Social and Ecological Assessment of Mangrove Ecosystem Services and Temporal Change:

Case Study of Maputo Bay, Mozambique

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Abstract
This study aims to assess the performance and importance of mangrove ecosystem services, focusing on supporting, provisioning, and regulating, and to investigate temporal changes in mangrove cover in Maputo Bay, Mozambique. It also examines the drivers behind these changes. The research questions address stakeholder perceptions of ecosystem services and their potential trade-offs, temporal changes in mangrove cover, and threats. A mixed-methods approach was employed, where the random forest classification was used to map changes in mangrove cover between years 2017 and 2025, followed by 15 stakeholder interviews. The results showed contradictions in both the temporal change and ecosystem services. While the model showed a decrease of 1862 hectares, most stakeholders perceived an overall increase. Similarly, most experts highlighted mangroves' biophysical characteristics when discussing ecosystem services, whereas most residents highlighted the social perspective. Regulating and supporting services were frequently highlighted, with an overall decline in provisional services. The drivers affecting mangroves were site-specific and included anthropogenic factors like implementation challenges and urban expansion, as well as natural factors like storms, all contributing to ecosystem services trade-offs. While stakeholders highlighted the existence of ecosystem services, their values and use depended on socioeconomic factors. Likewise, the quality of ecosystem services depended on biophysical structures, human pressures, and geographical locations, indicating dynamic variation. These variations cannot be captured solely through large-scale observations, creating a risk of overgeneralizing local realities. Thus, more site-specific analyses, where different stakeholders share their multifaceted insights, are required to fully capture the dynamics of mangroves and their ecosystem services.

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Summary

Mangroves are saline-resilient trees that are located in tropical climates and recognized for their contributions to disaster risk reduction and climate change adaptation through the ecosystem services (ES) they provide. Mangroves encompass the five ES that contribute to human well-being according to the Millennium Ecosystem Assessment (MA). These include regulating, cultural, provisional and supporting services. Through regulating services, they reduce the impact of coastal hazards, and through their supportive services, they provide a nursery for aquatic animals, benefiting both the ecosystem and the social system. Thus, they have been recognized worldwide for their ability to reduce both exposure to hazards and vulnerabilities for communities near the coasts, providing services during and after hazards.

Mozambique, which is one of the most vulnerable countries to climate change impacts, has an extensive mangrove coverage along its coastline. Throughout the country, mangroves have been framed as crucial for their services, and various strategies and policies have been written to enhance conservation efforts. However, scattered research on mangroves throughout the country, high dominance in studying biological and physical functions, and underrepresentation of ES studies limit evidence-based decision-making. Further, the lack of studies that analyze the interactions of ES, their performance, importance, and trade-offs limits the understanding of mangroves from a wider perspective, especially when mangroves conflict with external factors such as urban expansion and climatic events. Maputo Bay, which is surrounded by urban, peri-urban, and rural areas, serves as an example of how external factors can affect the ES, despite the presence of policies and strategies.

This study aims to understand the trade-offs, performance, and importance of mangrove ES in Maputo Bay, with a focus on their regulating, supporting, and provisioning services. Moreover, this study discusses different perceptions of change in mangrove cover, as well as the external threats that affect the mangrove dynamics and, subsequently, its ES. This study used a mixed-method approach, encompassing both social and ecological perspectives of mangrove ES. Initially, this study utilized a tool called Random Forest (RF) classification to calculate the mangrove cover change between the years 2017 and 2025. Following the RF analysis, 15 stakeholder interviews, including both experts and local residents, were conducted. The interviews were one-on-one and consisted of questions revolving around temporal changes of mangrove cover, ES, trade-offs, threats to mangroves, and mangrove interventions. The interviews were later analyzed following abductive reasoning, generating six main themes along with 14 sub-themes.

The result showed contradictions between stakeholder perceptions, both in terms of temporal change and ES importance and performance. While the RF model showed an overall mangrove decrease of 1862 hectares, the majority of stakeholders mentioned an overall increase. However, when zooming in on various regions within the Maputo Bay, the observations changed. Some stakeholders mentioned localized decrease driven by factors like urban expansion, implementation challenges, and unsustainable cutting, while others indicated continuous increase attributed to factors like stricter regulations and increased safeguarding initiatives. This shows that changes in mangroves and their ES vary depending on their locations. In contrast, as RF is based on global data, it tends to overgeneralize these variations. Factors such as high resolution and 82% overall accuracy of the RF model further lead to misclassifications of the land cover classes. Overall, the RF model and stakeholders' observations present two perspectives from which mangroves can be observed, and treating these in isolation risks the accuracy of mangrove interventions.

In terms of ES, stakeholders highlighted supporting and regulating services as the most relevant, with a decline in provisioning services over time. However, similar to mangrove dynamics, the importance and performance of these services are context-specific and based on individual perceptions. Most experts focused on biophysical functions and structural characteristics, stating that mangroves in Maputo City are less well recognized for their regulating services than in the northern parts of the country. In contrast, residents highlighted the importance of protecting against hazards such as erosion and wind. The importance of supporting and provisioning services also varied in terms of their socio-economic relevance, where urban and peri-urban areas indicated less dependence on mangroves and thus less importance for their ES. This shows that despite the presence of the ES, they do not always perform highly on their provisioning services or are perceived as important by individuals.

Therefore, there is a need for more site-specific research in which different stakeholders can share the insights of their perception of ES and mangrove dynamics, thereby informing more coherent and efficient conservation policies. Moreover, there is a need to address the implementation challenges, their underlying causes, and the continuous promotion of community involvement and engagement in mangrove conservation. While this study focused solely on mangroves, there is also a growing need to understand the broader ecosystem that mangroves reside in and their interactions.

Abbreviations

ES – Ecosystem Services

MA – Millennium Ecosystem Assessment

RF – Random Forest

RQ – Research Questions

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1. INTRODUCTION

The IPCC (2022) says that there is a 50% likelihood for the global temperature to exceed the 1.5 °C threshold in the future. This means that there will be an increase in frequency and intensity of hazards such as storm surges and floods, which leads to cascading effects, such as increased risk for food insecurity, conflicts, and poverty (IPCC, 2022; Mirzabaev et al., 2023). According to UNDP (n.d.*a*), coastal areas are the most exposed to these threats, given their geographical features and proximity to coastal hazards. As a result, this impacts over 748 million people residing near the coast worldwide (Cosby & Lebakula, 2024).

Due to its features and geographical location along the Indian Ocean, Mozambique is highly prone to various hazards like tropical cyclones, floods, and droughts. The country experiences an extreme climate event every 1-3 years (UN-HABITAT, 2023; Muleia et al., 2024). The coastal area, where 60% of the population live, is the most vulnerable in the country. The country's coastal area has been affected by intense cyclones such as Kenneth in 2019 and Eline in 1999, which led to mass displacement, loss of livelihoods, and infrastructure damage (Ministry of Land and Environment, 2023). Following these events and future climate projections, mangrove management became an emerging topic in the country (Frosi et al., 2025).

Many scholars suggest various nature-based strategies to reduce the risks that prevent coastal hazards from becoming disasters (Justine & Seenath, 2025), including the use of mangroves (Macamo, 2021). Mangroves serve a high importance in climate change mitigation and adaptation through their provision of ecosystem services (ES). ES are defined as benefits that a certain ecosystem provides for human well-being (Millennium Ecosystem Assessment, 2005). These include, for example, coastal protection, biodiversity, and carbon storage, where mangroves store 3-4 times more carbon than other forests (Naidoo, 2023; Frosi et al., 2025; Omar et al., 2025). These ES are especially crucial in countries like Mozambique, which is classified as one of the world's most vulnerable nations to climate-induced changes (UNDP, n.d.*b*).

Growing attention to mangroves in Mozambique has been accompanied by increased research efforts. The latter is especially evident in the capital of Maputo, where mangroves have been shown to deliver multiple site-specific ES that provide various benefits (Macamo et al., 2015;

Macamo, 2021). These benefits include coastal protection, biodiversity conservation, tourism, research, and construction materials (Paula et al 2014; da Costa & Riberio, 2017). However, gaps remain in understanding the benefits and trade-offs of the different services, as well as integrating social and ecological perspectives. Instead, higher-level stakeholders focus on biophysical aspects, such as species ecology and carbon, and use large-scale open data, without integrating multifaceted perspectives and observations of different stakeholders (Frosi et al., 2025). Frosi et al. (2025) continue to mention that less than 10% of studies done on mangroves in Mozambique are focused on ES. It can be argued that this makes it difficult to gain a comprehensive understanding of ***how*** the mangroves function and interact in context-specific environments and ***why*** certain ES are perceived as more important than others. This highlights the premature framing of the policy-oriented term "nature-based solution" for mangrove ecosystems, which is a broader issue across different contexts, noted by Dudley et al. (2022).

These research gaps are evident in Maputo Bay, which includes a dynamic environment where mangrove interventions clash with infrastructure development in urban areas and the unsustainable cutting of mangroves for material provision in rural areas. This is reflected in da Costa and Ribeiro's (2017) estimate that approximately 90% of Maputo's mangroves have been lost over the past 50 years. The degradation progressively affects the distribution of the ES. For example, it has resulted in a decline in biodiversity supported by mangroves, including fisheries, which threatens food security and increases social vulnerability among aquaculturalists (Evidencia, 2025). Arguably, this underscores the importance of understanding the dynamics of the different ES from multiple perspectives to develop more practical interventions that reflect local use patterns and effectively target the underlying drivers for mangrove degradation.

1.1 AIM AND RESEARCH QUESTIONS

This research aims to integrate social and ecological perspectives to assess temporal changes in mangrove cover between the years 2017 and 2025 and explore the importance, performance, and interactions of mangrove ecosystem services from stakeholders' perspectives. The researched ecosystem services in this study include biodiversity support, material provision, and protection against coastal hazards in Maputo Bay, Mozambique. Furthermore, this study aims to explore the drivers that negatively impact mangroves and their Ecosystem Services. To achieve the aim, this study will combine the use of satellite images and open data, existing literature, and stakeholder interviews to answer the research questions (RQ) mentioned below:

1. How are mangrove ecosystem services perceived, and what potential trade-offs are identified by stakeholders from a socio-ecological perspective in the Maputo Bay area?
2. How do stakeholders' observations compare with the temporal changes of mangrove cover based on open data?
3. What are the perceived threats that damage mangroves and affect their ecosystem service performance in the Maputo Bay area?

1.2 SCOPE OF THE STUDY

Initially, it is essential to mention the geographical boundaries and scope of this study. Given that the focus area is Maputo Bay, this study will mainly focus on the mangroves surrounding this area, which encompasses the national park, several islands, and the capital city. Furthermore, as previously mentioned, this study will be limited to the functions of **three** ES: biodiversity support (marine species and tree cover), material provision, and coastal protection. These services encompass provisioning, supporting, and regulating pillars according to the Millennium Ecosystem Assessment (MA) (2005).

Considering climatic, ecological, and social variations worldwide, mangroves' ES are highly context-specific (Nyangoko et al., 2022). Hence, the latter services were chosen in consideration of their relevance to the Maputo Bay area, which faces major coastal hazards, while simultaneously being dependent on livelihoods from tourism and fisheries, as previously highlighted. Likewise, these services were chosen due to their multifaceted nature, meaning that they are easy to evaluate from both social and ecological perspectives, through community interviews and remotely observable functions, compared to services that require a more field-based approach.

1.3 KEY CONCEPTS

Before continuing further into this study, it is important to mention key concepts, as well as their clarifications and interconnections.

