in four districts around Inhambane Bay, with surveys in mangrove areas and interviews in villages in close proximity to mangrove areas (Table 1). Sites were selected to fully represent the mangrove spatial cover in the bay while including the diverse communities of individuals living in this area.

2.2. Data collection methods

This research forms part of a research project entitled '*Merging local knowledge with scientific study in Mozambican and South African mangrove habitats*', which runs from 2018 to 2024; and aims to understand the successful model of a community-led conservation initiative in southern Africa and multi-stakeholder collaboration. This research was conducted through a collaboration between various researchers from three universities, non-governmental organizations, a government department, and community members. Field trips were conducted in the districts of Inhambane (Guindzive, and Marrambone), Jangamo (Guiua), Maxixe and Morrumbene. These areas were selected to represent the extent of mangroves around the bay. At least one community member participated in each field trip, usually from the area where samples were collected. Field notes were recorded in detail and included the diversity of mangrove habitats, in addition to information on community use of resources associated with mangroves and conservation measures. Volunteers assisted the researchers in conducting the surveys and interviews.

A total of six biodiversity surveys were conducted every three months between February 2018 and July 2019 to allow for seasonal observations. For the physicochemical parameters, a Hanna HI 9829 MultiMeter probe was used to measure pore water in the mangroves. This included measurements of temperature (°C), salinity, pH, and dissolved oxygen. Tree surveys were conducted in three 5 × 5m quadrats at each site. Within each of the three quadrat, all trees were identified height, diameter at breast height (1.3 m), presence of flowers (an indication of reproductive activity), seedlings, and epifauna were recorded for all individual trees.

During faunal surveys, gastropod and brachyuran densities were determined by counting crab burrows and individuals at the surface, and by digging 2 cm below the surface to record all burrowing gastropods in 0.5 × 0.5 m sub-quadrats (3 per quadrat) placed within the broader 5 × 5 m quadrat. Crab burrows were identified based on size, shape, pellets, and observation of emergent species. Individuals were identified using Branch et al. (2010) and Richmond (2011).

Table 1
Location of the surveys and interviews in the districts of Inhambane, Maxixe, Morrumbene and Jangamo around Inhambane Bay.

Districts of Inhambane Bay	Mangrove biodiversity surveys	Interviews in the community areas
Inhambane	Inhambane, Guindzive, Marrambone	Inhambane (Guindzive, Muelé, Nhampossa, Liberdade)
Maxixe	Maxixe	Maxixe (Chambone)
Morrumbene	Morrumbene	Morrumbene (Cocane)
Jangamo	Guiua	Nhaduga and Madava

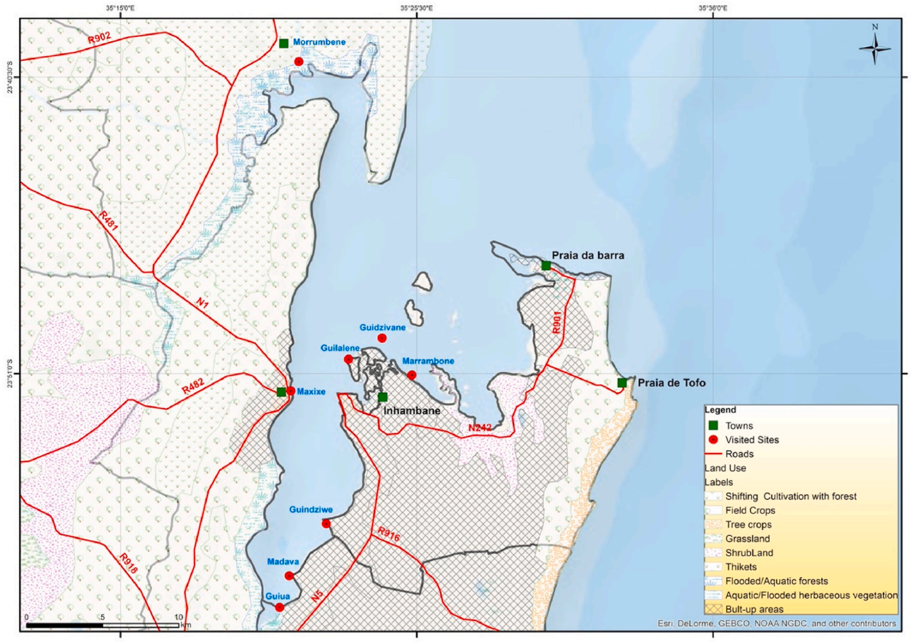

Fig. 1. Location of Inhambane Bay in Southern Mozambique. The study comprised the districts of Inhambane city, Jangamo, Maxixe and Morrumbene, represented in the map (Data from the National Cartography and Remote Sensing Centre in Mozambique - CENACARTA).

Statistical analyses were conducted to describe mangrove forest structure using the mangroveStructure package (Araújo and Shideler 2019) in R (R Development Core Team 2021) to examine height, DBH, basal area, abundance, density, importance value of each species, and Holdridge complexity index. Basal area (dominance) refers to the total area occupied by the stems of a species, abundance was determined by the percentage of plots in which a given species was recorded, while density refers to the number of stems per unit area (Araújo and Shideler 2019). The relative dominance, relative abundance, and relative density were then summed to calculate the importance value of each species to each respective site (Curtis 1959). The Holdridge's Complexity Index was calculated as follows:

$$HCI = H \times BA \times D \times N$$

Where H refers to average height (m), BA indicates basal area (m^2/0.1 ha), D indicates density (ind/0.1 ha), and N indicates the number of species (Holdridge 1967).

