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Use and management of seagrass ecosystems in southwestern Madagascar

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Madagascar's seagrass meadows are among the least-studied ecosystems in the western Indian Ocean region. To facilitate sustainable management, understanding the traditional uses of seagrass areas in relation to current management policies is necessary. This study assessed the uses of, and policies relevant to, seagrass ecosystems off southwestern Madagascar. We interviewed 131 community members in five coastal villages around the Bay of Ranobe in Toliara Province. Answers to the survey revealed a good level of awareness of seagrass, though 55% of respondents perceived the status of the seagrass areas as deteriorating. Opinions varied on the source or degree of threats to seagrass, but 74.8% of respondents suggested destructive fishing methods or other factors, including natural phenomena and animal grazing. The responses highlight that seagrass meadows serve as areas important for fishing, seaweed cultivation or sea cucumber farming, and the passage of boat/pirogue transportation. There are currently no tangible policies that directly protect or manage the seagrass areas regarding these activities, although some national regulations and local management initiatives are indirectly relevant, notably no-take zones and the local-level codes known as *Dina*. Development and implementation of a national management plan for seagrass ecosystems is a key gap. This demands the collection of scientific data to support decision-making to ensure long-term provision of the services provided by seagrass meadows. The involvement of coastal communities in the management of seagrass ecosystems will be necessary for the success of any new policies.

Keywords: Bay of Ranobe, coastal communities, community perceptions, legislation, local knowledge, local resources, survey questionnaire, threats

Supplementary material online: The Supplementary Information, available at <https://doi.org/10.2989/1814232X.2024.2321857>, includes information on the population around Ranobe Bay in southwestern Madagascar (Table S1), a template of the survey questions (Table S2), and a summary of all responses (Table S3).

Introduction

Seagrass meadows are recognised as a 'blue carbon ecosystem', alongside mangroves and salt marshes, because they capture inorganic carbon and sequester it as organic carbon for long periods (Vanderklift et al. 2022). Seagrasses are flowering plants that grow in intertidal or shallow subtidal depths in coastal and estuarine habitats, and occasionally far from the coast where the water is shallow enough. Protecting and restoring seagrasses can play a role in mitigating climate change (Arias Ortiz 2019; Francisco et al. 2019). Seagrass ecosystems also support key ecological processes and provide food and shelter for many species of marine organisms (Du et al. 2020). In some places they stabilise the substrate (Duarte et al. 2010). They can underpin socio-economic uses by humans (McKenzie et al. 2021) and provide multiple benefits for coastal communities (Duarte 2000; Duffy 2006; Unsworth et al. 2010; Kaarlep 2014; Baker et al. 2015; Kurniawan et al. 2019), including as a source of income and protein (Folke 1998; Torre-Castro 2006; Lilley and Unsworth 2014).

Despite the important roles of seagrass ecosystems, they are less studied than coastal ecosystems like

coral reefs and mangroves, especially in Madagascar (Vanderklift et al. 2019). On the eastern African coast, research on seagrass ecosystems began a few decades ago (Björk et al. 2008). In Madagascar, only a few research programmes have been conducted and most of them remain unpublished. On the southwestern coast of Madagascar, information about the social, environmental and economic aspects of seagrasses is scarce or absent, apart from a small number of studies of species diversity and geographical distribution (Lepoint et al. 2008; Roy et al. 2009; Hantanirina and Benbow 2013). Seagrass meadows in southwestern Madagascar are highly connected with other ecosystems such as coral reefs, which act as barriers creating sheltered bays (Gullström et al. 2002; Carter et al. 2016). This connectivity facilitates the occurrence of juveniles of multiple species (Jaonalison et al. 2016). Seagrass meadows and coral reefs also provide a habitat for the growth and development of associated fauna (Torre-Castro et al. 2009).

In the Bay of Ranobe in southwestern Madagascar, the daily activities of local communities rely on the sea.

These activities potentially have a negative impact on seagrass ecosystems (Torre-Castro 2006). Despite this, seagrasses are not often considered in policies regulating the local use and management of natural resources. Understanding how people use seagrass ecosystems, and what regulations exist, is foundational to the development of management plans and actions to protect seagrass ecosystems. Understanding their use also assists recognition of the value of seagrass ecosystems at the national level, which in turn is needed to ensure sustainable economic development and to contribute to policies and actions that promote nature-based solutions to climate change adaptation and mitigation (UNEP 2020). Like many countries in the western Indian Ocean region, Madagascar has developed strategies to ensure sustainable management of marine ecosystems such as coral reefs and mangroves. Locally managed marine areas (LMMAs) are a form of resource management in which coastal communities, and others based in the immediate area, make decisions about conservation actions (Rakotomahazo et al. 2022). It is crucial to use LMMAs effectively for conservation and to benefit the livelihoods of coastal communities, incorporating knowledge about how ecosystems are used, as well as how they are perceived by local people (Rakotoson and Tanner 2006; Berkström et al. 2019; Rakotomahazo et al. 2021).

Our main objective in this study was to survey the use of seagrass ecosystems by local communities in southwestern Madagascar, and to review relevant policies. The study focused primarily on local knowledge. Local knowledge differs from traditional ecological knowledge; though both concepts refer to knowledge held by communities, local knowledge focuses on practical and day-to-day information related to the use of ecosystems and natural resources, whereas traditional ecological knowledge encompasses broader aspects, cultural value and intergenerational transmission (Lemahieu et al. 2018; Berkström et al. 2019). To achieve this, we (i) assessed the local knowledge about seagrasses around the Bay of Ranobe; (ii) surveyed the importance of the seagrass ecosystems to the coastal communities; (iii) identified perceptions about the threats to and pressures on seagrasses and the potential impacts; and (iv) identified existing policies relevant to seagrass meadows in the area.