1.3.1 ECOSYSTEM SERVICES

ES are the benefits that humans acquire from a certain ecosystem (Wang et al., 2022; Vihervaara et al., 2010). They are dynamic and affected by factors such as anthropogenic processes (Wang et al., 2024; Vihervaara et al., 2010). Beyond being dynamic, they are interconnected and influence each other, both positively and negatively. For example, vegetation growth enhances carbon sequestration, thereby increasing biodiversity (Yang et al., 2024). In a broader context, ES are commonly included in policies and associated with policy-related terminology such as “nature-based solutions” (Lozano et al., 2025).

The term became increasingly recognized by the early 1990s, with emerging research but no concrete framework (Vihervaara et al., 2010). In 2005, however, the MA categorized the ES into four *pillars*: provisioning (goods and materials), supporting (ecological processes), regulating (processes that regulate environmental conditions), and cultural (recreational benefits) (Millennium Ecosystem Assessment, 2005; Vihervaara et al., 2010). MA further describes the interconnection between the socio-ecological dimensions of ES, stating that they are essential for human well-being (Millennium Ecosystem Assessment, 2005). Given the focus of this study, biodiversity support is categorized under the supporting pillar, given its support for species distribution. Material provision is categorized under the provisioning pillar, and coastal protection is categorized under the regulating pillar, in accordance with the Millennium Ecosystem Assessment (2005).

1.3.2 TRADE-OFFS OF ECOSYSTEM SERVICES

The trade-offs of the mangrove ES are the changes of one ES and its consequent effect on another (Yang et al., 2024; Rodríguez et al., 2006; Su & Liu, 2023). They can occur directly where they are influenced by each other, or indirectly, where they are influenced by an external driver (Su & Liu, 2023). To exemplify, biodiversity support services may require dense vegetation, which can obscure fishing activities and/or ocean views for other stakeholders (Le Heron et al., 2022), illustrating a direct trade-off. In contrast, urban expansion, which could be an external driver, could affect the ESs' interactions, indicating an indirect trade-off. Trade-offs are, similar to the ES, dynamic and occur across various contexts and times, influenced mostly by humans' decisions and priorities (Su & Liu, 2023). For example, Rodríguez et al. (2006) state that short-term gain of one ES may lead to long-term damage in another, illustrating temporal pressures. As a consequence, if a certain ES is impacting another in significant ways, it can lead to permanent changes like irreversible species loss (Rodríguez et al., 2006). Essentially, trade-offs can result in unequal distribution of ES across different communities (Su & Liu, 2023), increasing vulnerability through increased exposure and sensitivity to hazards or reduced livelihood opportunities.

1.3.3 PERFORMANCE AND IMPORTANCE OF ECOSYSTEM SERVICES

In this study, the performance of ES reflects on how well the service in question is functioning, oftentimes through the use of multiple indicators (Kumar et al., 2021; Breyene et al., 2021). In contrast, importance refers to how different individuals value different ES (Breyene et al., 2021). To compare the performance of multiple co-existing ES, performance is evaluated in terms of biophysical indicators, awareness, distribution, and their usage (Kumar et al., 2021; Breyene et al., 2021). Importance, on the other hand, is assessed through socio-cultural values, incorporating multiple opinions between different individuals (Breyene et al., 2021). Together, these terminologies influence each other through shaping interpretations and decisions that can affect the performance of ES (Breyene et al., 2021). Both the performance and importance of these benefits depend on several external factors, such as power relations, human-nature relations, supply and demand, as well as overall vulnerability and adaptive capacity of both the mangroves and local communities (Hölting et al., 2020; Breyene et al., 2021).

1.3.4 ADAPTIVE CAPACITY

In this study, adaptive capacity is understood as multiple factors that affect the communities' ability to respond and adapt to environmental changes and surroundings (Nelson et al., 2007; Villegas-Palacio et al., 2020). It is one of the factors that determines the level of vulnerability, as it determines how communities respond to exposures (Jakku & Lynam, 2010). Villegas-Palacio et al. (2020) further state that adaptive capacity in relation to ES can be divided into two interconnecting levels: internal and external. Internal level includes factors like knowledge dissemination, whereas the external level includes factors like access to information and resources. These levels affect each other as the external level can either constrain or enhance internal capacities, whereas the internal level assesses how well the external resources are being used (Villegas-Palacio, 2020). Within the context of this study, mangrove ES contributes to adaptive capacity through the provision of both natural and socio-economic services. But their strength depends on both internal and external factors (Foggia et al., 2025).

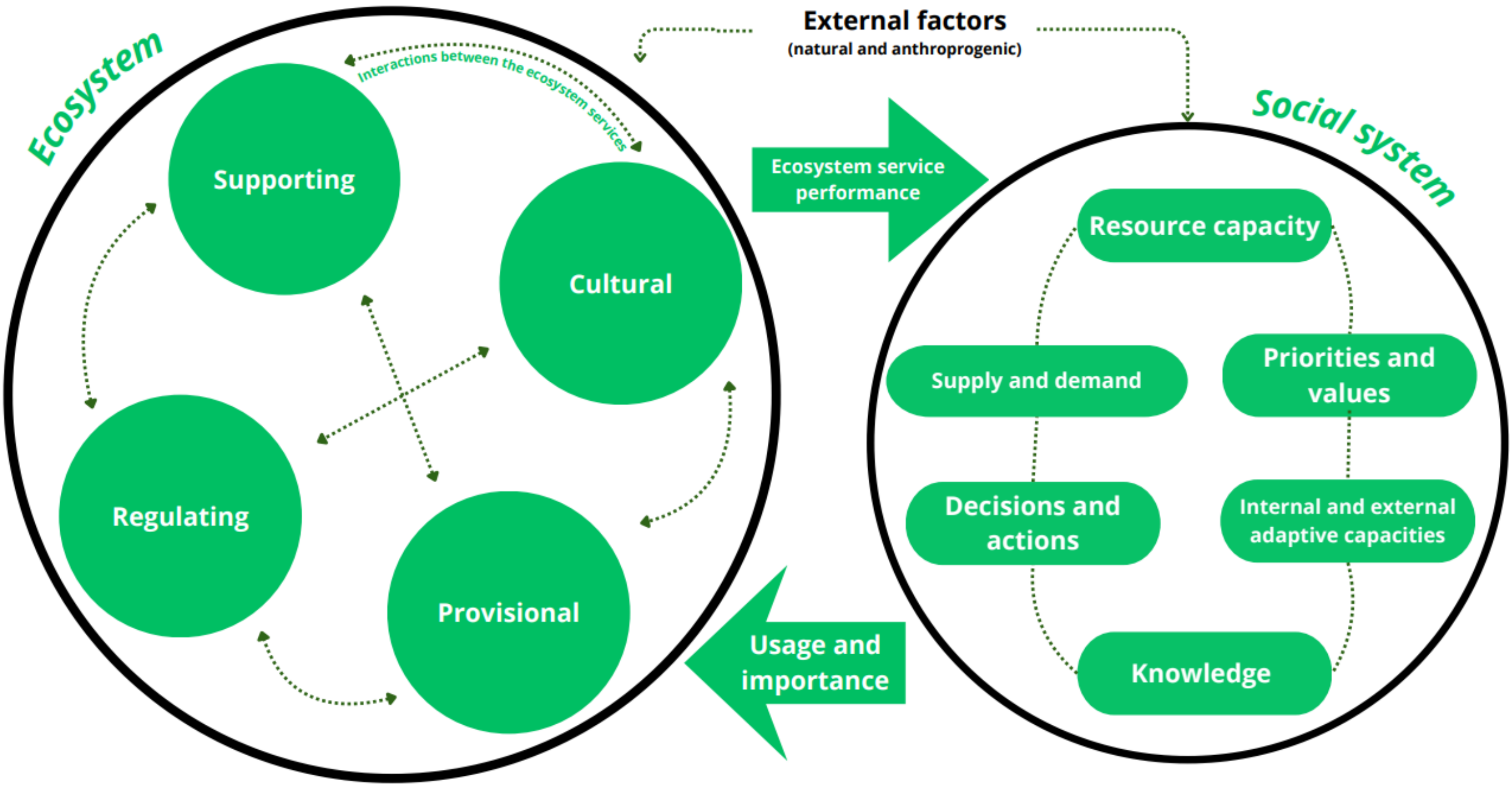
1.3.5 VULNERABILITIES

Vulnerabilities are defined as the degree of susceptibility to harm accompanied by the capacity to respond to risks (UN, 2003). In this study, the vulnerabilities are conceptualized through social and ecological pressures (Hagger et al., 2022). The social vulnerabilities at the local level include unequal distribution of mangrove ES and communities' dependence on these services. At the national/regional level, this study will also consider human-induced factors and drivers contributing to the limited capacity of the social system to effectively manage and maintain the selected ES (Hagger et al., 2022). A few examples include different values between stakeholders and priorities (Martin et al., 2025; da Costa & Riberio, 2017), creating temporal and indirect trade-offs of ES. These are social vulnerabilities, as they can form weak policies and promote silo thinking, essentially affecting the local level through high susceptibility and low response to disaster risks (UN, 2003). Ecological vulnerabilities in this study revolve around mangroves and their exposure and susceptibility to both natural hazards (Hagger et al., 2022) and anthropogenic factors. Arguably, this concept is heavily interconnected and dependent on social vulnerability. For example, due to extensive overexploitation of mangroves or urban expansion, they are becoming less able to protect against coastal erosion and storm surges (da Costa, 2016).

1.3.6 CONNECTING THE CONCEPTS

In total, this thesis encompasses five main concepts. Fig. 1 captures the conceptual relationships between these concepts, showcasing how two systems (ecosystem and social system) interact with each other. The ecosystem describes mangroves, which include the four ES pillars in accordance with MA, illustrating their interactions with each other as previously described by Su & Liu (2023). ES can influence each other through direct and indirect trade-offs, affecting the performance of ES and the distribution of benefits to the social system.

In contrast, the importance of mangroves' ES is site-specific, as expressed by Breyene et al. (2021). Factors such as supply and demand, how individuals perceive ES, awareness, individual action, and internal/external adaptive capacities affect how mangrove ES are being perceived and to what extent they are being used. At the same time, both systems are affected by natural and anthropogenic factors, such as extreme weather events and higher-level decisions. These drivers can increase social and ecological vulnerabilities that essentially influence the interaction between the two systems.



(Wang et al., 2022; Rodríguez et al., 2006; Su & Liu, 2023; Vihervaara et al., 2010; MA, 2005; Villegas-Palacio et al., 2020; Kumar et al., 2021; Yang et al., 2024; Hölting et al., 2024; Breyene et al., 2021)

Figure 1: Illustration of conceptual relationships. Illustration made by the author.

2. BACKGROUND

This chapter will start by explaining the general characteristics of mangroves, their importance, and their ES trade-offs from a global perspective, focusing on biodiversity, material provision, and coastal protection. Later, this chapter will narrow down to the local scale, focusing on mangroves in the Maputo Bay area, their usage of the three ES, threats, and current research gaps.

2.1 CHARACTERISTICS, ECOSYSTEM SERVICES AND PERCEPTIONS OF MANGROVES: THE GLOBAL PERSPECTIVE

Mangrove ecosystems are commonly described as saline-resilient trees and/or shrubs located in tropical dynamic coastal areas (UNEP, n.d; Naidoo, 2023). Globally, they cover 14.8 million hectares of coastal areas, with annual fluctuations reflecting losses and gains, which are mainly attributed to anthropogenic factors (FAO, 2023). Nevertheless, these ecosystems provide various ES, ranging from supporting to provisioning, benefiting the coastal communities and the surrounding ecosystem (Naidoo, 2023). For example, the biophysical features of mangroves include a root system that can survive waterlogged soil, thereby contributing to ecosystem stabilization and providing habitat that supports marine biodiversity (Srinkath et al., 2015). Srinkath et al. (2015) further add that their root system contributes to sediment accumulation, which in turn reduces coastal erosion and absorbs wave energy, protecting nearby communities.