Community interviews were conducted in October 2019. A total of 31 semi-structured interviews were conducted in four districts spread over eight areas of Inhambane Bay (Fig. 1). The purpose of the interviews were to understand communities' perceptions of the mangrove ecosystems, the benefits derived from these ecosystems, and their initiatives to conserve mangroves. An interview guide was used that included questions on the changes in mangrove areas over the last 50 years. The questions asked how the mangroves trees have grown bigger or have reduced in areas; if local communities harvest or use mangroves; if these uses have changed over the years and how the changes occurred; and if the local communities contribute to preserve mangroves. Three to seven interviewees, conducted in either Guitonga or Portuguese, depending on the respondent preference, were selected at each site using the snowball method. A total of nine women between the ages of 30 and 65 years were interviewed, most of them fishers, harvesters, and seafood vendors. A total of 22 men between the ages of 26 and 80 were also interviewed, who were either current or former fishers, vendors, sailors, boat carpenters, local leaders, and members of Community Fishing Councils (CCP). The CCP members comprises a individuals identified by a group or association, with a clear organizational structure (presidents by regions, secretaries, vocals, treasurers) and responsibilities to manage and promote the protection of the coastal and marine resources in the bay, with focus on fishing activities. This includes fishers (active and former fishers), sailors, vendors and fiscals. During the interviews, the largest age group was between 46 and 65 years old (61%), followed by 25–45 years old (26%) and the 66–80 years old age group (16%). Topics raised in the interviews included mangroves protection and benefits, establishment and management of nursery areas, and the role of CCPs in natural resource management in the Bay. The consent form was explained by the interviewer prior to the interviews and signed by all respondents. Responses were recorded using a portable recording device and by taking notes during the interviews. These were later transcribed and coded using computer-assisted qualitative data software, Atlas.ti (version 9). Patterns of words and phrases were assessed using Atlas.ti graphical representations in the form of charts or word clouds. Word clouds are visual representations of words, in which attributes of the text, such as size, weight, or colour, can be used to summarize text through patterns and represent importance among items (Barth et al., 2014).

3. Results

3.1. Description of the mangrove ecosystem and its uses

A total of seven mangrove tree species were recorded, i.e., *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Lumnitzera racemosa, Rhizophora mucronata, Sonneratia alba,* and *Xylocarpus granatum*. The survey data showed that Maxixe had the lowest species richness with only four mangrove species, while Guiua and Morrumbene had seven species each (Fig. 2). At three of the sites, namely Guindzive, Maxixe and Inhambane, *A. marina* was the most abundant mangrove species. *Ceriops tagal* was most abundant at the southernmost and northernmost sites, i.e., Guiua and Morrumbene with *Rhizophora mucronata* dominating in Guiua. While *B. gymnorrhiza* was predominant in Marrambone, *S. alba* was most abundant in the two urban sites. Overall, *Xylocarpus granatum* was the least abundant and present only in Guiua and Morrumbene (Fig. 2).

Regarding DBH, the surveys revealed that Guiua and Maxixe had the highest average values (+SE), 5.00 (±0.51) cm and 6.94 (±0.97) cm, respectively. Marrambone had the lowest value with 0.33 (±0.06) cm mean DBH. Conversely, Marrambone had the highest stand density

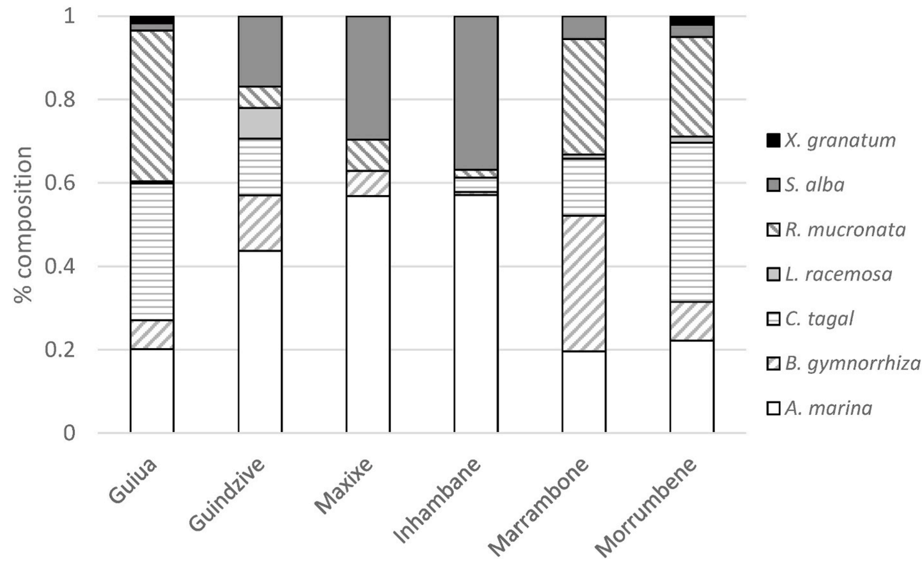

Fig. 2. Percentage composition of mangrove tree diversity and abundance at each of the six sampling sites.

(13390 ind./0.1 ha), while Maxixe had the lowest (2940 ind./0.1 ha). Complexity indices show that Guiua and Morrumbene are the most complex stands, while Inhambane and Marrambone are the least complex despite their high densities (Table 2).