Materials and methods

Study location

The study was conducted in the Bay of Ranobe, southwestern Madagascar, between 43°30' E, 23°00' S and 43°38' E, 23°18' S (Figure 1). The bay is delimited by the Manombo River in the north and the Fiherena River in the south, which both disgorge into the Mozambique Channel. The warm season in the Bay of Ranobe is from December to April, with an average temperature of over 30 °C during the day. The cooler season is from May to September, with an average daily temperature below 27 °C (Weather Spark 2018). The rainy period of the year extends from October to April, with a 31-day rainfall of at least 13 mm. The amplitude of the tidal range varies from 1.2 m during spring tide to 0.3 m during neap tide (Moustapha et al. 2021).

The bay area is a community-managed marine reserve overseen by the community organisation FIMI HARA and co-managed by the nonprofit organisation ReefDoctor (Belle et al. 2009). FIMI HARA is the acronym for 'Fikambanana Miaro sy Hanasoa ny Ranomasina', which can be translated as 'Association to Protect and Enhance the Marine Environment'. The reserve was established in 2006 and officially obtained protected status in May 2007 under the Code of Protected Areas (*Code des Aires Protégées* or COAP). A management plan was developed but was valid only until 2011 (ReefDoctor 2013). However, no implementation of conservation activities related to seagrass have ever been carried out in the bay, primarily because of a lack of initiatives and community involvement, and there is no new management plan in place.

Site-selection criteria

Five of the 13 coastal villages in the Bay of Ranobe were included in the study: Andrevo, Ambolomailake, Amboaboake, Mangily and Ifaty (Figure 1). The southern part of the bay (Ifaty, Mangily, Amboaboake) is almost entirely urbanised, with modern infrastructure, hotels and solid houses. The northern part (Ambolomailake and Andrevo) is more rural. All villages have large areas of seagrasses in the adjacent lagoon.

The five fishing villages are mainly inhabited by Vezo people (91% of the population of the bay), who share a common history and culture, while each village has its own characteristics. Ifaty, Mangily and Amboaboake are known for tourist activities, offering beaches and tourist sites. The villages of Ambolomailake and Andrevo are characterised by the presence of the Masikoro (9% of the population of the bay), an inland people who migrated to the coast and who now also engage in fishing. Several villages in the Bay of Ranobe practice aquaculture, but among the five studied villages, only Ambolomailake and Andrevo practice seaweed and sea cucumber farming.

Characteristics of the survey participants

Activities of the coastal communities are closely linked to the sea. According to INSTAT (2017), the population at Ranobe Bay comprised about 44 786 individuals (24 808 men and 19 978 women). The population of the five villages studied accounted for 75.49% of Ranobe Bay: Ifaty with 2 446 people (5.46%); Mangily with 25 805 people (57.62%); Amboaboake with 765 people (1.71%); Ambolomailake with 2 356 people (5.26%); and Andrevo with 2 436 people (5.44%). The population of this combined community is relatively young (Supplementary Table S1), with ~67% under age 18 (Table 1).

The majority of the inhabitants around the bay belong to the Vezo ethnic group. Other ethnicities in this area include the Masikoro, Tanalana, Antandroy, Betsileo and Merina, as well as foreigners. These groups engage in various economic sectors, such as trade, restaurants and especially tourism (Ranaivomanana 2016).

Data collection

Local perceptions of seagrass and its associated resources

To assess local perceptions about seagrass, we conducted a survey between January and June 2021 in five villages.