Subsequently, ES can lead to a source of livelihood from a socio-economic perspective. For example, Dulyakasem et al. (2026) mention that three coastal communities in Thailand have benefited from mangroves' different ES. For example, 72% of the residents have generated income from mangrove ecosystems in the form of ecotourism and fisheries. Similarly, throughout the villages of Bhitarkanika, India, Rasquinha & Mishra (2021) state that fuelwood supplies a significant amount of the daily needs, highlighting the high valuation of the supporting services that mangroves provide.

From a disaster risk reduction (DRR) perspective, mangroves' ability to withstand harsh conditions and reduce the impact of coastal hazards makes them an essential asset in protecting coastal communities (Lai et al., 2022). They are usually the first barrier that absorbs the impact of strong winds and waves. For example, during Cyclone Idai in 2019, which struck the central part of Mozambique, mangroves were recognized for their role in protecting the nearby infrastructure against coastal hazards (Macamo et al., 2021). Similarly, mangroves acted as a wave barrier during the 2004 tsunami in Aceh, Indonesia, and later provided supporting services, raising incomes for the affected families (Chen, 2021). This shows the varying socio-ecological benefits that mangroves can provide, in terms of reducing both immediate and long-term vulnerability to disasters.

While the aforementioned authors highlight the benefits of ES, many scholars, such as Dahdouh-Guebas et al. (2020) and Afonso et al. (2022), highlight prevailing negative impressions of mangrove ecosystems and perceived trade-offs of ES. These include negative perception of the mangroves' support for biodiversity, for example, that mangroves contain "dangerous animals", increased risk for invasive species, and mosquitoes that can lead to the spread of vector-borne diseases (Dahdouh-Guebas et al., 2020; Afonso et al., 2022). Other negative perceptions can be influenced by different values between stakeholders and priorities. For example, urbanization pressures can lead to an indirect trade-off between urban expansion and the response of mangrove ES, where municipalities prioritize population growth and short-term immediate results over long-term ES benefits, as exemplified by Ureta et al. (2025). This de-prioritization of mangroves and their ES is attributed to various context-dependent factors. For example, in the study by Ureta et al. (2025) in Ecuador, they are attributed to a lack of resources, while da Costa and Ribeiro's (2017) study in Maputo, Mozambique, highlights limited scientific evidence of mangroves regulating services in that region. For these reasons, mangroves worldwide have been undervalued for years, overlooked for their broader benefits, and evaluated in terms of trade-offs instead (Worthington & Spalding 2018).

However, it is important to note the relationship between the extent of mangrove ignorance and their protective services, as continued mismanagement and degradation increase mangroves' vulnerability to coastal hazards and may ultimately make them ecologically vulnerable (Charrua et al., 2020). These issues come down to the interactive and interconnected nature of mangroves' multiple perceived ES, such as material provision, and their clash with enhanced protectiveness and biodiversity support (Rodríguez et al., 2006). To give an example, McNally et al. (2011) note that prioritizing one ES, such as fuelwood provision, can unintentionally reduce the regulating services as mangrove cover decreases. Therefore, it can be argued that it can be difficult to see the benefits of mangroves and easier to frame them as ineffective. In addition, Dahdouh-Guebas et al. (2020) state that the negative perception of mangroves, such as mosquitoes or mangrove cover that obscures the view, is a natural process of a mangrove ecosystem. Many authors state that they can be mitigated through various initiatives such as effective conservation efforts and awareness-raising (Dahdouh-Guebas et al., 2020; Afonso et al., 2022).

2.2 FROM GLOBAL TO LOCAL: MANGROVE ECOSYSTEMS IN MAPUTO BAY, MOZAMBIQUE.

Maputo Bay is an area located in southern Mozambique, surrounded by the coast of Maputo City as well as various islands, including Portuguese and Inhaca islands (see Fig. 2). The subtropical climate leads to seasons with intense rainfall and cyclones that typically last from November to April, where 46% of Maputo's coast is susceptible to fluvial floods (Foggia et al., 2025). The flood risk is especially evident in low-lying areas, where the low-income communities that are dependent on climate-sensitive livelihoods live (Evidencia, 2025; Dürrangel et al., 2025). For example, from a national perspective, around 2.4 million people are dependent on aquaculture, and 28,000 are dependent on ecotourism, where mangroves are becoming increasingly recognized (FAO, 2023; Government of Mozambique, 2018). A significant portion of livelihoods relies on mangroves, which cover approximately 18,000 ha of the Maputo Bay area as of 2022 (Machava-António, 2022).

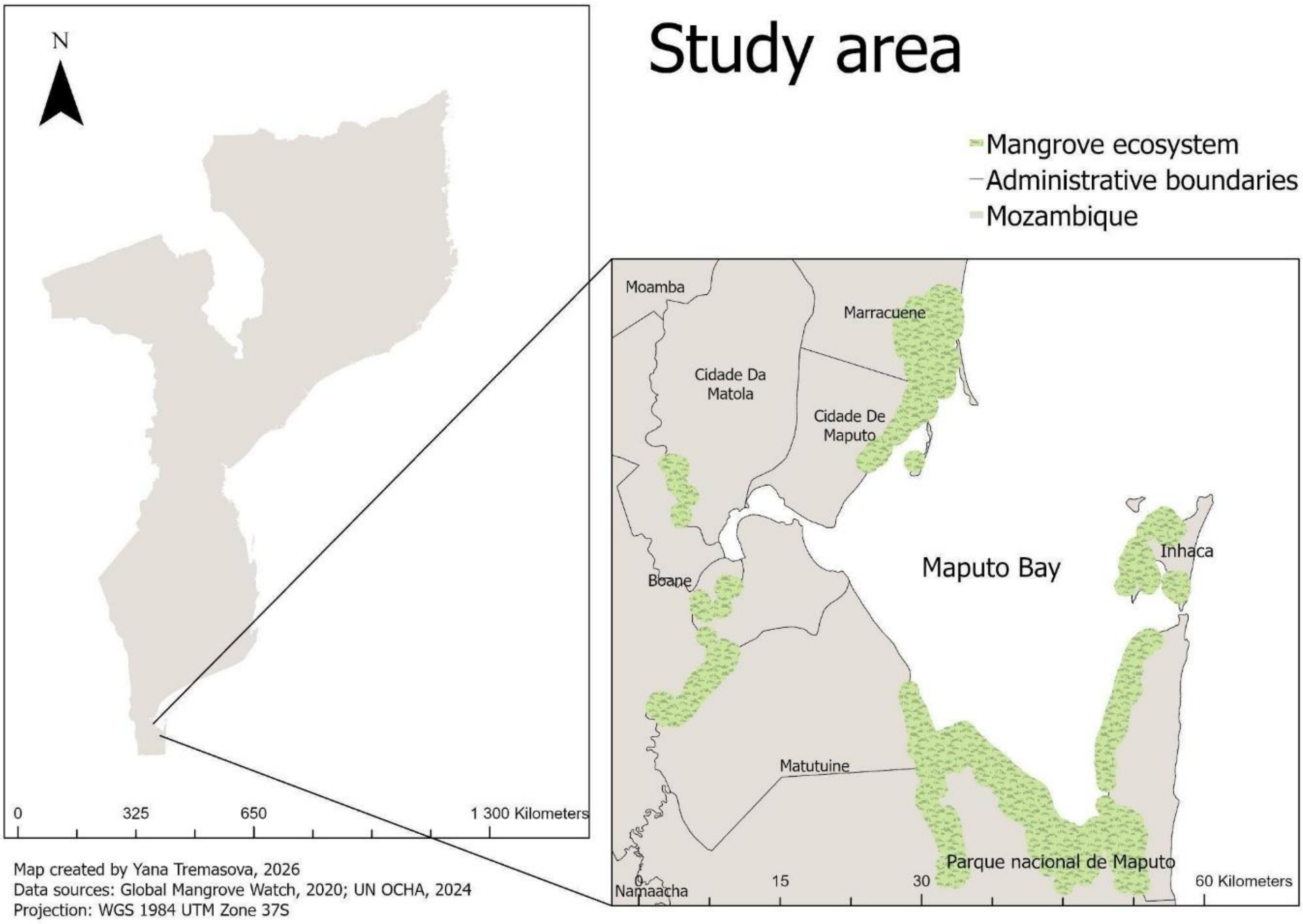


Figure 2: Illustration of the study area with mangrove ecosystems covered with 1 km buffer.

In practice, the limited implementation of policies at the national and regional levels can challenge their realization. For example, in 2020, the government of Maputo proposed a “Mangal Management Strategy” that has been operationalized between the years **2020-2024** (360 Mozambique, 2023). This plan aimed to promote sustainable mangal management through incorporating multiple stakeholders and communities into the implementation process, as well as enhancing capacities and acknowledging uncertainties within the current research gaps (The Council of Ministers, 2020). Some sources have reported increased mangrove cover and engagement following these policies (IUCN, 2025), whilst others reported that national policies have not been effectively operationalized at local levels (Evidencia, 2025). Instead, there are indications of continuous degradation of mangroves, which has destroyed nesting areas for fish and invertebrates (Evidencia, 2025).

Moreover, a recent study by Rodrigues (2024) highlights the continuous prioritization of roads and infrastructure over mangroves, especially within Maputo City. For example, in the Costa do Sol area (see Fig. 3), infrastructure was constructed in front of the mangroves, dislocating them from the sea. Consequently, this area has suffered major flood events, as roads were not built to withstand the capacity of coastal hazards (Rodrigues, 2024). In other, more peri-urban and rural areas surrounding the bay, such as Inhaca Island and Maputo National Park, conservation and restoration efforts are more extensive, leading to the effective provision of ES, such as increased biodiversity (Peace Parks Foundation, 2025; Massango, 2023). Inhaca Island has several mangrove research sites where an increase in canopy cover has been observed in the early decades of the century, driven by both natural processes and human influences, despite the island’s high population density and dependence on natural resources (de Boer, 2002). This illustrates how ES performance changes when importance is considered.

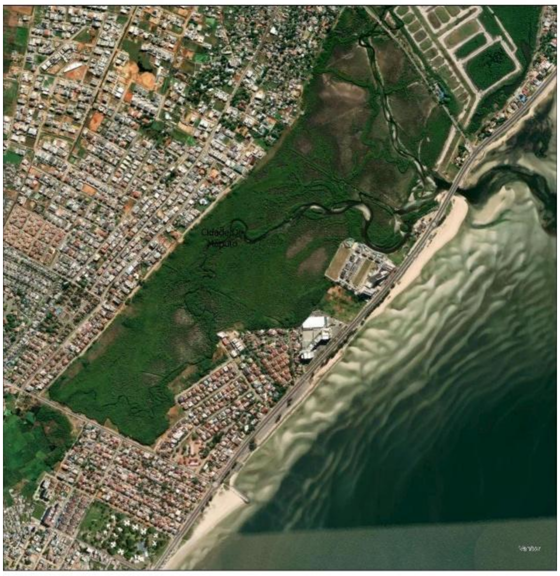


Figure 3: Illustration of mangroves surrounded by infrastructure in Costa do Sol, Maputo City.

2.3 ONGOING RESEARCH AND CURRENT GAPS WITHIN MANGROVE ECOSYSTEM SERVICES IN MOZAMBIQUE

The emerging research on mangroves is scattered throughout the country, with higher emphasis on the central and northern parts of Mozambique that contain larger mangrove ecosystems than the Maputo Bay (Barbosa et al., 2001). Instead, Maputo province continues to rely on gray infrastructure and innovations for climate change adaptation and mitigation. Consequently, only scarce evidence of mangrove importance exists in Maputo Bay (da Costa, 2020).