At most sites, either *A. marina* or *S. alba* had the highest importance scores (Table 3). *Rhizophora mucronata* ranked high in Guiua along with *C. tagal*, while at Marrambone *R. mucronata* and *B. gymnorrhiza* also ranked (>50) and led in frequency and density (Table 2).

Mangrove trees are harvested for timber and firewood. The entire tree is rarely cut down, with harvesters usually opting to remove a few branches per tree. It was noted that mangroves had previously been cut down in the urban centre of Inhambane for aesthetic reasons. However, this was no longer considered acceptable, and at the time of sampling, replanting initiatives (mainly using *A. marina* and *S. alba* seedlings) were underway.

3.2. Faunal occurrence and uses

Faunal surveys revealed that *Dotilla fenestrata* was the most abundant brachyuran on average, primarily due to the high density of Maxixe populations (216 ± 53 ind.m^{-2} -Table 4). The most abundant gastropoda, *Terebralia palustris*, had a maximum average density of 181 ind. m^{-2}. The most urbanised sites (Inhambane and Maxixe) had the lowest species richness (Table 4) but the highest abundance of key brachyuran species including *D. fenestrata*, *Metopograpsus cannicci*, *Austruca occidentalis*, *Paraleptuca chlorophthalmus*, *Tubuca urvillei*, *Parasesarma guttatum*.

The fiddler crab *A. occidentalis,* and the sesarmid *Parasesarma guttatum* were the most widespread brachyurans occurring at all six sites (Table 4). The giant mangrove whelk *Terebralia palustris,* the truncated mangrove whelk *Cerithidea decollata,* and two littorinid species (*L. subvittata* and *L. pallescens*) were also found at all sites. A few species were present consistently over time but had limited distribution, such as *Cranuca inversa,* which was found at only one partial site in the Marrambone sampling area. Similarly, *Chiromantes eulimene*, *C. ortmanni*, and *S. crassum* were found only at a subsite in Morrumbene. The haminoeid *Haminoea natalensis* was present in Guiua but was not counted because of its sporadic occurrence.

Information from interviews and field observations indicate that *Terebralia palustris* is a food item. The shells of this species are also mixed into concrete and used as pavement. Mangrove crabs are generally not consumed, with the exception of *Scylla serrata,* which was found at all sites, although it could not be quantified (Table 4). In this case, predominantly male harvesters were observed digging up crabs in the mangroves (N. Peer, pers. obs.).

3.3. Community perceptions of mangrove ecosystem services

The responses from the respondents provided information about their perceptions of changes to mangroves in the Bay over the past fifty years. Responses indicated that 61% of respondents perceived an expansion of mangrove cover (Fig. 3), particularly in Inhambane (in Nhampossa, Muelé, and Liberdade), Maxixe (Chambone), Morrumbene (Cocane), and Jangamo (Madava and Nhaduga). While 13% of respondents reported that mangrove cover had declined, mainly due to illegal logging and erosion. Perceptions of changes in mangrove areas varied among respondents, even in the same areas, as in the case of Inhambane (Guidzivane), where no changes in mangrove areas, expanded mangrove areas, and no mangroves in the area were reported.

As shown in Fig. 4, 45% of the respondents were aware of the

Table 2
Mangrove height, density, cover and complexity value for each site. Standard error is presented in brackets for averages. 'n' refers to the number of trees measured while 'Q' represents the total number of quadrats.

	Guiua		Guindzive		Maxixe		Inhambane		Marrambone		Morrumbene	
	n = 243	Q = 15	n = 391	Q = 18	n = 132	Q = 18	n = 479	Q = 18	n = 603	Q = 18	n = 398	Q = 18
Mean DBH (cm)	5.00 (0.51)		1.21 (0.17)		6.94 (0.97)		1.16 (0.12)		0.33 (0.06)		2.50 (0.41)	
Mean height (m)	3.10 (0.20)		1.17 (0.06)		2.69 (0.18)		1.28 (0.05)		0.86 (0.03)		1.53 (0.10)	
Canopy height (m)	14.07		8.1		8.1		6.2		6.09		13.33	
Stand density (ind/0.1ha)	6490		8690		2940		10650		13390		8840	
Basal area (m^2/0.1 ha)	45.25		8.49		39.64		6.82		2.16		51.43	
No. of species	7		6		4		5		6		7	
Complexity index	289.99		36.46		37.86		22.37		12.61		363.95	

Table 3
Percentage of relative dominance, relative frequency and relative density of each species at each site along with the importance value. Note that 'p' is used to represent where the species was present, but data were not collected.