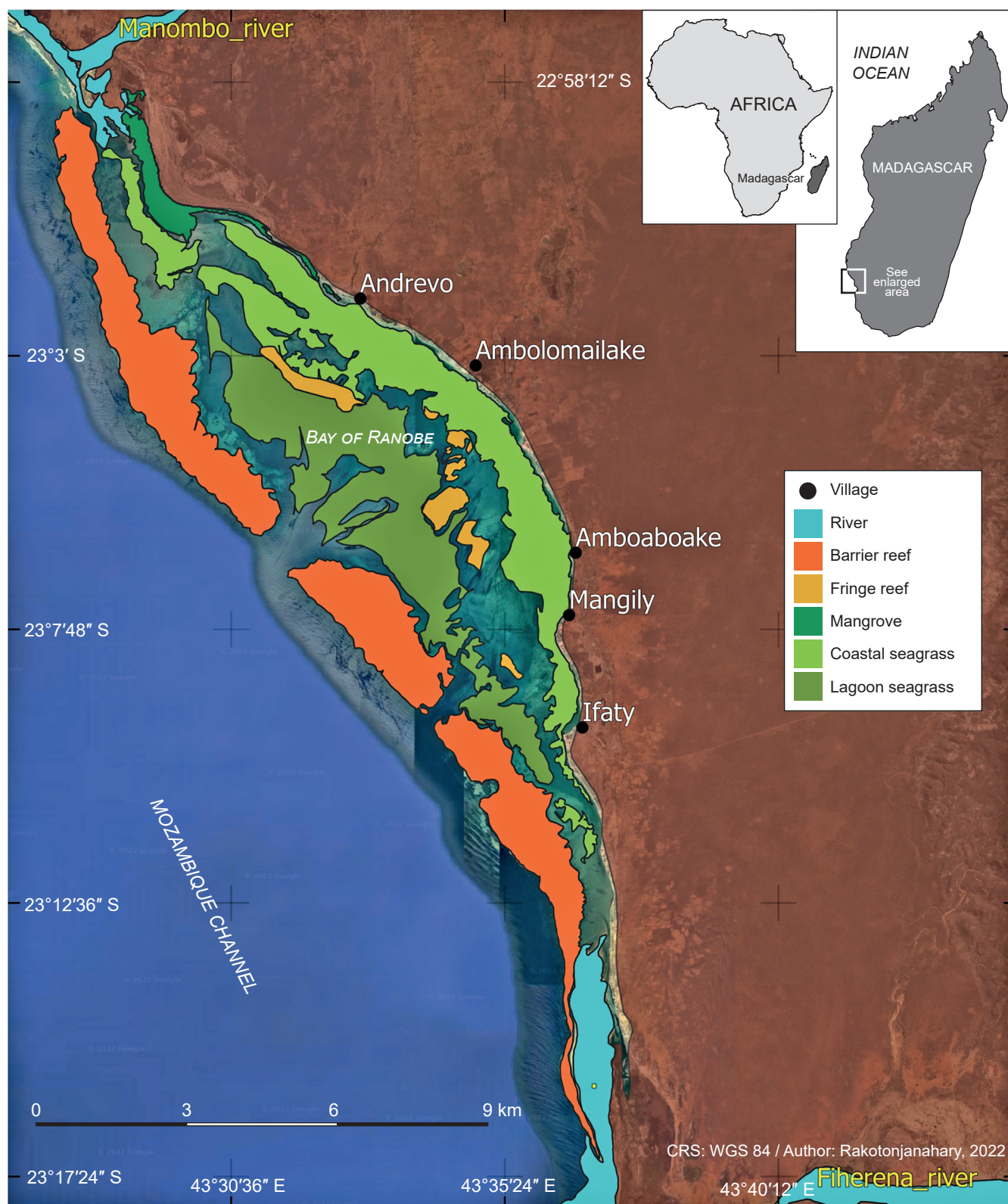


Figure 1: Map of the Bay of Ranobe, southwestern Madagascar, indicating different ecosystems and locations of the five villages visited in this study

Table 1: Ages (years) and gender (%) of the population in the Bay of Ranobe, southwestern Madagascar (INSTAT 2017)

	Aged <6	Aged 6–18	Aged 18–60	Aged ≥60
Men	21.17	16.88	14.27	3.08
Women	15.23	13.99	13.08	2.31
Total	36.39	30.87	27.35	5.39

We surveyed 131 respondents, including farmers, fishers, village leaders, community organisations and staff from nonprofit organisations. The survey was conducted through interviews. The participants consisted of adults of ages 18 to 63. Participants were selected based on their knowledge of the village setting and local activities related to seagrass. Before conducting interviews, we first presented our study objectives to village chiefs and community members to secure their consent. Upon receiving consent from the participants, we proceeded with the interviews. The respondents were interviewed at public meeting places, fishing landing sites, or the homes of fishers (Wallner-Hahn et al. 2022). The survey comprised both semi-structured interviews and in-depth interviews, as described below.

Semi-structured interviews were conducted with 131 individuals: 118 fishers, 8 seaweed or sea cucumber farmers, and 5 people engaged in other activities. In this category, the survey questions were generally asked of individuals, but on some occasions the participants responded through group discussion. We gathered basic information such as gender, age, and social identity to determine whether respondents belonged to the Vezo or other tribes, and asked questions about seagrass and activities related to it. All 131 participants were asked about the status of the seagrass areas, and trends over the last five years. Other questions were asked about threats and pressures affecting seagrass areas as well as the opinions of the respondent on the sources of these threats. A template of the survey questions is given in Supplementary Table S2.

In-depth interviews were conducted with key community members, including the heads of villages, leaders of local organisations, and elders of the villages. The principal respondents for this category of interview comprised seven individuals: the five heads of the five villages, the head of a non-profit (ReefDoctor), and the head of an LMMA organisation (FIMI HARA). The purpose of the in-depth interviews was to gain a deeper understanding of the local perception of seagrass and its importance to the community. By engaging with these key stakeholders, we were able to gather valuable insights into the cultural and social significance of seagrass areas in the local context.

Understanding the importance of seagrass ecosystems through participatory mapping

Participatory mapping was used to understand the importance and the uses of seagrass ecosystems. To do this, we used group discussion, with each group composed at least five individuals (Figure 2). The groups comprised different participants, including farmers, fishers and local authorities. They were asked to sketch a map on a flip chart (using different coloured markers) showing the activities



Figure 2: Group discussion during participatory mapping of seagrass areas in the village of Andrevo, southwestern Madagascar

that the villagers conduct in seagrass meadows and where they occurred. The maps were subsequently gathered and digitised using QGIS software, and saved as georeferenced shapefiles. These shapefiles were then formatted to create a map that illustrates the collective perspectives on the utilisation of seagrass areas in Ranobe Bay.

Identification of existing management laws and policies regarding the seagrass ecosystems in the bay

Identification of the existing forms of management regarding seagrass ecosystems around the bay was performed through reviews of national to local legal and policy documents. Of the 48 documents reviewed, comprising research articles and other documents on seagrass ecosystems, ecosystem management and management related to seagrass ecosystems, only five related specifically to the Bay of Ranobe. These included COAP, the local management plan, the local-level codes known as *Dina*, and miscellaneous documents concerning community-based aquaculture from the private society Ocean Farmers, the Indian Ocean Trepang enterprise, the non-profit organisation ReefDoctor, and FIMI HARA. The content of those documents was analysed to determine whether there were texts that directly or indirectly concerned the conservation or protection of the seagrass ecosystem. We also examined the involvement of local communities in seagrass management at the local level.

Supplementary Table S3 summarises all respondents' answers to the survey questions.

Data analysis

A mix of quantitative and qualitative data were generated in this study. Respondents' answers to the survey were collected and analysed by topic. Given the qualitative and unstructured nature of many of the responses, technical coding was applied to standardise and classify the content into categories: knowledge of seagrass, status of seagrass areas, activities and significance of these areas, threats and pressures, and management. From the classified data, we

identified 14 variables: seven concerning uses, and seven regarding perceptions about seagrass. Descriptive statistical measures such as means and percentages were used. The data analysis did not consider gender and age as separate independent factors. Instead, the analysis focused solely on the number of survey respondents. The inclusion of women and children in the surveys was based on their involvement in specific activities related to seagrass ecosystems. Thus, our primary interest was in understanding the activities and perceptions of the villagers regarding seagrass areas.