From a national perspective, there is also an overemphasis on species science and ecological perspectives, focusing on *functions* instead of *services* (Frosi et al., 2025). In contrast, there are only a few studies that focus on socio-ecological values and ES, primarily using qualitative data, as shown by Candeago et al.'s (2023) study on Inhaca Island of Maputo Bay. In this study, residents were interviewed about their perception of mangroves and their ES, where provisioning, cultural, and regulating services dominated, and where the participants mutually agreed on increased protection of the mangroves. Outside of Maputo Bay, similar studies that try to address some of these research gaps include a study by Come et al. (2023) in Inhambane Bay, Mozambique, where a socio-ecological approach was used to evaluate the performance of different ES, stating high community awareness but weak enforcement mechanisms from higher levels.

The aforementioned studies show various angles of mangrove performance and importance within and outside of the Maputo Bay region. However, they either validate Frosi et al’s (2025) statement of overemphasis on ecological and functioning aspects or fail to fully integrate the socio-ecological aspects in terms of ES and their trade-offs. This type of research in Maputo Bay is still scarce, providing an insight into research gaps highlighted by Frosi et al. (2025). From a global level, these gaps are still persistent as well. For example, Hölting et al. (2020) mention the importance of the drivers behind the values of ES, such as supply and demand, and different stakeholder conflicts that are often overlooked in studies that focus primarily on isolated stakeholder groups. Furthermore, trade-offs within the ES and their dynamics, especially the indirect ones, are under-researched due to the difficulties in identifying the drivers and case-specific factors (Su & Liu, 2023). This leads to inconsistent interventions and ecosystem management (Su & Liu, 2023). As mentioned in the introduction, this highlights a significant research gap in understanding the reasons behind the interactions of specific ES, which is arguably essential for more informed decision-making.

4. METHODOLOGY

The study design includes a case study that adopts a mixed-methods approach, combining both machine learning to detect mangrove changes with local interviews to interpret perceptions and the importance of mangrove ES. This approach enables pattern establishment where relationships will be examined both across and within the qualitative and quantitative datasets (Creswell, 2013). The quantitative method includes the quantification of the temporal change of mangrove cover, using the Random Forest (RF) analysis tool in ArcGIS software. The qualitative method includes stakeholder interviews, where stakeholders are asked about their perceptions of mangrove changes, mangrove ES, their performance, and importance in Maputo Bay.

Through data analysis, these methods are integrated following an abductive approach. According to Blaikie (2010), abductive reasoning seeks to understand and explain incompleteness and inconsistent observations, which is especially relevant given the interplay between the secondary and primary data used in this study. Therefore, rather than following a pre-defined hypothesis or forming a grounded theory, this approach moves between theoretical concepts described in the background and the results derived from the methods to generate a conclusion (Blaikie, 2010).

4.1 REMOTE SENSING MANGROVE DYNAMICS: INTRODUCING A RANDOM FOREST CLASSIFICATION MODEL

There are various ways to remotely assess mangrove dynamics in the form of losses and gains. The most common method, however, is to utilize RF classification, which is a supervised tool available in various geographic information systems (GIS) platforms (Chaiyana et al., 2025; Purwato et al., 2023). The tool was initially created by Leo Breiman in 2001 and introduced in the article "*Random Forest*", to create a method that combines multiple decision trees for classification tasks, making it suitable for various range of applications that include forest dynamic analysis (Breiman, 2001). Being a supervised method, the tool learns from high-quality and high-precision data points, building on past observations to identify land-cover classes and predict outcomes for the new input data (Salman et al., 2024).

To date, RF has been globally used to classify mangroves as well as detect and quantify net changes over a set time span, utilizing different tools ranging from elevation models to field-collected GPS points (Purwato et al., 2023; Hu et al., 2018; Fernando & Macamo, 2023).

Various open sources, such as Global Mangrove Watch (GMW), use the RF tool for science-backed decision-making on mangrove mapping and extent to define hotspot areas for conservation and restoration (CEOS, 2024), strengthening its global relevance. Moreover, various studies, such as Prodhan et al. (2025), use RF to study socio-ecological perspectives of mangrove ES, using different indicators. This illustrates the model's relevance and its multi-use within mangrove studies.

4.1.1 TEMPORAL CHANGE DETECTION ANALYSIS OF MANGROVES IN MAPUTO: TRAINING THE MODEL

To perform mangrove change detection, this study used RF, which is identified as '*Forest Classification and Regression*' in the ArcGIS Pro software. Due to the lack of publicly available data in Mozambique, the RF tool was trained through manual creation of land cover classification points. This methodology is verified by similar studies in Mozambique that used manual classification to train RF (Fernando & Macamo, 2023).

In order to do a manual classification, a Sentinel 2L satellite image displaying Maputo Bay was downloaded from the Sentinel EO browser hub and imported into ArcGIS Pro, with an applicable projection to Mozambique. The image contained minimal cloud coverage (0%), with July 2025 as the chosen month, as it is considered a part of the dry season in Mozambique (The World Bank Group, 2025) and thus provides enhanced visualization of the mangroves without additional noise (Bezerra et al., 2023). To further reduce inland and offshore misclassifications, mangrove polygons were buffered by one kilometer (km), following the recommendation of Liu et al. (2008) that potential mangrove areas usually occur within this distance. Additionally, Hu et al. (2018) note the challenges the RF model faces in distinguishing mangroves from large-scale water pixels, further justifying the buffering.

To semi-automate the classification process, mangrove polygon layers were downloaded from GMW, displaying the year 2020, and modified into the 2025 image, aiding in identifying mangrove areas. Smaller areas containing mangroves that could not be downloaded through GMW were manually digitized into polygons and buffered accordingly. The buffered output layer corresponds to the study area shown in Fig. 2. Consequently, all of the Sentinel 2L bands displayed in Table 1 below were clipped to this extent. To train the RF model, approximately 2300 points in total were manually created within the buffering zone and classified into "mangrove" and "non-mangrove" features. These points served as input for the RF model, along with the clipped Sentinel 2L image from 2025, displaying NDVI and NDWI indices, along with the raw bands mentioned in Table 1 below. These bands and indices allow the RF model to easily distinguish between vegetation, water, and other features through the use of various short-wave bands and infrared light (Ashok et al., 2021; Liu et al., 2008). Lastly, the tool allows a proportion of the sample points to be reserved for validation, which were subsequently used for map accuracy assessment and excluded from the training process. Following the recommendation of Gülci et al. (2025), 25 % of the points were allocated for validation, while the remaining 75 % were used to train the RF model.

To conduct change detection and showcase mangrove dynamics over the past eight years, a Sentinel 2L image from 2017, taken in July with 0% cloud cover, was downloaded from the Sentinel EO browser hub. This image was clipped to the mangrove polygon area and used in the RF model with the same spectral bands. The 2025 image and bands were retained as the primary input, while the 2017 image and bands were instead included as explanatory variables. After both classifications were produced, a raster calculator was used to subtract the classifications and identify pixels that had changed. The result was later converted into hectares.

Table 1: Illustrating all of the data that was downloaded for Chapter 4.1.1

Type of data	**Year**	**Resolution (m)**	**Bands**	**Source/website**
Sentinel 2L	2025	31	True color, NDVI, NDWI, raw band(s) 1,2,3,4,5,6,7,8,8A9,11,12	Copernicus Browser (n.d.).
Sentinel 2L	2017	31	True color, NDVI, NDWI, raw band(s) 1,2,3,4,5,6,7,8, 8A, 9, 11, 12	Copernicus Browser (n.d.).
Polygon	2020	25	N/A	Bunting et al. (2022).

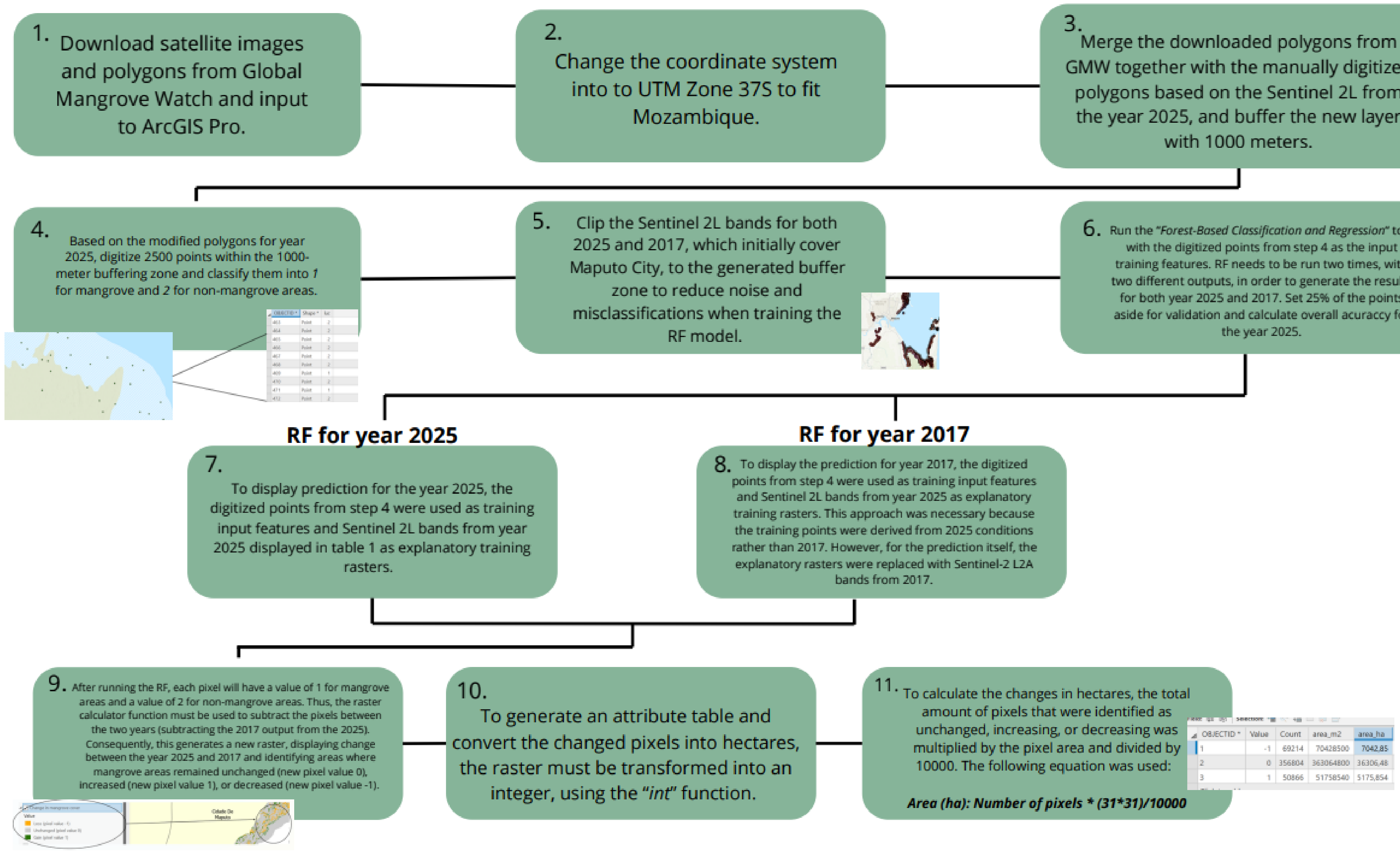


Figure 4: Visualization and general workflow for RF change detection between the years 2017 and 2025 in Maputo Bay. Illustration made by the author.