Sites	%	*A. marina*	*B. gymnorrhiza*	*C. tagal*	*L. racemosa*	*R. mucronata*	*S. alba*	*X. granatum*
Morrumbene	Dominance	88.8	1.4	1.3	0.1	0.8	7.5	p
	Frequency	26.6	14.1	25	3.1	21.9	9.4	
	Density	22.2	9.3	38.2	1.5	23.9	5	
	Importance Value	**137.6**	**24.8**	**64.5**	**4.7**	**46.6**	**21.9**	
Marrambone	Dominance	0	0	0	1.8	0	98.2	–
	Frequency	16.4	21.8	12.7	3.6	29.1	16.4	
	Density	19.6	32.6	13.7	1	27.7	5.5	
	Importance Value	**36**	**54.4**	**26.4**	**6.4**	**56.8**	**120.1**	
Inhambane	Dominance	35.7	0	0.5	–	0.3	63.4	–
	Frequency	30	7.5	12.5		12.5	37.5	
	Density	57.2	0.7	3.4		1.9	36.9	
	Importance Value	**122.9**	**8.2**	**16.4**		**14.7**	**137.8**	
Maxixe	Dominance	56.9	0.3	–	–	0.1	42.8	–
	Frequency	44.1	2.9			8.8	44.1	
	Density	56.8	6.1			7.5	29.6	
	Importance Value	**157.8**	**9.3**			**16.4**	**116.5**	
Guindzive	Dominance	35.8	8.2	2.8	3	0	50.2	–
	Frequency	19	16.7	21.4	7.1	11.9	23.8	
	Density	43.7	13.3	13.6	7.4	5.1	16.9	
	Importance Value	**98.5**	**38.2**	**37.8**	**17.5**	**17**	**90.9**	
Guiua	Dominance	63.1	2.1	5.2	0.1	18.2	10.1	1.3
	Frequency	29.5	9.1	22.7	2.3	22.7	9.1	4.5
	Density	20.2	6.9	32.8	0.5	36.2	1.7	1.7
	Importance Value	**112.8**	**18.1**	**60.7**	**2.9**	**77.1**	**20.9**	**7.5**

provisioning services provided by the mangroves and indicated that the mangroves were a source of food, income, and construction materials. While 24% of respondents mentioned supporting services, indicating that mangroves serve as nursery, breeding, and feeding areas for various faunal species, 12% mentioned regulating services such as protection from waves and wind, and 7% mentioned protection from erosion. While 7% of respondents could not name any benefits they would receive from mangrove ecosystems because there are no mangroves near their areas. None of the respondents mentioned cultural services provided by mangrove ecosystems.

The results from the interviews further indicated that the benefits of mangroves are commonly known by some of the respondents. This includes regulating services (e.g. coastal protection from storms, flooding, sea level rise and erosion), supporting services (e.g. nursery and breeding habitats for several fauna), provisioning services (e.g. food, firewood, poles for building houses and boats, and fish traps). Despite the widespread awareness of mangrove ecosystem services, responses indicated a decline in the use of provisioning services (e.g. food and construction material). As shown in Fig. 5, 16% of respondents stated that they do not use mangroves for food or raw materials, 57% of respondents mentioned cutting mangroves for firewood, and 5% of respondents mentioned harvesting salt as old practices. To this end, 13% of respondents mentioned harvesting crabs and snails, and 3% of respondents mentioned collecting fish bait.

3.4. Regulations and community perceptions regarding mangrove conservation

The protection and conservation of mangroves in Mozambique falls under the wetlands legislation, which includes the Forest and Wildlife Act (No. 10 1999), and the Environmental Law (No. 20 1997), under the regulation 45/2003, which ratifies the Ramsar Convention. Currently, Mozambique is implementing the Mangrove Strategy 2020–2024 (MIMAIP et al., 2020), for the effective management of mangrove ecosystems. This includes the dissemination of the global and national value of these ecosystems, causes of degradation, restoration initiatives at the local level and law enforcement. Harvesting activities are monitored by Community Fishing Committees (CCP) in each area. The Inhambane CCP has the official support of the Provincial Directorate of Fisheries, and the Maritime Police Department which assists in conducting routine patrols of the bay. As shown in Fig. 5, most of the respondents were aware of the need for community initiatives to conserve mangroves. Awareness of the benefits of mangroves and the expansion of mangrove areas were mentioned most frequently by respondents.

Local community members were aware of mangrove conservation initiatives. Interviews (Fig. 6) revealed that 56% of respondents knew that mangrove logging was prohibited in Inhambane Bay. While 14% explained the process of obtaining written permits for logging dried and damaged mangroves. Still, 18% mentioned the campaigns to raise awareness of the importance of mangroves and the need to protect these ecosystems in a collaboration with the local government and bridging organizations. Moreover, 12% of respondents referred to the sanctions imposed by local communities and local government for illegal mangrove deforestation. These range from arrest to reporting to the Captaincy (Maritime Authority), a temporary ban on fishing or harvesting natural resources, and fines. Finally, 21% of respondents indicated that dried and damaged mangroves can be cut under requests made in collaboration with the Community Fishing Councils (CCPs), and written permits are issued by the local provincial fisheries department office. After the ban on mangrove clearing, it was reported that many areas in Inhambane Bay have been recovering, and the mangrove population is expanding.

Community participation in mangrove conservation is the result of community meetings and awareness campaigns conducted by CCPs. Community members report mangrove cutting to CCPs and local authorities and participate in apprehending illegal users. Of the 31 respondents, 42% referred to community enforcement in the form of reporting to local authorities, setting sanctions related to fishing activities, and punishment. Protection was more effective in some areas than others, due to local conflicts surrounding overfishing areas and

Table 4
Overall presence and abundance (ind.m^{-2}) of brachyurans and gastropods at six mangrove sites within Inhambane Bay. Numbers represent averages with standard error in brackets. Where counts were not possible, a 'p' is used to denote presence.