Results

Terms used to describe seagrass

Most of the respondents were aware of seagrass but the terms they used varied: 59.54% of the respondents called seagrass *ariano*, *oriana* or *oriagna*; 26.72% called it algae; and 1.53% called it vegetation. A relatively small proportion (12.21%) were not aware of seagrass (see Supplementary Table S3).

Activities conducted by villagers in the vicinity of seagrass meadows

Three main activities were practiced within seagrass meadows in the Bay of Ranobe (Figure 3a), including fishing, with 92.19% of respondents indicating that it was their main activity, and that seagrass meadows were one of the most-frequented areas for fishing. Fishing gear varied according to the type of habitat, such as mangroves, reef zones, lagoons and seagrass. Fishers operating in seagrass meadows in the Bay of Ranobe (Figure 3b) frequently used gillnets (60%), primarily to capture shoals of fish in the lagoon (Behivoke 2022). They also employed harpoons or spear guns (19% of the respondents) and beach-seines (15%). Beach-seining (Figure 4a) with mosquito netting could be frequently observed in the villages of Andrevo and Ambolomailake. Gleaning (Figure 4b) and beach-seining with gillnets were fishing techniques often used by women and children during low spring tide.

Following fisheries, the second-most-practised activity was aquaculture, the principal activity of 6.25% of the

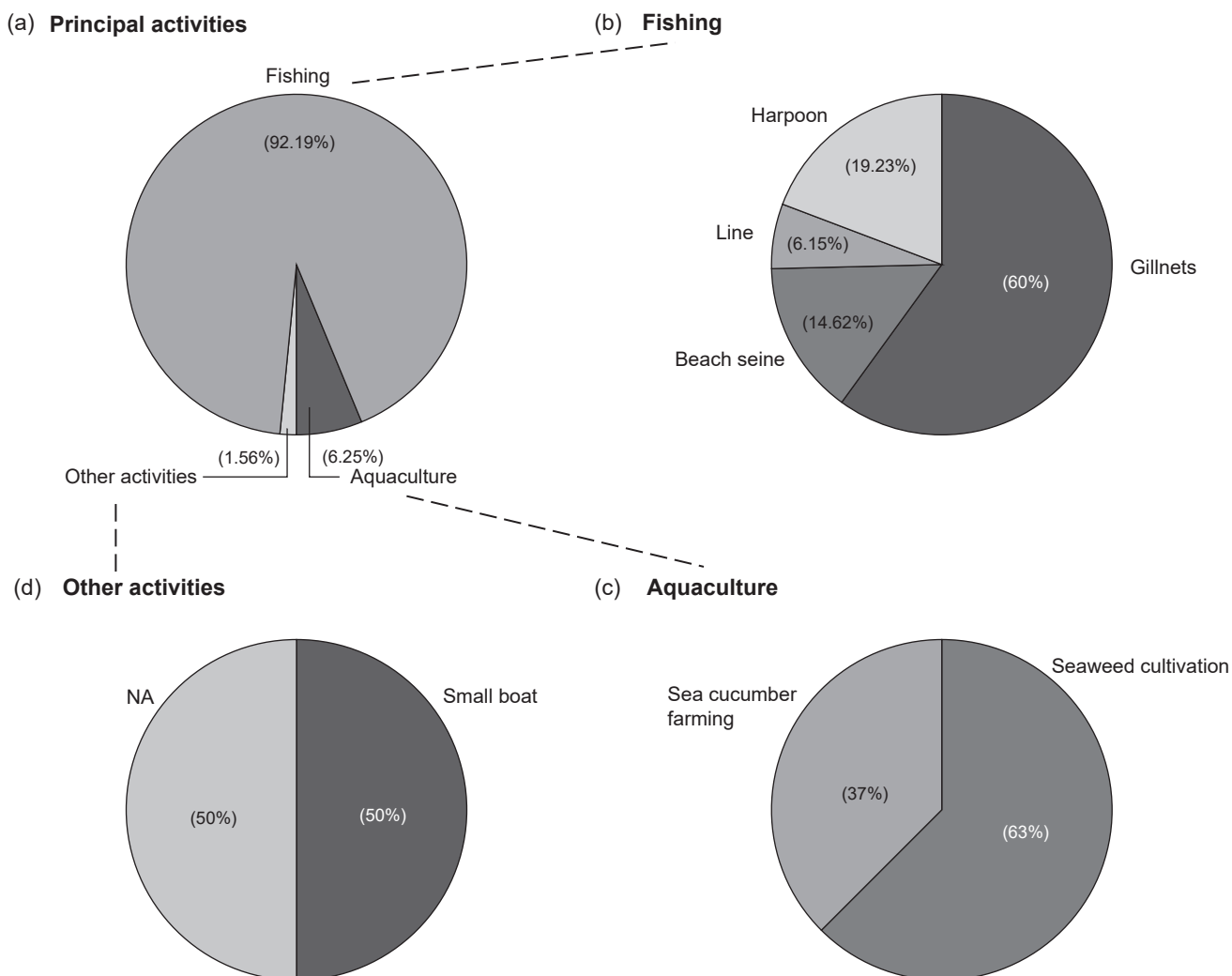


Figure 3: (a) Principal activities undertaken by villagers in the vicinity of seagrass beds in southwestern Madagascar, as identified through participatory mapping, further subdivided into types of (b) aquaculture, (c) fishing, and (d) other, including boat skipping



Figure 4: Activities implemented by villagers in seagrass areas in the Bay of Ranobe, southwestern Madagascar, including: (a, b) fishing techniques used by the local community, such as beach-seine netting and gleaning; (c, d) aquaculture, namely seaweed cultivation and sea cucumber farming; and (e) means of transport, such as traditional pirogues for fishing and visiting family, and boats with outboard motors used for tourist activities and research

respondents. This percentage is further divided into two categories: seaweed cultivation, representing 63% of individuals who said they were engaged in aquaculture, and sea cucumber farming, representing 37% (Figure 3c). For

seaweed cultivation, the duration of a cycle from seeding to harvesting is 45 days. Farmers first tie seaweed to ropes (Figure 4c); they then visit their seaweed farms by foot or by pirogue every low spring tide, to clean and maintain them.