4.2 INTERVIEWS

Semi-structured interviews were conducted to assess the benefits and trade-offs of the ES and mangrove changes. By adding a social perspective, comparison across data sources was possible. The interviews were held both in-person and online through Teams and consisted of closed-ended questions for general background information and open-ended questions for insights that will help answer RQ 1, 2, and 3 (see Appendices 1 and 2). The interview guide also allowed for follow-up questions. Previous studies, such as those from Su & Liu (2023) and da Costa & Ribeiro (2017), were used as inspiration during the creation of the interview questions. Initially, a total of 23 secondary stakeholders were contacted. Out of these, 9 secondary stakeholders responded and were interviewed, consisting of *experts, researchers, consultants, and key informants* who work on mangrove-related projects from various organizations and institutions. To get a perspective from local residents, 6 primary stakeholders were interviewed, including *aquaculturalists, residents, and guides.* Both primary and secondary actors had the same interviewing guide, with the same predetermined questions and structure. The questions were categorized into different parts, consisting of mangrove dynamics, ES, trade-offs, threats, adaptive capacities, and social and ecological vulnerability. As mentioned in the introduction, the focused ES discussed during the interviews consisted of provisioning, supporting, and regulating pillars, excluding the cultural pillar. Due to the diverse geographical specialization of certain stakeholders, the interview guide allowed for elaborations and comparisons of the mangrove ecosystems in the northern parts of Maputo.

Due to the small sample size of primary stakeholders, they were identified through combined sampling methods, depending on location and local dynamics, as interviews were conducted in Costa do Sol and Inhaca Island. Purposeful sampling, which is commonly defined as intentional or targeted collection of data (Tajik et al., 2024), was used whenever possible. Through this sampling method, participants were chosen based on their profession, connection to, and knowledge of the mangroves. In contrast, the snowballing method was used in areas where primary stakeholders were difficult to identify and where trust-based access was necessary. The secondary actors, however, were mainly identified through host contact from NIRAS and Eduardo Mondlane University, who maintain strong connections and trust with various institutions surrounding the Maputo Bay area, and were further identified using a snowballing method, where interviewees recommended additional relevant contacts.

4.2.1 CODING PROCESS AND ANALYSIS OF THE INTERVIEWS

The coding and analysis were conducted as a thematic analysis, where the results were coded and organized into broader themes (Creswell, 2013). The responses from the interviews were voice-recorded through Teams for online interviews and voice memos for on-site interviews. The voice recordings were subsequently transcribed through TurboScribe, which is a software that converts audio and translates from Portuguese to English, which in this case was needed when the primary stakeholders were interviewed. To maintain the anonymity of the participants, the secondary interview participants were named TI 1, TI 2, et cetera, whereas the primary participants were identified as TIP 1, TIP 2, and so forth. In addition, sensitive and personal information such as names and personal experiences were erased from the transcription files before the coding phase. The transcriptions were later coded through NVivo software, where the emerging codes were manually created and organized for every interview.

Initially, the analysis followed an open coding process, which aimed at dismantling the raw data into general codes. Subsequently, as similar wordings or ideas emerged in the interviews, the codes were organized into initial, informal categories. This approach helped identify patterns, contradictions, and inconsistencies within the data, which informed the subsequent axial coding phase, where relationships between codes were further developed and refined. This phase identified 169 initial codes. During the axial code phase, the initial codes were re-analyzed with the corresponding interviews, following the recommendation of Vila-Henninger et al. (2022) that mentions the importance of validating initial interpretations to generate representative and precise codes. Furthermore, the codes were iteratively compared with the literature and the RF model, through which more refined and detailed categories were developed to organize the codes. As a result, the initial 169 codes were reduced to 139 codes, as some were further merged while others were excluded due to their limited relevance to the analysis. Memo writing was used both during the open and axial coding phases, as it creates early engagement with the data and the ability to revisit early insights and interpretations of the results (Vila-Henninger et al., 2022; McLeod, 2024). Based on the outcome of the coding phases and memos, six overarching themes were identified, along with 14 sub-themes. The main themes were derived through recurring and similar codes, whereas sub-themes were created to further specify each theme.

4.3 METHODOLOGICAL LIMITATIONS

The methodological limitations of this study include its reliance on secondary data with coarse resolution and interviews. Satellite disturbances such as cloud cover, land class misclassifications, and tide alterations (Chaiyana et al., 2025) were addressed by focusing on

0% cloud cover, the clearest season, and a buffer around the identified mangrove ecosystem. However, limitations such as misclassifications still occurred. For the assessment of mangrove cover, the methodology's primary focus was on the impact of coastal hazards and anthropogenic practices. However, on-site measurements and validations were not performed, which limits the precision of the results and increases the risk of assumptions, misclassifications, and lower map accuracy. Furthermore, given that mangroves are situated in an interconnected ecosystem together with other vegetation such as seagrass, bushes, and other tree species (Carlson et al., 2021), it is difficult to perform change analysis and attribute the decline solely to mangrove ecosystems, which essentially draws back to increased risk for assumptions and misclassifications. In addition, important factors that can also influence the performance of the mangroves include, for example, species distribution and salinity levels (Chaiyana et al. 2025). As these factors were excluded in the methods, it leads to simplifications of an otherwise interconnected complex system, hindering a comprehensive overview of the mangroves' state. However, this is not seen as a significant weakness, as this study still investigates the interactions between the different ES and can be used as a base for more detailed studies.

A full overview and representation of the overarching Maputo Bay area is also limited to only 6 primary and 9 secondary actors. In contrast, these actors serve as an insight into the local residents' perspectives through a qualitative analysis. Still, this was treated as a potential limitation, as this study cannot speak for all the actors within the study area. Furthermore, important actors that were initially considered, such as municipal planners and governmental workers, were not interviewed, limiting the viewpoints to mainly researchers and experts. Similarly, primary stakeholders who wanted to speak in Shangaan, one of the local languages in Maputo, were not interviewed. This is because the transcription software TurboScribe lacked direct translation to this language, which would limit researchers' interpretation of the interviews. At the same time, this approach limits the selection to Portuguese-speaking participants, filtering out potentially important insights from the local population.

Another limitation includes language differences and interpretations. As English is not the primary language for any stakeholder who was interviewed, their ability to fully express their perspectives may have been constrained. On the other hand, for the primary stakeholders who were interviewed in Portuguese, some meanings and sentences have been lost during the translation process and therefore required interpretation by the researcher. Expressions, meanings, and words are culture- and language-specific, and some experiences may not be fully captured in words (van Nes et al., 2010). Additionally, some expressions or sayings cannot be directly translated into English. As a result, the researcher must interpret multiple perceptions, which may lead to changes or loss of initial meaning, potentially generating misinterpreted codes.

4.4 ETHICAL CONSIDERATIONS

Several ethical considerations were considered for both the RF training and interviewing. Regarding the RF approach, Fernholz et al. (2024) highlight several ethical concerns associated with the use of open data, including the risk of misuse, treating existing datasets as ground truth, localization issues related to identifying individuals, informed consent, and bias. In this study, these issues were addressed through transparent documentation of the data sources, spectral bands, and thresholds used, as well as by avoiding the presentation of exact locations of primary and secondary stakeholder interviews. Furthermore, gaps in data, such as potential misclassifications of mangroves by the RF model, are acknowledged to avoid presenting the RF data as fully representative of local realities. These are addressed using validation points, which ultimately present the overall accuracy of the RF model, as further discussed in the Results. The bias includes both assumptions of ES based on mangrove dynamics and the classification of mangrove areas. Therefore, while RF was helpful for the analysis and overarching picture, it risks oversimplifying and underestimating contextual issues, representing a broader issue with using open data, as noted by Schmit et al. (2006) and Amaral et al. (2023). To mitigate these biases, local stakeholders were interviewed.

Regarding the interviews, SRA (2021) and Creswell (2013) mention various ethical issues, including anonymity, transparency, and consent. Since this study includes interviews of stakeholders, where some of them are potentially dependent on mangroves, ethical issues such as topic sensitivity and trust can arise. Firstly, as the research is conducted from a Western academic perspective, differences in ontological and epistemological viewpoints may exist between the researcher and interviewees, which could unintentionally influence the structure and content of the interviews. As the fieldwork was taking place for a month, the author might not have had the opportunity to gain the residents' trust completely. For this reason, questions could create unintentional discomfort or misunderstandings. To address these issues, the interview questions were reviewed by the host contact from Eduardo Mondlane University, who ensured that the questions were harmless for the stakeholders. Further, the university also provided a local translator (recent graduate) fluent in both Portuguese and Shangaan to assist during the primary stakeholder interviews. This approach was chosen to support inclusive engagement with the local population and provide a mutual learning opportunity.

All of the interviews were conducted through informed consent that included a verbal agreement between both parties. Initially, the stakeholders were presented with a "terms and conditions" document outlining information about the author, the purpose, and the process of the interviews. The document consists of information about how their answers would be processed in accordance with the principles of anonymity and voluntariness, following SRA's (2021) recommendations. The interviewees were also reminded about the contents of this document before starting the interview. Furthermore, no monetary benefits were provided to primary or secondary actors in this study, which they were also informed about before the interview. While SRA (2021) highlights several advantages of financial compensation, Masoumi (2024) argues that such payments can also be perceived as exploitative, presenting an ethical dilemma. In the context of this study, offering monetary benefits could be seen as unfair if they were provided to primary actors but withheld from secondary actors. This measure was explicitly addressed in the study's terms and conditions document.

The issues of power imbalances and perception still prevail. While being supported by a national university can increase credibility, it can also influence the primary stakeholders' responses (Anyan, 2013). It can even unintentionally pressure them to participate due to perceived expectations, especially given the university's involvement in mangrove restoration activities, even when informed consent has been obtained.

Regarding the dilemma of both online and on-site interviews, SRA (2021) mentions the differences in seeing facial expressions and looking for social cues. Moreover, SRA (2021) mentions the importance of finding a safe and quiet environment so that the participants can have a quiet and safe place to express their opinions, which the option to conduct interviews on-site or remotely provides for the secondary actors. Social cues were monitored during all the interviews, and participants were reminded that answering was entirely voluntary and of their right to end the interview at any time or refuse to answer a certain question. This way, coercion could be avoided, and a more equal balance of power between the interviewee participant and the interviewer could be obtained (Anyan, 2013).

5. RESULTS AND DATA ANALYSIS

This chapter consists of results from both RF assessment and interviews. Initially, the results from the change detection analysis are presented, along with an analysis of the outcomes. Further, the results from the interviews are presented, where the themes and sub-themes are described, illustrated, and compared with the RF analysis.

5.1 RESULTS FROM TEMPORAL CHANGE DETECTION ANALYSIS

Fig. 5 showcases temporal changes in mangrove cover between 2017 and 2025 in both eastern and western parts of Maputo Bay. It can be seen that certain parts of Maputo Bay experience localized changes, such as Inhaca Island (top right zoomed-in illustration on the eastern Maputo Bay), which seems to mostly visualize an overall increase, while Maputo City seems to visualize an overall decrease (top right zoomed-in illustration on the western Maputo Bay). It can also be seen that certain areas remained unchanged, such as the bottom-right zoomed-in illustration of Western Maputo Bay.

The figure also highlights potential errors in the RF tool's output. The RF model reached 82% overall accuracy, based on 25% of the validation points used for the map accuracy assessment. This means that 18% of the validation points were misclassified. This indicates that the tool did not accurately capture all spatial patterns, making the map fairly reliable but less accurate at the local scale. For example, it incorrectly detected an increase in areas such as Maputo City and Inhaca Island in land cover classes that were not considered mangroves.