	Guiua	Guindzive	Maxixe	Inhambane	Marrambone	Morrumbene
Brachyura						
Dotillidae						
Dotilla fenestrata	–	31 (8)	216 (53)	57 (9)	32 (4)	–
Grapsidae						
Metopograpsus cannicci	6 (1)	2 (0.4)	9 (1)	–	4 (1)	5 (1)
Macrophthalmidae						
Macrophthalmus (Macropthalmus) grandidierii	–	3 (0.3)	10 (4)	10 (1)	–	8 (1)
Macropthalmus (Mareotis) depressus	–	6 (1)	–	7 (1)	2 (1)	–
Chaenostoma sinuspersici	–	1 (0.4)	–	–	7 (1)	11 (1)
Ocypodidae						
Austruca occidentalis	24 (3)	21 (2)	113 (32)	26 (3)	23 (2)	16 (1)
Paraleptuca chlorophthalmus	11 (1)	2 (1)	44 (7)	–	12 (1)	19 (3)
Tubuca urvillei	7 (2)	2 (1)	13 (1)	–	2 (0.5)	5 (1)
Gelasimus hesperiae	–	5 (2)	7 (4)	–	3 (1)	3 (1)
Cranuca inversa	–	–	–	–	7 (1)	–
Oziidae						
Epixanthus frontalis	–	–	4 (1)	1 (0.3)	–	–
Pilumnidae						
Eurycarcinus natalensis	1 (0.2)	–	1 (1)	1 (0.2)	–	2 (1)
Portunidae						
Scylla serrata	p	p	P	p	P	p
Sesarmidae						
Parasesarma guttatum	6 (1)	5 (1)	30 (7)	5 (1)	7 (1)	8 (1)
Selatium brockii	3 (0.3)	2 (1)	–	–	–	–
Neosarmatium africanum	10 (6)	1 (0.3)	–	–	5 (1)	2 (1)
Chiromantes eulimene	–	–	–	–	–	7 (0.3)
Chiromantes ortmanni	–	–	–	–	–	2 (0.5)
Sarmatium crassum	–	–	–	–	–	6 (1)
Gastropoda						
Assimineidae						
Assiminea sp.	–	–	–	2 (1)	–	49 (32)
Cerithiidae						
Cerithium dialeucum	–	–	–	1 (0.2)	–	29 (4)
Ellobiidae						
Cassidula labrella	17 (8)	8 (3)	–	–	–	–
Haminoeidae						
Haminoea natalensis	p	–	–	–	–	–
Littorinidae						
Littoraria subvittata	p	p	p	p	p	p
Littoraria pallescens	p	p	p	p	p	p
Littoraria scabra	–	p	p	p	p	p
Littoraria coccinea glabrata	–	–	–	p	–	–
Littoraria intermedia	–	–	p	–	–	–
Potamididae						
Cerithidea decollata	26 (4)	20 (4)		20 (7)	17 (1)	12 (2)
Terebralia palustris	–	24 (3)	19 (4)	81 (9)	93 (15)	53 (17)

temporary closure mechanisms for harvesting and fishing areas. Mangroves were also not evenly distributed across the bay, as in the case of some coastal areas of Guidzivane where there were no mangroves at all due to erosion.

3.5. Causes of mangrove decline

Despite widespread awareness of the benefits of mangroves and the ban on mangrove clearing, mangrove conservation is not evenly distributed. In some cases, mangroves are being destroyed by people from other areas, without any community enforcement to protect the mangroves, as in the case of Madava. Coastal erosion has also been cited as a cause of mangrove decline in some areas. The increased occurrence of extreme events such as tropical storms and altered ocean currents as a result of climate change was also cited as a reason for mangrove damage in some areas, with 4% of respondents referring to the destruction of mangrove areas by Cyclone Dineo in 2017.

3.6. Mangrove rehabilitation initiatives

The respondents from the interviews cited mangrove rehabilitation initiatives that included replanting programmes, awareness, and enforcement. These initiatives were perceived to be effective in preventing coastal erosion and protecting homes from flooding in many areas of the Bay, particularly in Mucucune. Mangrove reforestation was carried out by communities with the support of CCPs, and in collaboration with provincial and local government representatives, the Fishing Provincial Directorate, and the District Services of Economic Activities. Seedlings were provided by the local government. CCPs conducts awareness campaigns on mangrove conservation, with youth and school children being the most involved. Mangrove seedlings were provided by community greenhouses located in the Inhambane districts. According to the respondents, the establishment of greenhouses in the districts results from a collaboration between the local government and community members (INH10, fisher in Mucucune).

Fig. 7 represents the responses of respondents (n = 31) on their perceived benefits of mangrove ecosystems, the need for conservation and protection, impacts on mangrove ecosystems, and current management initiatives undertaken by both local government and communities. It shows the community perceived relationships and linkages between mangrove ecosystems.