Table 2: Proportion (%) per village of the activities related to seagrass areas in the Bay of Ranobe, southwestern Madagascar

Village	Fishing	Sea cucumber farming	Seaweed cultivation	Boat skipping	NA
Andrevo	84.33	4.33	7.00	2.33	2.00
Ambolomailake	88.80	4.88	4.88	1.44	–
Amboaboake	95.45	–	–	–	4.55
Mangily	94.24	–	–	2.88	2.88
Ifaty	97.24	–	–	2.76	–

For farming sea cucumbers (Holothuridae), two parts of the production cycle, namely the hatchery and nursery phases, are conducted inland and do not involve seagrass habitat; however, the grow-out phase takes place within enclosures installed in seagrass zones (Figure 4d).

Other activities carried out by 1.56% of the interviewed population included transportation and renting small boats and pirogues for tourism and research purposes (Figure 3d). Coastal villagers use traditional pirogues for all travel activities whenever weather conditions permit (Figure 4e). Non-profit organisations, tourism operators, and research efforts employ small boats with outboard motors (Figure 4f). All boat transportation methods can involve crossing seagrass meadows.

Table 2 shows the proportion of people interviewed in each village who primarily engaged in these various activities. Aquaculture activities were practiced in only two of the five villages studied.

Spatial distribution of seagrass use

Figure 5 illustrates the activities performed by the coastal communities of the Bay of Ranobe, as determined through participatory mapping conducted in five villages. Fishers from the five villages reported that all areas of the bay were fished. Beach-seines were used most frequently by the villagers of Andrevo, Ambolomailake and Ifaty; aquaculture activities occurred only in the villages of Andrevo and Ambolomailake (Figure 5). The two access channels, formed by the separation of the reef barriers, serve as entry and exit points to Ranobe Bay, accessible by traditional pirogues and small boats with outboard motors. The maps illustrate that the areas with the highest frequency of beach-seine usage coincided with locations where farmers were engaged in seaweed farming or sea cucumber farming at both Andrevo and Ambolomailake. These areas often experienced conflicts between fishers and farmers, particularly concerning the use of destructive techniques such as beach-seining.

Community perceptions on the status of seagrass areas

Across the community in the five villages, 51.72% of the interviewed individuals perceived a decrease in seagrasses over the last five years, while 16.47% perceived no change (Figure 6a). Community perspectives on the current state of the seagrass areas were nearly identical in four of the five villages we surveyed. Over half of the respondents in four villages (Ifaty, Mangily, Ambolomailake and Andrevo) indicated that they thought seagrass meadows had been degraded (Figure 6b). Respondents from Amboaboake

were the exception, but there was a high proportion of no responses from this village. Less than a quarter of respondents in all villages reported that there was no change in seagrass condition (Figure 6b). According to 74.81% of respondents, the perceived decline was due to anthropogenic activities, while 12.98% attributed it to sea urchin predation (Figure 6c).

We calculated that an individual with a foot size of 200 cm² and a walking speed of 0.45 m s⁻¹ (1/3 of normal speed) can trample approximately 9.895 m² of seagrass while maintaining a sea cucumber enclosure or engaging in gleaning for 2 hours. Considering one month as having 14 days of favourable tides, it was estimated that the 366 farmers in Andrevo village could feasibly trample ~51 hectares of seagrass (FR pers. obs.).

Some respondents (7.63%) surmised that damage to seagrass areas was caused by natural phenomena such as strong waves during cyclonic periods and high temperatures (Figure 6c). The Bay of Ranobe, situated in the Mozambique Channel, experiences regular cyclones from February to May each year, resulting in strong waves and currents that can affect seagrass growth and survival (Côté-Laurin et al. 2017). Exposure to sunlight during low spring tide can also negatively affect seagrasses. Sedimentation, turbidity and algal blooms caused by high amounts of terrigenous sediment from inland rivers, such as the Fiherena River that transports ~9 million tonnes of sediments per year, pose additional threats to the Bay of Ranobe (Mahafina 2011; Murray et al. 2021). Out of the total respondents, only 2.29% expressed the view that there was no change to or pressure on the seagrass areas.

Existing systems of seagrass management in the Bay of Ranobe

Based on our review of available laws and policies, we found that there is currently no specific management framework or legal protection for seagrass areas in Madagascar generally, or the Bay of Ranobe in particular. However, the management of this ecosystem type is indirectly addressed through the implementation of measures such as MPAs. Legal frameworks that indirectly cover seagrass ecosystems include the COAP and various laws and decrees (Table 3).

The Bay of Ranobe includes marine areas managed through a set of local-level codes known as *Dina*; these are established by coastal communities engaged in coastal activities like fishing or aquaculture, and are reinforced by official laws related to those activities. For instance, coastal communities in villages where *Dina* codes have been