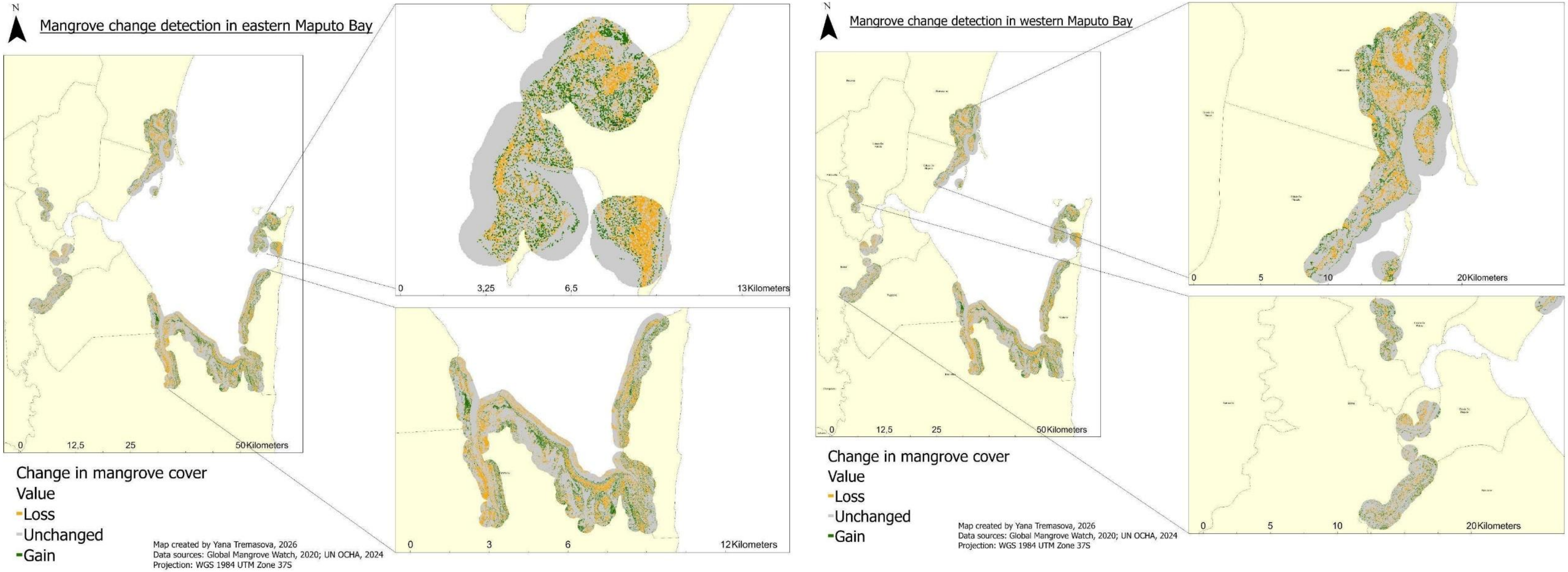


Figure 5: Map of Maputo Bay displaying temporal changes in mangrove cover between the years 2017 and 2025, with a 1 km buffer.

Table 2 shows total mangrove loss and gain in hectares (ha) within the study area, as well as net mangrove change, which is 1862 ha loss. This table represents an overall change, however, when comparing it to Fig. 5, it can be seen that the orange color, representing mangrove loss, is mainly concentrated in Maputo City, the Maputo National Park area, and the Maputo River, which shows significant loss (bottom right zoomed-in illustration on the eastern Maputo Bay).

Table 2: Illustration of temporal mangrove change between the years 2017 and 2025 in hectares (ha).

Mangrove loss (ha)	**Mangrove gain (ha)**	**Net mangrove change (ha)**
7042	5175	-1862

5.2 RESULTS FROM THE INTERVIEWS

As previously mentioned, the interviews created 169 initial codes, which were narrowed down to 139 and grouped into 14 detailed categories. Based on these codes and categories, six overall themes and 14 sub-themes emerged, which are presented in Fig. 6 below.

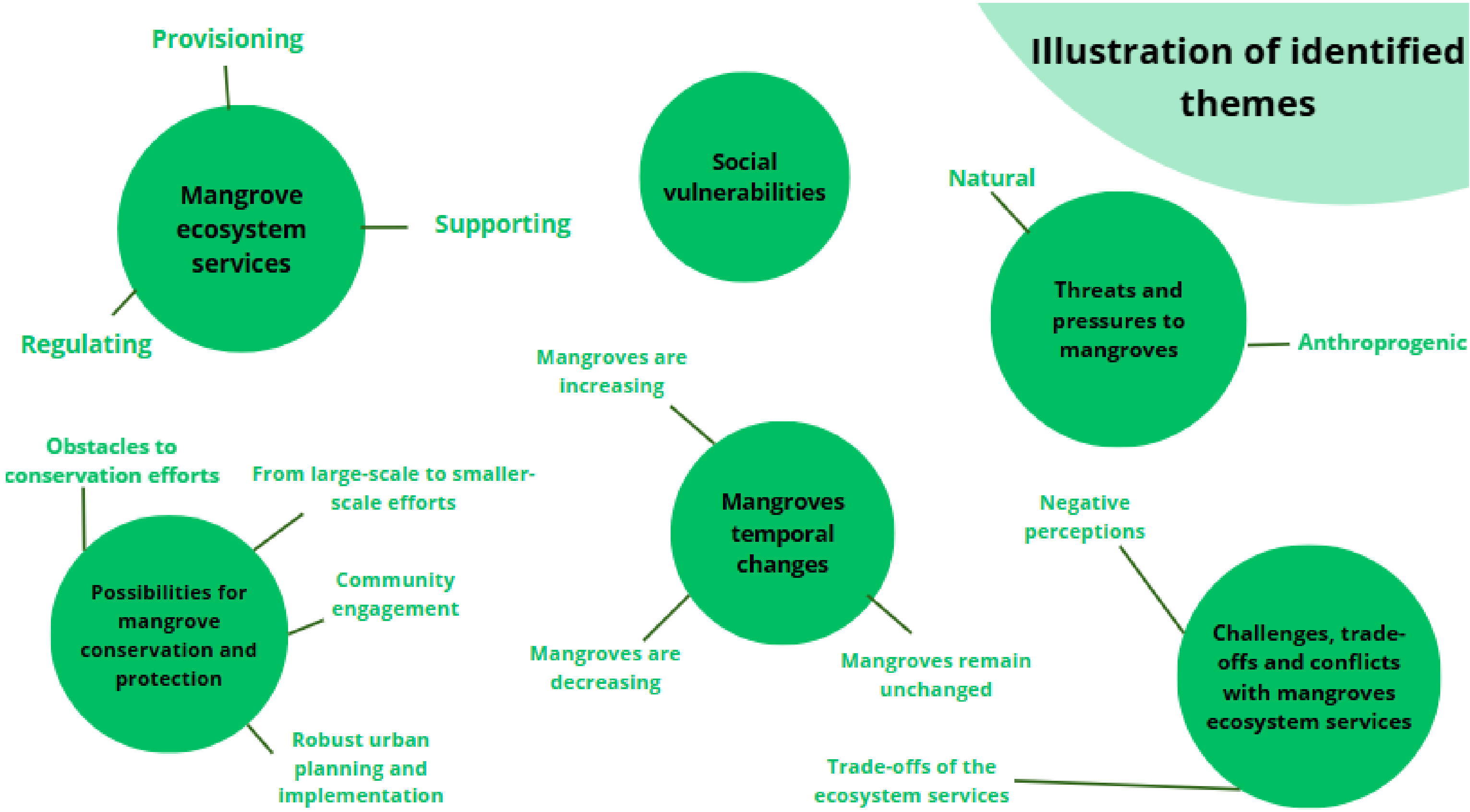


Figure 6: Illustration of identified themes. Illustration made by the author.

Mangrove ecosystem services

Both primary and secondary stakeholders mentioned perceived social and ecological values from mangrove ecosystems, highlighting all four pillars in the MA. While four secondary stakeholders mentioned the cultural pillar, where mangroves hold a spiritual meaning and are used as a space for praying, cleansing, and ecotourism, this pillar will not be discussed in detail, as it falls beyond the scope of this study in the context of Maputo Bay.

Provisioning

Provisioning service was one of the most discussed, where the provision of charcoal and fuelwood was frequently mentioned. The answers under this theme were scattered, with most secondary stakeholders mentioning that mangrove logging is context-specific, with large variations depending on the mangrove species, structure, geographical locations, and demand. For example, three secondary and one primary stakeholder mentioned that Maputo City and the surrounding urban areas within Maputo Bay have alternative material options, thus reducing the need for the provisioning of ES, compared to rural areas. In addition, one secondary stakeholder mentioned that mangroves in Maputo Bay are usually crooked and small, limiting their utility. Other secondary stakeholders compared the usage of provisioning service with the northern parts of Maputo, highlighting that the species distribution and wood quality are generally higher in the north, leading to a higher demand that can be used to construct fishing boats and fishing traps due to its saline tolerance compared to other woods. However, certain secondary and primary stakeholders highlighted that the provisioning service is still used within Maputo Bay, while others mentioned that the demand has decreased due to prohibitions and protected areas such as Inhaca, showcasing a contradiction in the actual usage of this service.

"*No not anymore of course it's illegal now. Sometimes it might happen, [...], but it's not common to see anymore*" - Secondary stakeholder.

In contrast to secondary stakeholders, the majority of the primary stakeholders in Maputo Bay highlighted that this service is not attractive anymore due to regulations and restrictions. One primary stakeholder mentioned that cutting mangroves is "*no longer in fashion*". Four primary stakeholders mentioned ongoing issues with mangrove logging for personal consumption, stating how it has disrupted the mangrove ecosystem and caused fish to go offshore. In total, nine stakeholders, two primary and seven secondary stakeholders, mentioned ongoing use of provisioning services for charcoal or consumption. Furthermore, two primary stakeholders and five secondary stakeholders mentioned mangrove cutting for small infrastructure, such as barracks and fences. One secondary stakeholder mentioned cutting for village expansion, however, this can also mean degradation to increase land rather than direct use of the services.

Regulating

Both secondary and primary stakeholders mentioned regulating services such as carbon sequestration and mitigation against erosion, flood impacts, soil stabilization, infrastructure, and wind protection. Five primary stakeholders reported that they have been directly protected from wind gusts and coastal erosion. Similar to the provisioning services, three secondary stakeholders mentioned that these services are more evident in the northern part of the country, which is more susceptible to coastal hazards and cyclones compared to Maputo. For this reason, the regulating services of mangroves in Maputo Bay are less documented. Three secondary stakeholders mentioned that it is difficult to attribute the regulating services solely to mangroves, due to Maputo's dependence on other mitigation efforts and mangroves' interplay with other vegetation, such as seagrass. Others noted that the service is visible but poorly documented due to mangrove degradation, which weakens its protective function. One stakeholder added that increased flood impacts following mangrove clearing for urban expansion in unsuitable areas indirectly highlight their regulating role.

"*But as I said, it's a combination of a natural phenomenon, because mangroves are naturally a dynamic system, and then there is anthropogenic pressure, but in general, they do provide that coastal protection services, and you can see that a lot in expanding neighborhoods in Maputo. You know there is an area in Costa do Sol, where people are building inside the mangroves [...], and what you have immediately, or very quickly, is the houses being flooded, of course, because they are in a wetland area...*" - Secondary Stakeholder.

It was observed that the secondary stakeholders were trying to quantify or find scientific evidence for mangroves' role in coastal protection, whereas primary stakeholders spoke from experience.