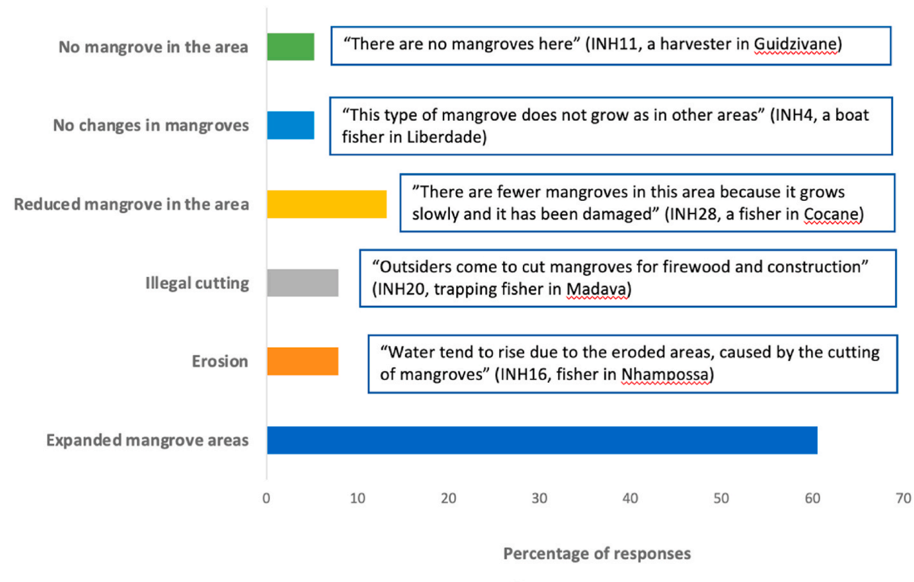

Fig. 3. Community perceptions on changes in Inhambane Bay over the last fifty years. The quotes represent direct translations from interviews conducted in Portuguese and Guitonga. A total of 38 responses were provided from the 31 interviewees (n represents the number of responses, n = 38).

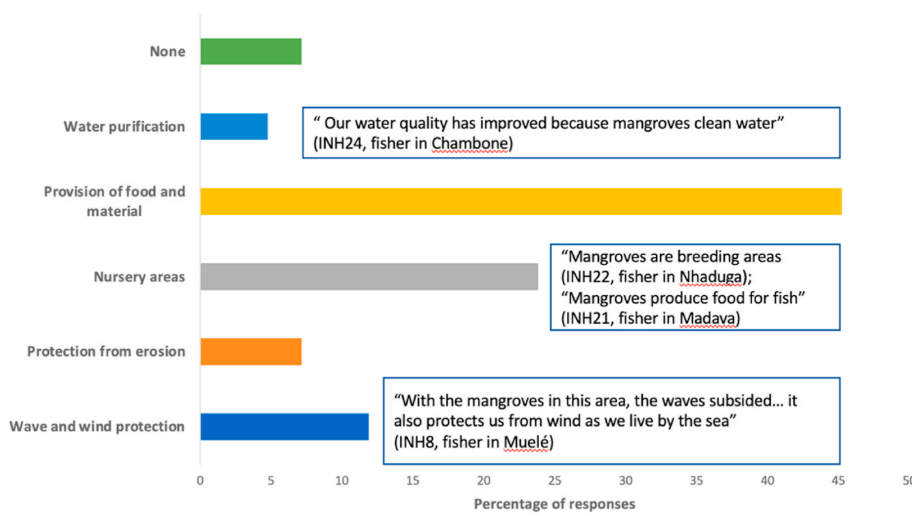

Fig. 4. Perceptions of local communities on the benefits they obtain from mangrove ecosystems. The quotes represent direct translations from interviews conducted in Portuguese and Guitonga (n represents the number of responses, n = 42).

4. Discussion

4.1. Tree complexity reflects human use (zones)

The towns of Inhambane and Maxixe (Fig. 1) have infrastructure designed to serve the functions of a heavily populated centre. Based on field observations, commercial and residential buildings have been built on the edge of the mangroves. There are ports for the ferry that crosses the bay and connects the two towns, and fishing/harvesting is done daily. Beyond these towns, smaller communities utilise the littoral zone. Pathways are carved by people walking to and from the water, houses are less likely to be built of concrete, and fishing/harvesting are still regular activities. At the far ends of the bay, where two major rivers enter the system (the Nhanombe River to the south and the Mutamba River to the North), there exist lesser-used mangrove areas. Guiua and Morrumbene are well-used but are less impacted by humans. In some areas, the mangrove stands are dense and are consequently not traversed by humans. The highly relative dominance and highest important score of *A. marina* or *S. alba* mangrove species, most likely results from the thick trunks of the large, old individuals found at most of our sites, some of which were reported to be over 200 years old (JL Nhamussua pers. cc.).

The diversity of flora and fauna appears to reflect zones where a low diversity of trees is found in urban areas, while the most complex and mixed mangrove stands were found in the least traversed sites (Table 3). The fauna shows a similar pattern, with the highest species richness found at Guiua and Morrumbene but the highest abundance of some key species measured at disturbed sites (Table 4). This is true for *S. alba* and *A. marina* at Inhambane and Maxixe (Table 3), and for *D. fenestrata* and *T. palustris* (Table 4). The apparent trend of high abundance and low diversity at more used sites is not common, as researchers often find that disturbed sites have the same or sometimes greater diversity than surrounding more pristine areas (Cannicci et al., 2009; Peer et al., 2018; Stiepani et al., 2021). Aside from human activity, several other factors explain the habitat complexity and diversity patterns of mangrove fauna and flora. For example, nutrient input is influential and is expected to