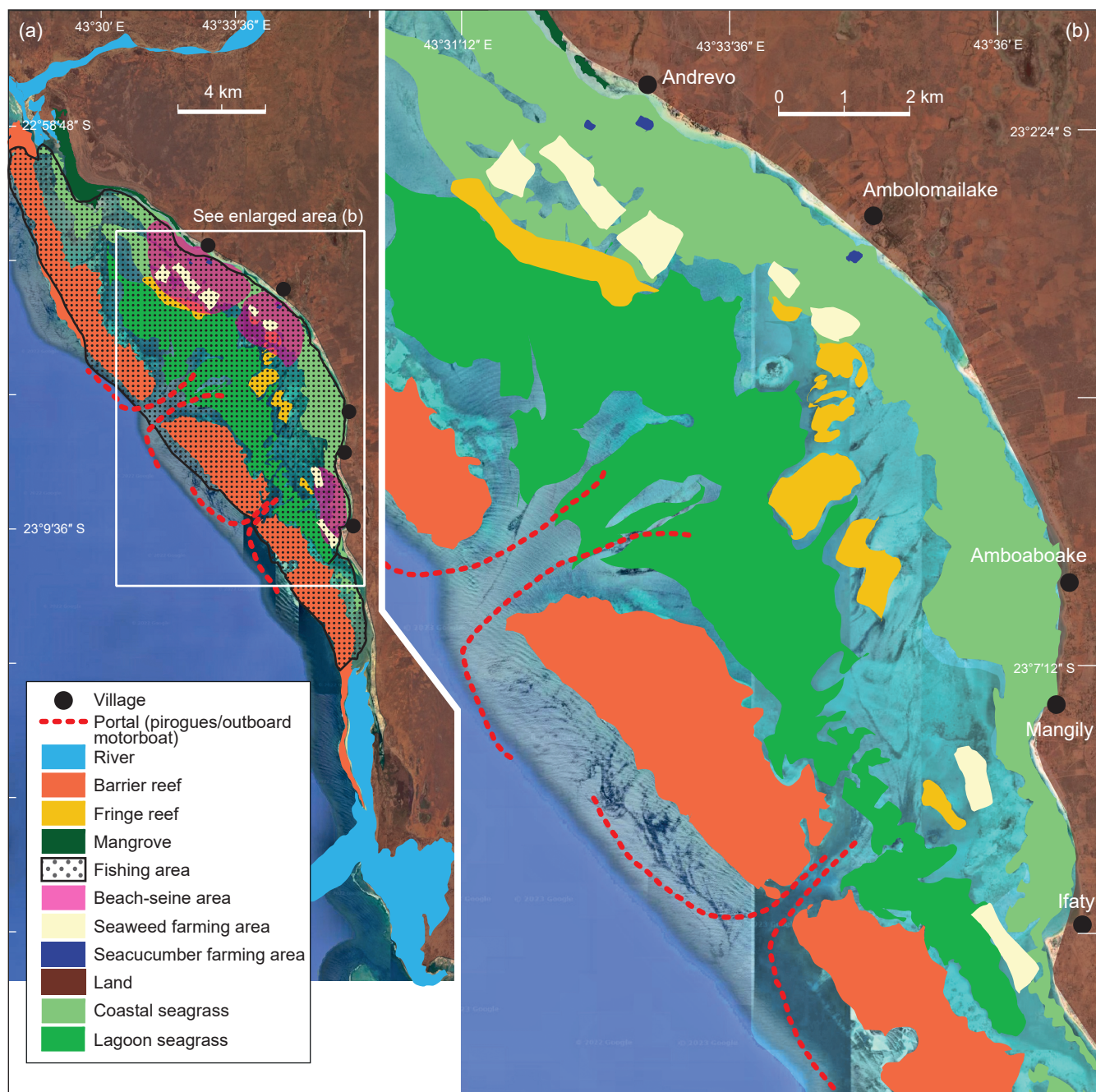


Figure 5: Results of participatory mapping of activities related to seagrass areas in the Bay of Ranobe, southwestern Madagascar

established can enforce these rules against individuals who engage in deliberate destructive fishing practices. By doing so, these regulations indirectly contribute to the protection of Madagascar’s seagrass meadows.

Discussion

Our study on the use and management of seagrass ecosystems in the Bay of Ranobe, southwestern Madagascar, used survey questions to elicit local knowledge so that we might better understand how seagrass meadows

are used in the daily life of coastal villagers. Our study also focused on pressures that the seagrass areas are subjected to as well as on existing systems of management (laws and policies). This approach underlines the importance of seagrass meadows not only as a local resource, but also as an integral component of coastal ecosystems (Berkes 1999) and a space for other activities.

We found that the livelihoods of local communities involve extensive use of seagrass meadows, and most of those people have some knowledge about this ecosystem. Seagrass meadows are used as fishing grounds and