Supporting

Both primary and secondary stakeholders agreed that mangroves have increased biodiversity in terms of fish and invertebrates. Many secondary and primary stakeholders have mentioned that mangroves yield small fish and crabs that are used for both food and livelihood, highlighting mangroves as a source for food security. For example, one primary stakeholder says, "*So it [mangroves] helps a lot, for example, you don't have to buy from outside, so we catch crab here…".* However, due to mangrove harvesting, certain primary stakeholders mentioned that this service has decreased, potentially leading to higher exports of fish. This has affected communities that reside near the mangroves. For example, one secondary stakeholder mentioned that in rural areas, certain communities are fully reliant on mangrove supporting services for their livelihood. On the other hand, one secondary stakeholder mentioned that fauna is not only attributed to mangroves themselves, but also to the surrounding ecosystem, and two other secondary stakeholders mentioned the limited biodiversity services of mangroves in Maputo Bay compared to the northern parts of the country.

Challenges, trade-offs, and conflicts with mangrove ecosystem services

Negative perceptions

Both secondary and primary stakeholders mentioned negative perceptions of mangroves, such as mosquitoes, bees, obscurity, bad smell, and a hiding place for thieves as a potential hindering factor in utilizing the services provided by mangrove ecosystems. One primary stakeholder mentioned that they reside further away and thus do not perceive any negative effects or trade-offs. The majority of primary and secondary stakeholders did not report any negative perceptions, mentioning that these effects are a part of the "wetland phenomena" and that humans are the colonizers who must adapt to the environmental surroundings and cycles. Following this, one secondary stakeholder gave an example of how floods are not always seen as a negative side effect.

"*It's part of the natural cycle. […] the same thing you could say about floods. Back then, people would not build permanent houses in the floodplain. So, when it's raining, they go to the houses upland and they are happy because the rain and floods are bringing nutrients to the land. And then, as the water recedes, people are using that land to produce food. And then in the peak, the dry season, people are there in the very same area that is really flooded during the rainy season […], and when floods come back, they [the residents] just leave. Whatever they built in the floodplain is something that they don't mind losing…*" - Secondary Stakeholder.

One primary stakeholder mentioned using mosquito repellent, and another stated that the positives outweigh the negative perceptions of mangroves. One secondary stakeholder suggested more appropriate locations for housing to reduce the susceptibility to coastal hazards.

Trade-offs between the mangrove ecosystem services

In line with the negative perceptions, four primary and eight secondary stakeholders also mentioned several trade-offs between ES. The most mentioned trade-offs included provisioning services that weaken regulating and supporting services. Both primary and secondary stakeholders agreed that unsustainable cutting of mangroves for production and consumption threatens ecosystem integrity and biodiversity, ultimately affecting food security.

"*…and also shelter for biodiversity, because when you don't have mangroves, the fish and crabs and other animals that live there, exclusively there, may be affected*" - Secondary Stakeholder.

As for the trade-offs between harvesting and regulating services, several primary and secondary stakeholders mentioned that overuse of the provision service can reduce mangroves' ability to protect against coastal hazards. However, one secondary stakeholder noted that limited natural resources in a dense urban area increase pressure to harvest mangroves, despite community interest in preserving them for coastal protection, highlighting how external resource needs drive this trade-off.

"*Maputo is a city, you do not have forests around. So, the mangroves are the easiest way accessible to almost anyone. And then again, you have one side of your community that wants to preserve that wood for coastal protection, and then other people who do not have alternatives or want to use the mangroves because it's easier….*" - Secondary Stakeholder.

Mangroves temporal changes

When being presented with the mapped area of mangrove ecosystems in Maputo Bay, several secondary stakeholders had a hesitant reaction, pointing out the errors in the map and stating that the mapping is inaccurate in certain locations, such as Inhaca Island. Consequently, one of the secondary stakeholders mentioned the inconsistencies with using open data based on global generalizations in localized studies. The stakeholder also emphasized that conservation projects based on global data are sometimes rejected because they do not accurately reflect local realities. Furthermore, Fig. 5 and Table 2 contradict the interviewees' viewpoints, as presented below.

Increase in mangroves over the past eight years

Eight stakeholders reported an increase in mangrove over the past eight years rather than a decrease or no change. The majority of primary and secondary stakeholders mentioned a visible increase in Maputo City, where one primary stakeholder visually observed that "*...in the last 8 years, mangroves have not decreased but increased. It wasn't like this before, mangroves were almost there, but they have grown a lot here*". Other locations of increase mentioned by the stakeholders include Maputo National Park, Inhaca, Inkomati River, and Matola River.

Comparing the interviewees' answers with the RF model, it can be seen that the increase in mangrove cover on Inhaca Island is visible. However, areas such as Maputo National Park and Maputo City show significant decreases. Along with an overall decrease of 1862 ha, the map showcases a contradiction with the interviewees' perspectives.

Decrease in mangroves over the past eight years

In comparison to the above, six stakeholders mentioned a decrease in mangroves.

"From my point of view, mangroves are getting worse" – Primary Stakeholder.

One primary stakeholder noted a decline in Inhaca, while others mentioned decreases in the Maputo River and Katembe. Most reported losses, however, were concentrated near urban areas such as Matola, Maputo City, and Machanlugo. Three secondary stakeholders also mentioned an overall decrease.

When comparing the decreased locations with the increased locations, slight contradictions can be spotted in terms of changes in Inhaca, Matola, and Maputo City. However, when comparing the decrease trends with Fig. 5 and Table 2, it can be observed that the Maputo River, Matola River, Maputo city, and Machanlugo Islands also show overall declines, indicating agreement.

Mangroves have remained unchanged over the past eight years

Only three stakeholders reported no visible change in mangrove cover over the past eight years. For example, one secondary stakeholder referred to a recent project in Inhaca, where there were no indicated changes. However, as no follow-up questions were asked about the specifics of the project, the details remain unclear, limiting transparency. It was observed that the two remaining stakeholders who reported no visible changes indicated uncertainties regarding monitoring.

Threats and pressures to mangrove

Anthropogenic threats and pressures

Anthropogenic threats identified by both primary and secondary stakeholders include unsustainable harvesting, reliance on gray infrastructure, urban planning difficulties, and solid waste pollution. One primary stakeholder mentioned that there are no current anthropogenic threats to mangroves because of efficient management.

Urban expansion was the most frequently mentioned threat, where primary and secondary stakeholders explained the conversion from mangroves to infrastructure. One secondary stakeholder mentioned the need to accommodate communities that migrate to the south for job opportunities. Another secondary stakeholder mentioned that "*...the city [Maputo] was built on Mangroves"*. One primary stakeholder mentioned that the continuous infrastructure development inside the mangal area leads to damage to the infrastructure in the long term. This is followed by implementation challenges.

"There are people who cut those trees and build houses right there. When they do that, they themselves suffer." – Primary Stakeholder

Six secondary stakeholders noted that policies and strategies for mangrove management are well written and well outlined, but their implementation is limited. Two secondary stakeholders further noted that there is a perceived uneven enforcement of existing regulations. Additionally, five secondary stakeholders mentioned that this is fueled by engagement difficulties, limited capacities, and a lack of trained personnel. One mentioned the lack of staffing, while another highlighted that mangrove services are underestimated because of their biophysical characteristics, especially when compared to larger mangrove systems in the north. However, one secondary stakeholder mentioned that these limitations result in a lack of public awareness, where mangrove degradation limits them from fully showcasing their regulating and supporting services.

"*By destroying mangroves, you are also limiting the ability for people to understand the utility of mangrove for humanity and for those local communities in particular.*" - Secondary Stakeholder.

Further, one secondary stakeholder mentioned the difficulties in implementing conservation projects when local engagement and involvement are low, noting that landowners may request compensation for conservation activities on their land. Another secondary stakeholder mentioned that even if strategies and policies are open source, limitations such as internet access and illiteracy are significant barriers to knowledge dissemination. Five primary stakeholders simply stated that mangrove cutting is prohibited. Another primary stakeholder reported unawareness of ongoing mangrove regulations and interventions.

Natural threats and pressures

Natural threats and pressures identified by primary and secondary stakeholders include sea-level rise, hailstorms, extreme weather events, and floods. Two secondary stakeholders mentioned a severe hailstorm event that potentially degraded mangroves in the Maputo River area, which corresponds to observations made in the RF model. Another primary stakeholder mentioned that extreme rainfall events can disrupt mangrove conditions by altering salinity levels through increased freshwater input, which decreases mangrove supporting services.

"Yes, it [storms] reduces, because sometimes the trees break. Sometimes, with that adjustment of rainwater - mangroves like salty water." – Primary Stakeholder.

Social vulnerabilities

Primary and secondary stakeholders identified multiple factors leading to increased social vulnerabilities. One frequently mentioned factor by both primaries and secondaries includes infrastructural challenges due to improper placement of houses, fueled by urban expansion. This results in lower protection from the aforementioned coastal hazards, such as erosion and storm surges, which affect the communities living near mangroves, as mentioned by certain primary stakeholders. Essentially, one secondary stakeholder mentioned that many of the houses built near the mangrove areas are left abandoned due to continuous floods, indicating that both regulating and supporting mangrove services are lost together with the built properties.

"*The moment you cut it down to build your property, you are going to lose*" - Primary Stakeholder.

"*You see people wanting to be in a safe place to build new houses in a highly valuable area close to the beach. To do that, they need to cut mangroves, and when they cut the mangroves, they lose their property because the area is flooded, [...]. So, this is something that people really struggle to understand, that sometimes an area is a high-value area is only high-value because you have the ecosystem there*" - Secondary Stakeholder.

As a consequence of lost services by the mangroves, many primary stakeholders mentioned how they have personally been affected by the floods, "*I was affected by mangrove loss in my province, when it rained, the water got inside our houses*".

The loss of supporting services proved to be another factor in increased vulnerabilities. While six primary and secondary stakeholders mentioned that alternative livelihoods exist, especially in urban areas, seven stakeholders mentioned that communities near mangrove areas are primarily dependent on their services. One primary stakeholder mentioned that when mangroves are harvested, they lose their source of livelihood as fisheries decrease. There were no mentions of the dependence of provisioning services of mangroves by either secondary or primary stakeholders, indicating that supporting and regulating services are more valued when their disruption is experienced.

Possibilities for mangrove conservation and protection

Five primary stakeholders mentioned alternative adaptive strategies to complement mangrove loss, such as plantations of casuarina trees, placing stones near the coast, or going further offshore to fish, whereas one could not think of any alternatives. However, some stakeholders also emphasized the need for more effective mangrove conservation to avoid reliance on such measures.

From large-scale to smaller-scale efforts

Four secondary stakeholders highlighted the need for smaller-scale studies and efforts. This is because national-level efforts do not always translate into local realities,

> "*But if you're looking at the entire country, the general picture shows that mangroves in Mozambique are increasing, but locally, the impact or the effects might be different*" - Secondary Stakeholder.

One secondary stakeholder further mentioned the creation of localized management plans, stating that strictly prohibiting local communities from using mangrove provisioning services collides with their local needs. Instead, the stakeholder suggested that harvesting could be done more sustainably and controlled. Another secondary stakeholder added that mangrove ecosystems in Mozambique are diverse, providing different ES, as exemplified by the different characteristics between mangroves in Maputo Bay and in the northern parts of Mozambique, and therefore, it is difficult to generalize the conditions and base the conservation efforts on them. One primary and two secondary stakeholders mentioned ongoing localized activities, mainly conducted by the university or international organizations, focusing on Inhaca Island and stating that they have observed positive outcomes.