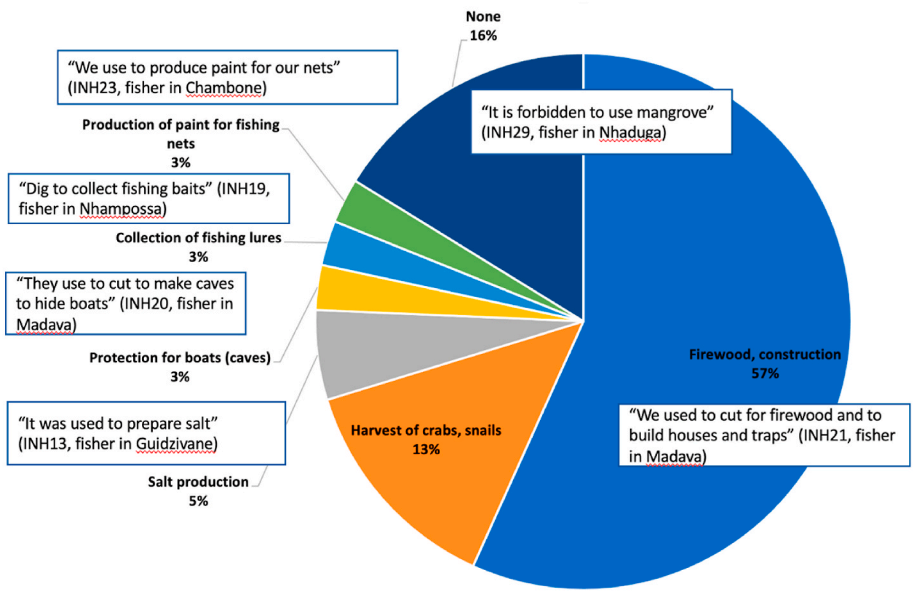

Fig. 5. Community perceptions on benefits and uses of mangroves (n = 31). The quotes represent direct translations from interviews conducted in Portuguese and Guitonga.

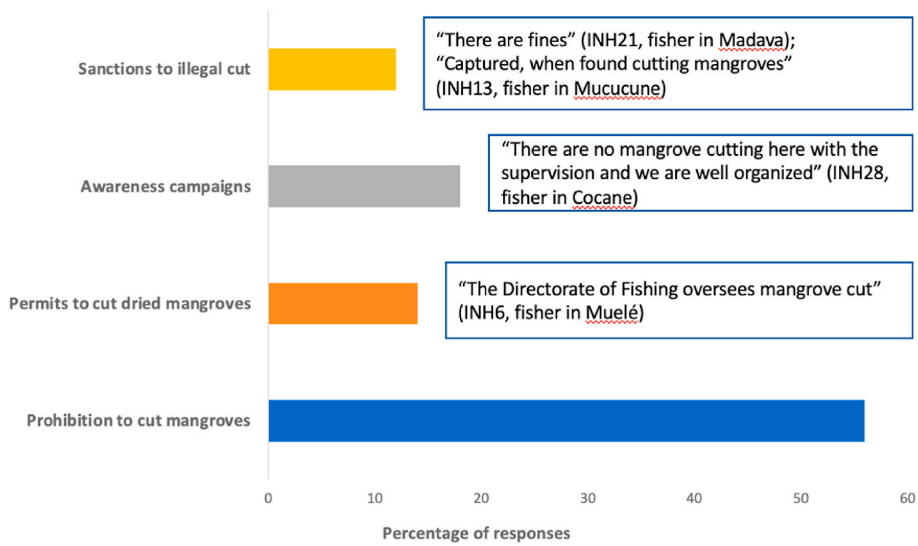

Fig. 6. Local perceptions on current management measures of mangroves in Inhambane Bay (n = 31). The quotes represent direct translations from interviews conducted in Portuguese and Bitonga.

vary among the six sampled sites due to differences in freshwater and groundwater inflows and anthropogenic activities. Sand grain size, tree diversity and habitat complexity are also drivers of macrobenthic diversity (Quiroga et al., 2022; Theron et al., 2022) and were not investigated during this study. There is scope for more detailed analysis of faunal diversity building on the observed trends, especially as there is a need for bioindicators in Mozambican mangrove systems (Pereira et al., 2014; Macamo et al., 2021).

Regarding the use of mangroves and mangrove-associated species by coexisting communities, patterns appear similar to other sites in the Western Indian Ocean region (Kairo et al., 2001; Zorini et al., 2004; Ajonina et al., 2008). In South Africa, Kenya and other parts of Mozambique, mangroves are harvested for firewood and timber (Friess et al., 2019; Dahdouh-Guebas et al., 2020). While, invertebrate harvesting in Kenya and Tanzania appears to occur more frequently in seagrass beds than in mangroves (Musembi et al., 2019; Alati et al., 2020). Similarly, a recent study by Chitará-Nhandimo et al. (2022) comprehensively examined collecting activity in seagrass meadows adjacent to mangroves in Inhambane. The authors found that invertebrate harvesting contributed to small-scale and subsistence activities with a peak of 7.6 tons collected per week during peak weeks (spring tide) (Chitará-Nhandimo et al., 2022). If most crab and snail species are collected from adjacent seagrass habitats, this could explain the low reliance on mangrove invertebrates as a source of food and income.

4.2. *Perceived benefits and value of mangrove ecosystems*

Mangroves are an important source of livelihood for coastal communities, providing coastal protection, food, building materials, firewood, and salt production (Maina et al., 2021). In Mozambique, a variety of shellfish, snails and crabs are harvested from mangrove ecosystems for sale and domestic consumption (Bandeira et al., 2009; Alati et al., 2020). Protection from flooding, erosion, storms and tidal waves is one of the most important services provided by mangrove ecosystems