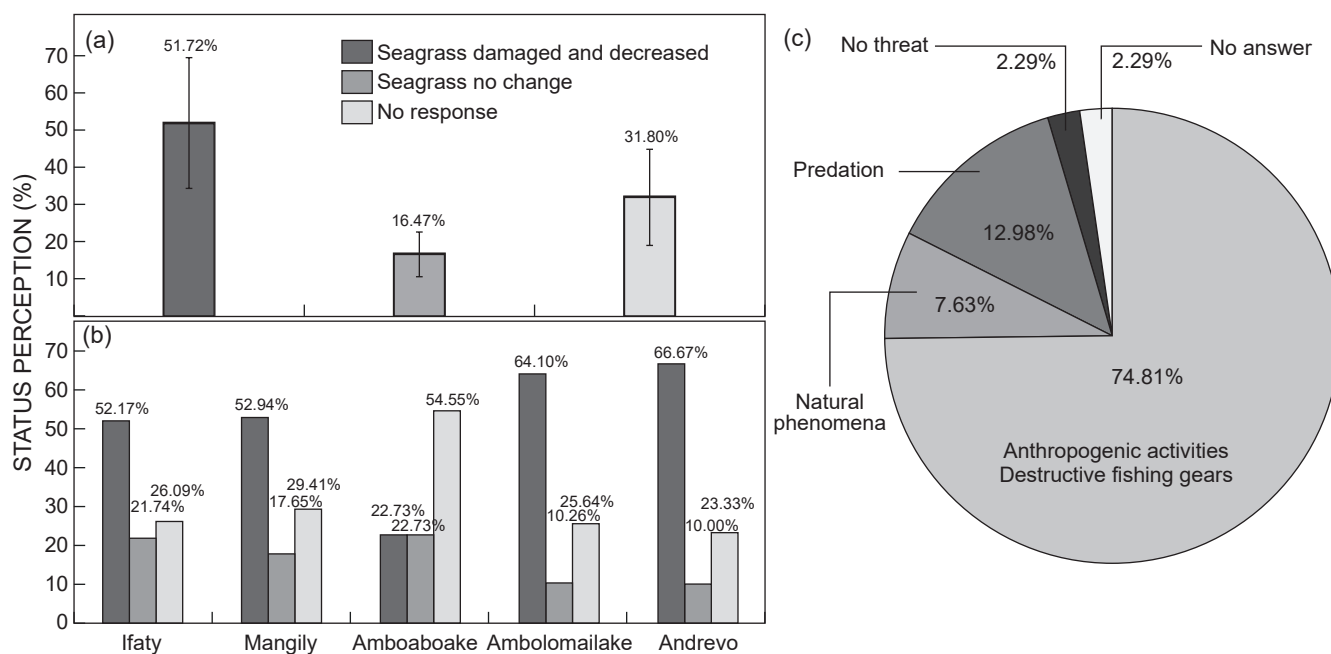


Figure 6: (a) Overall perception by villagers of the status of seagrass areas in the Bay of Ranobe, southwestern Madagascar, and (b) general perception of the status of seagrass by residents of each village. (c) Factors respondents perceived to be causing damage to seagrass areas

Table 3: Existing laws in Madagascar that are relevant to sustainable management of marine and coastal environments that include seagrasses

Legislation	Objectives
Law No. 2001-004 of October 25, 2001	Locally-based rules or codes known as <i>Dina</i> are a commonly used instrument for the management of natural resources in Madagascar. This law provided a path to legitimise <i>Dina</i> through the local court system (known as homologation), which at the same time allowed for some scrutiny and oversight of the village codes being created
Law No. 2015-053 on the Fisheries and Aquaculture Code	This law aims at sustainable governance and management of fishery resources with a view to preserving aquatic ecosystems and protecting the biological diversity of Malagasy waters, including those in the deep seas
Law No. 95-013 of February 22, 1996	The Environmental Protection Law sets up rules for managing natural resources, preventing pollution, and safeguarding public health. It includes measures that indirectly safeguard seagrasses by placing restrictions on destructive activities that could degrade their quality
Law No. 99-006 of January 14, 2000	The Coastal Zone Management Law ensures the sustainable management of coastal areas, including seagrass meadows. It regulates fishing activities, prohibits destructive techniques, and enables the creation of marine protected areas to protect these ecosystems
Decree No. 2005-256 of April 20, 2005	A decree that provides detailed guidelines for implementing Law No. 99-006 of January 14, 2000 (see above)
Decree No. 2016-128 of February 16, 2016	A decree officially adopting the National Strategy and Action Plans for Biodiversity of Madagascar (2015–2025), outlining targeted measures for conserving and restoring marine ecosystems, including seagrass meadows

places where aquaculture occurs (seaweed cultivation and sea cucumber farming). Other uses of seagrass meadows include tourism, research, and passage by boat transport. Most local villagers inhabiting the Bay of Ranobe reported a perception that the seagrass areas are declining, and that this is mainly due to human activities such as destructive fishing practices (beach-seining, gleaning, and the use of boats). Other factors perceived as contributing

to seagrass degradation included natural phenomena like severe weather events.

Importance of seagrass areas and the implication for local management

Our results showed that seagrass areas are part of a broader ecosystem that is heavily relied on by the coastal communities living around the Bay of Ranobe. An awareness of seagrass

was high among the respondents. Indeed, knowledge is incorporated into the Malagasy language, with names for seagrass as a habitat and names for different species reflected in local terms. For example, seagrass as habitat is called *akatan-driaky* or *ahi-driaky*. Both are combinations of two words: *akata* + *riaky* and *ahitse* + *riaky* (*akata* and *ahitse* are Malagasy names for grass, and *riaky* means the sea). Some respondents referred to seagrass to as algae, which is known locally as *lomotse*. Some used different descriptions to distinguish between various species of seagrass depending on the shape. For instance, species of *Syringodium* have a cylindrical morphology similar to a chive and are referred to as *lomo-tongolo*, a combination of *lomotse* (algae) and *tongolo* (chive), while species of *Thalassodendron* have large leaves and are called *lomotse beravy*, meaning 'big leaf algae'.

Farmers involved in aquaculture activities (seaweed cultivation and sea cucumber farming) indicated that it is a source of income and an alternative to fishing that reduces the pressure on marine resources exerted by fisheries (Behivoke et al. 2016).

Human threats to Madagascar's seagrass meadows: toward effective conservation planning

Many villagers expressed their perception that the seagrass meadows are being degraded and that practices such as fishing with the use of destructive gear, trampling, and aquaculture are responsible for declines in seagrass areas. In the Bay of Ranobe, intensive fishing is considered to be one of the greatest risks to seagrass areas (Murray et al. 2021). Trampling from shore fishing and aquaculture can also damage seagrass, as can boating and tourism activities through anchors and motorboat propellers (Nadiarti et al. 2021).

Accessibility on foot is essential for gleaning activities and for many small-scale aquaculture activities in shallow nearshore environments, like seaweed farming and sea cucumber aquaculture. These activities are often carried out by women or young fishermen. Our calculations revealed, in the case of Andrevo village, that with 14 days of favourable tides 366 farmers could trample ~51 hectares of seagrass, potentially causing negative impacts on the seagrass areas. These activities could lead to decline of the seagrass habitat as well as the associated fauna and marine resources (Ranaivomanana et al. 2006; Torre-Castro 2006). The accumulation of repeated minor damage could result in the destruction of large areas of seagrass (Zieman 1976; Sargent et al. 1995; Gravier 2019). This is likely underappreciated, and we suggest that raising awareness about the potential impact of trampling on seagrass ecosystems is an important precursor to developing and promoting sustainable practices that allow livelihoods to continue in a way that preserves the ecosystem that the villagers so heavily rely on.

Conflicts of activities in seagrass areas: the challenges of planning and regulation

In relation to the seagrass areas, the communities around the Bay of Ranobe mainly engage in fishing, aquaculture (seaweed and sea cucumber farming) and transportation (community travel by pirogues and tourist transportation by outboard motorboat). However, conflicts may arise between farmers and fishers who want to use the same areas owing to the development of aquaculture activities

in collaboration with the private sector. Additionally, stakeholders in the local tourism industry have raised concerns about changes in the landscape caused by these activities, and managing seagrass areas has become a significant challenge (Ranaivoson et al. 2018; Veriza and André-Bigot 2020). Whereas local indigenous inhabitants may be able to make agreements to prevent conflicts between them, migrants into the coastal communities often refuse to officially and administratively integrate into the host villages and may not follow local structures. Therefore, it is crucial to establish a balance between the different activities and interests involved (Rakotomahazo et al. 2019). This can be achieved through proper planning and regulations to reduce conflicts among different users of seagrass meadows and thereby ensure the sustainable use of marine resources.

Towards sustainable management of seagrass ecosystems in Madagascar: national legal and policy frameworks

In the western Indian Ocean region, seagrass conservation is typically considered only indirectly through protected areas (Gullström et al. 2002). In Madagascar, seagrass ecosystems are considered one of the least known, least protected and most mismanaged ecosystems (Murray et al. 2021) and are ranked as Data Deficient in accordance with IUCN Red List of Ecosystems assessment criteria (Bland et al. 2015). Madagascar has the largest areas of seagrass meadows in the region (Gullström et al. 2002), extending along the country's entire west coast (Hantanirina and Benbow 2013). The surface area of seagrass meadows in Madagascar might be greater than that of coral reefs, and the meadows are estimated to cover 9 385 km² in the coastal waters (Vanderklift et al. 2019). Large areas of seagrass of ~2 000 hectares have also been recorded on the southern coast (Murray et al. 2021).

Despite their importance and extent, we found no official laws or management policies that specifically protect seagrass ecosystems. National legislation and policies exist for the protection of global marine and coastal ecosystems (Table 3), and seagrass ecosystems are indirectly included in these. These regulations provide general measures for the prevention of pollution and the prohibition of destructive fishing techniques. This emphasises the commitment of the Malagasy government to promoting sustainable management of marine ecosystems, including seagrass meadows, through comprehensive policies and legislation.

At the local level, despite some conservation efforts led by the local association (FIMIARA) and supported by an external non-profit organisation (ReefDoctor), such as the creation of an MPA, these initiatives do not specifically address seagrass areas. Instead, the management is primarily governed by local-level codes called *Dina*. *Dina* is a form of community-based self-governance or social convention that enables democratic representatives to manage natural marine resources and coastal zones, for example (Rakotomahazo et al. 2021). These codes are acknowledged as the strongest customary law in Malagasy society by the local police (gendarmerie) and the judicial court (Rakotoson and Tanner 2006), yet no regulations pertaining to seagrass areas have been included.

Incorporating seagrass ecosystems into LMMAs would allow communities to actively engage in conservation and management of the resources that they rely on. Active participation of local communities is key to achieving sustainable outcomes (McClanahan 2021). Using this approach, which may involve implementing temporary closures, establishing no-take zones, and promoting alternative livelihoods such as aquaculture, the sustainability of seagrass meadows and their associated marine resources can be facilitated (Rakotomahazo et al. 2022). Some adjustments to aquaculture practices could be made to limit trampling, such as monitoring sea cucumber farms during high tide by means of diving. Expediting the acquisition of basic knowledge and data is imperative for the proficient management of seagrass habitats. Consistent monitoring and comprehensive inventory assessments of seagrass meadows are indispensable for comprehending their status, distribution and ecological dynamics. Furthermore, up-to-date maps illustrating local and national variations in the distribution of seagrass areas play a crucial role in identifying priority areas for conservation activities and implementing focused management strategies (Moritz et al. 2016).

In conclusion, our study focused on understanding the use and management of seagrass ecosystems in the Bay of Ranobe, southwestern Madagascar. The study revealed that almost all respondents in five villages around the bay were aware of the existence of seagrass. Community perceptions indicated a general decline in the seagrass meadows, caused primarily by anthropogenic activities such as destructive fishing techniques and unsustainable resource exploitation. Despite this possible decline, fishing remains the primary livelihood for these communities, with seagrass areas being frequently fished. However, specific management measures dedicated to seagrass meadows are lacking. Existing initiatives mainly relied on local-level codes known as *Dina*, which governs the aquaculture zones involving activities like sea cucumber farming and seaweed cultivation. Nevertheless, this leads to conflicts between fishers and farmers engaged in aquaculture in seagrass areas owing to their competing interests in these areas.

To promote sustainable and equitable management, it is crucial to customise policies to address local needs, respect traditional and local knowledge, and encourage community participation. Incorporating local knowledge into conservation strategies fosters community inclusion and effective outcomes. Community involvement in seagrass management strengthens social ties and promotes a collaborative approach to marine resource management. Incorporating activities that protect seagrass into LMMAs is a strategy that should encourage sustainable uses. The establishment of national-level management plans for seagrass ecosystems is essential and requires broader scientific studies. Collaboration with research institutions can provide data to underpin these initiatives. Priorities should include national mapping of the current status and evolution of seagrass meadows, in-depth assessment of the biodiversity associated with seagrasses, and understanding the environmental, social and economic importance of seagrass areas for sustainable development. Additionally, exploring Madagascar's seagrass meadows as blue carbon ecosystems that contribute to the mitigation

of climate warming is paramount given that Madagascar was one of the first countries to sell blue carbon credits from mangroves in a voluntary carbon market. It is therefore possible to build on the existing carbon-credit framework by incorporating seagrass ecosystems through the technical experience acquired with mangrove areas (Blue Ventures 2014). Our research provides potentially valuable insights into the use and management of seagrass meadows on a local scale. To strengthen the relevance of our findings it is imperative to place them in a broader context. The integration of local knowledge into ecosystem management increases the effectiveness of management strategies and promotes community engagement and stewardship. In turn this will enable the development of inclusive and environmentally appropriate methods for the conservation and management of coastal and marine ecosystems, including seagrass meadows.

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