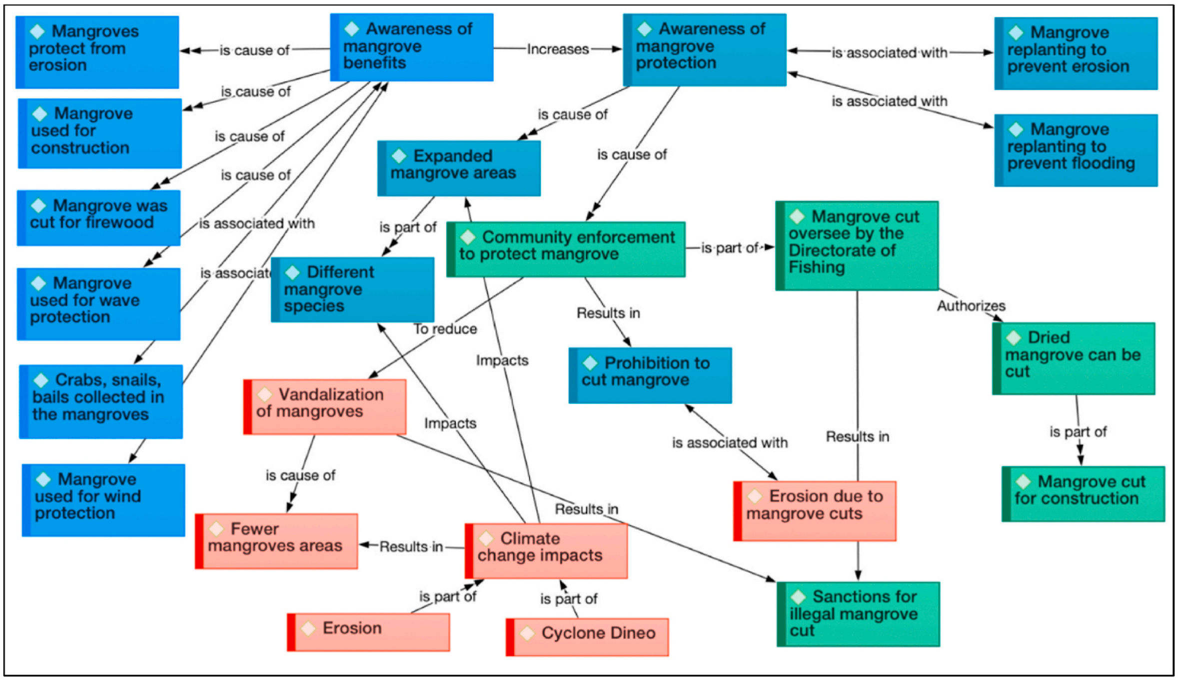

Fig. 7. Interconnections and relations of mangrove ecosystems in Inhambane Bay based on community perceptions of the benefits they obtain from mangroves, importance and the need for conservation. Data was obtained through semi-structured interviews in the Bay. The blue boxes represent awareness of mangrove benefits and importance, turquoise represents awareness of protection, green boxes represent local communities and government initiatives to protect mangroves, and red boxes represent threats to mangrove ecosystems. The arrows represent the causes and effects between the boxes (Designed on Atlas.ti, version 9).

(Ewel et al., 1998). However, unsustainable use and coastal development has led to the loss and degradation of mangroves (Duke et al., 2007). Despite knowledge of the importance of mangroves, their destruction continues to occur, mostly due to anthropogenic and natural causes (Ewel et al., 1998). Regardless, mangrove areas have increased in some areas due to conservation initiatives (Friess et al., 2019; Nyangoko et al., 2022). Efforts to protect and restore mangrove ecosystems have been translated into local community initiatives (Bandeira and Balidy 2016).

Although the importance and benefits of mangrove ecosystem services are perceived differently in different areas (Nyangoko et al., 2020), sustainable use, conservation and enforcement regulations contribute to mangrove conservation (Nyangoko et al., 2020). Capacity building and knowledge-generation initiatives have contributed to mutual learning and trust building through collaborative management initiatives between local communities, non-governmental organizations, and government departments (Randy et al., 2015). Collaborative efforts of this nature can have a significant impact on mangrove ecosystems (Ellison 2012). As noted by Stori et al. (2019), collaborative management initiatives enable benefits from cross-institutional agreements and promote scientific knowledge.

5. Conclusion

This study described the status of mangrove ecosystems in Inhambane in terms of cover, abundance and frequency, as well as the perceived benefits derived by local communities and their interactions with the mangrove ecosystem in Inhambane Bay. The research has identified areas of increased mangrove cover and some disturbance. There was widespread awareness of the ecosystem services that people derive from mangrove ecosystems. Additionally, community initiatives to protect, conserve and restore mangroves in the bay were highlighted. Although this perception describes the current situation and general awareness of the importance of mangroves, it cannot be generalised over the entire bay, as interviews revealed that some communities continue to cut mangroves and different communities experience localised challenges. However, from the findings, we found success stories, which demonstrate that bottom-up community initiatives, integrated law enforcement, and community-led mangrove restoration play an important role in raising awareness and actively protecting mangroves.

Ethics statement

This study received ethical approval from Stellenbosch University. Ethical clearance was granted by Stellenbosch University (Project No. 9530). Co-researchers were informed both verbally and in writing of the study procedure schedule, and planned engagement before the study began. All semi-structured interviews were conducted after the consent form was signed.

Authors contributions

This paper was conceptualized by N Peer, the PI for the project, with the supervision and collaboration of B Snow. N Peer, N Miranda, JL Nhamussua, AS Cabral, H Madivadua, J Narciso, and C Macamo conducted the biodiversity surveys, N Miranda, J Come, and JL Nhamussua conducted semi-structured interviews in Inhambane Bay with input from D Zacarias and B Snow. Data analyses were conducted by N Peer and J Come. All authors contributed to the article with reviews and approved the submitted manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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