Community engagement

Four secondary stakeholders mentioned the importance of community engagement to increase awareness, knowledge, and localized conservation efforts for mangroves. Four secondary stakeholders highlighted that the local communities are the owners and are therefore always included in conservation or restoration projects. However, engagement levels differ depending on factors such as beliefs and personal experience. For example, one secondary stakeholder observed that some communities maintain the belief that mangroves will naturally recover. In contrast, two secondary stakeholders noted higher levels of engagement and involvement when local communities directly observed the benefits of mangroves or were personally affected, which tended to override communities' initial beliefs.

"*...and even after the project ended, they still continued engaging in mangrove restoration, because they have learned from experience when the mangroves are not there, how it affects their livelihoods*." - Secondary Stakeholder.

Additionally, one secondary stakeholder suggested leveraging perceived negative aspects of mangroves, such as bees, and turning them into opportunities for beekeeping. The stakeholder added that this engages local communities in alternative livelihood options linked to mangrove ecosystems, which is an initiative that is ongoing in the northern parts of Mozambique.

Robust urban planning and implementation

Three secondary stakeholders underlined the need for more robust urban planning, as insufficient urban planning can increase vulnerability. One secondary stakeholder suggested building densely rather than expansively, which could accommodate more residents without the need for extensive land space. Another secondary stakeholder mentioned the need to adapt to natural processes, embrace mangrove ecosystems, and avoid construction in sensitive areas. Primary stakeholders did not identify this sub-theme directly. However, as previously mentioned, one stakeholder indicated the relationship between building in sensitive areas and infrastructure destruction as a result.

Obstacles to conservation efforts

In line with the robust urban planning, five secondary stakeholders mentioned constraints to conserving mangroves. One secondary stakeholder mentioned that current initiatives and regulations may disrupt local livelihoods.

"*Because people would say, okay, I agree. Let's protect, it's important. But then they would say, no, but I need to live. It's part of our right to have food every day.*" - Secondary Stakeholder.

Another secondary stakeholder mentioned the balance between culture and conservation. Much of the seafood in Mozambique is a part of the culture, however, extensive cultivation and harvesting of mangroves may reduce or disrupt fish yield. Thus, the secondary stakeholder reflected on whether restricting access to culturally important food sources for local communities is feasible or appropriate. Conflicts between urban expansion and conservation were also mentioned by one secondary stakeholder, highlighting different priorities on the regional level.

6. DISCUSSION

This chapter will discuss the results from the analysis, beginning with the identification of key patterns from the results, followed by a detailed discussion of each RQ and ending with a future research section.

6.1 DISCUSSING KEY FINDINGS

Importance of context-specific studies

The result shows contradictions and inconsistencies between the RF model and stakeholder views, indicating multiple realities from which a system can be interpreted. While the mangal management strategy explicitly states the inclusion of various stakeholders in the implementation process (The Council of Ministers, 2026), several secondary and primary stakeholders expressed limited awareness of these policies and/or questioned their implementation in practice. Similarly, while the RF analysis indicates an overall decrease, most stakeholders mention an increase. The latter contradiction between the RF model and stakeholder answers could indicate general risks of relying on global, open data, which is insufficient when studying local contexts (Schmit et al., 2006; Amaral et al., 2023). Instead, as suggested by certain secondary stakeholders, there is a need for more localized and context-specific analysis.

The results also confirmed that mangrove ES are dynamic systems, with ES that vary in performance and importance, as well as in supply and demand within the social system. While mangroves in the north provide supporting services such as natural medicine, fisheries are the dominant supporting services in the Maputo Bay. Secondary stakeholders also indicated that the ES faces different threats, such as urban expansion and implementation difficulties in the south, and unsustainable mangrove cutting in the north. These findings align with the overarching ES literature, which highlights dynamics and trade-offs often affected by local factors (Wang et al., 2024; Rodríguez et al., 2006; Vihervaara et al., 2010). It can be suggested that, due to the varying eco- and social systems of the mangroves in Maputo Bay, they are placed in a competitive environment where decision-making, governance, adaptive capacities, and values shape how ES are perceived and handled, which can create uneven ES performance.

These findings illustrate how localized the significance of mangrove ecosystems is. By conducting national-level studies that mostly focus on ecological and biophysical aspects, as indicated by certain stakeholders and the literature (Frosi et al., 2025), there is a risk of overgeneralization of local realities. As a result, this increases the risk of overlooking local needs and vulnerabilities, as shown in the inconsistent results between the RF model and local realities. Van der Hoek et al. (2015) highlight this issue in a broader context, stating that global conservation projects tend to follow standardized indices without including habitat-specific conditions and considerations.

Mismatched scales

On a national and regional scale, Mozambique has ambitious mangrove interventions that integrate socio-ecological considerations at multiple scales, as confirmed by secondary stakeholders. At the regional level, Maputo has several strategies and policies that also aim at protecting and restoring mangroves, which was also confirmed by secondary stakeholders. However, most stakeholders indicated their struggles in translating into day-to-day life. This aligns with the findings presented in the background, where strategies such as the *Mangal Management Strategy* are challenged by other priorities such as infrastructure advancement and the need for more land (Rodrigues, 2024). It can be further argued that limited knowledge circulation and dissemination of the strategies, as mentioned by certain secondary stakeholders, is another factor that exacerbates the challenges within implementation. For example, local beliefs that mangroves are permanent can reduce the urgency for interventions. At the same time, the view that mangroves in Maputo have limited regulating services can reduce incentives for conservation, despite several primaries mention their significance for coastal protection.

In parallel, it can be assumed that the varying perception and utilization of mangrove ES across Mozambique show a scale mismatch between local ES realities and research-level prioritization. Northern parts of the country host significant research practices on mangroves, as highlighted by several secondary stakeholders who emphasized the area's favorable biophysical characteristics and enhanced ES performance compared to the south. These findings align with Barbosa et al. (2001), who noted dispersed mangrove research throughout the country, which is a pattern that appears to hold even after 25 years. Furthermore, the findings support the literature indicating a strong focus on biophysical characteristics of mangroves in Maputo (Frosi et al., 2025).

Within Maputo Bay, there is a scale mismatch between national/regional strategies and localized infrastructure planning. The increasing rural-to-urban migration and surrounding locations intensify the pressure on urban expansion, especially in Maputo City (Rodrigues, 2019). Several stakeholders also noted that this leads to lower prioritization of mangrove conservation, which limits evidence-based findings of their services and creates potential indirect trade-offs where several ES are weakened. This is further reinforced by strong reliance on gray infrastructure, as mentioned by some stakeholders, which focuses on immediate outcomes rather than long-term benefits that mangroves provide (Opdyke et al., 2026).

Impact on vulnerabilities and adaptive capacities

In turn, scale mismatches can affect both ecological and social vulnerabilities. Identified national/regional vulnerabilities from the results include limited enforcement capacity and competing demands for land. However, residents' perspectives show more context-dependent interpretations of these challenges, highlighting varying levels of adaptive capacity.

Primary stakeholders mentioned the supporting and regulating services of mangroves as crucial in terms of livelihood and coastal protection. However, the perceptions of these services varied. Given the localized degradation of these ecosystems, a few primary stakeholders mentioned decreased regulating and supporting services, while others stated an increase in protection services and lower degradation due to efficient governmental management. These altered views suggest context-specific vulnerabilities between the location where stakeholders were interviewed and their degree of dependence on mangrove services. As one secondary stakeholder mentioned, the dependence is higher in rural and peri-urban areas than in urban areas, which is where most of the primary stakeholders were interviewed. While Evidencia (2025) highlighted the challenges of local fishermen in Maputo Bay, they were less evident in the results. Instead, alternative adaptation strategies such as switching to other professions, planting other tree species, and fishing further offshore were mentioned. This highlights the adaptability of local communities despite their exposure, but it also introduces additional risks associated with moving further offshore, including sudden shifts in weather conditions and injuries (Turner, 2024).

Similar to social vulnerability, the ecological vulnerability of mangroves is localized and dynamic, with varying anthropogenic threats such as the aforementioned urban expansion in the city and cutting in more rural locations. Similarly, natural threats such as storms varied, with the Maputo River impacted by a hailstorm that led to a decrease in mangrove cover, making them less able to protect against hazards. At the same time, stakeholders reported the difficulty of providing a quantification of damage and confidently attributing the threats to degradation. This illustrates the complex system of mangrove ecosystems, which is confirmed by the literature (Carlson et al., 2021).

Overall, these findings may suggest that both social and ecological vulnerabilities are not fixed terms. Instead, they seem to vary across different contexts, depending on external factors such as different priorities and localized climatic events. For this reason, it becomes difficult to base the terminology "vulnerability" on singular or isolating drivers (Amaral et al., 2023).

6.2 THE DIFFERENT PERCEPTIONS OF THE ECOSYSTEM SERVICES AND IDENTIFICATIONS OF POTENTIAL TRADE-OFFS

To address the first RQ, the identified ES of mangroves in Maputo Bay incorporated mostly supporting and regulating services, with fisheries and protection against erosion and floods being the most mentioned, with an overall decline in provisioning services. On the contrary, supporting, provisioning, and cultural services were seen as more significant in the northern parts of the country, as mentioned by secondary stakeholders. On a smaller scale, the ES performance and their importance seem to depend on the physical characteristics of the trees. In line with several sources (Machava-António et al., 2022; Nicolau et al., 2017), the structural characteristics of the mangrove ES have a considerable impact on their values and how they are used by local communities. For example, one secondary stakeholder mentioned that mangroves in Maputo City are shorter and curved compared to those in Inhaca Island. Consequently, they are seen as less important in coastal protection and extraction, and more valued for their aesthetics and livelihood support. This finding contradicts earlier studies that report the continued use of mangroves for construction materials in Maputo Bay (Paula et al., 2014; da Costa & Ribeiro, 2017), which may reflect dynamics of mangrove structure over time, given the age of these sources.

Beyond the biophysical characteristics, there is another layer that emerged from the results related to resource dependence. The availability of alternative income sources and methods, such as offshore fishing, as mentioned by one primary stakeholder, may reduce direct dependence on mangrove resources. Arguably, this can change how these ecosystems are used and perceived over time. The different perceptions can also limit the understanding of the ES mangroves provide and how they function as a whole, which was confirmed by one secondary stakeholder. Several stakeholders mentioned greater dependence on mangrove ES in peri-urban locations, where ES serves a higher importance to local livelihoods. Overall, this shows that, in addition to biophysical characteristics, mangroves have different perceived importance that depends on socioeconomic conditions and needs. It can be believed that these altered viewpoints can also influence community attitudes towards mangrove ecosystems and their usage.

The dominance of biophysical framings in research and secondary stakeholder narratives in Maputo may obscure the broader socio-ecological complexity of mangrove systems. As one stakeholder mentioned, other vegetation, such as seagrass or bushes that are interconnected or reside in proximity to mangroves, also contributes to ES. This is further confirmed by authors such as Carlson et al. (2021), who state that mangroves reside in an integrated seascape and that the provision of ES depends on interactions among different vegetation types. As per this definition, it can be suggested that ES are an interconnected coastal system and not something that is provided by mangroves in isolation. It can be assumed that this is one reason for stakeholders' hesitation to quantify the performance of mangrove ES confidently.

Combined, these altered ES perceptions highlight that the ecological significance of mangrove ES is not always reflected in perceived social values. This relationship has been discussed by various frameworks and authors, such as Prayunita et al. (2026) and the MA (2005), who argue that the dependence of an ecosystem affects its perceived importance and prioritization. In the context of Maputo Bay, this disconnection may contribute to a lower importance of the mangroves in more urban areas, where alternative livelihood options are more accessible, as mentioned by one primary stakeholder. This lower demand could, according to Hölting et al. (2020), also weaken the performance of the provisioning ES.

Contrary to the benefits, the negative perceptions of mangroves did not seem to be significant in Maputo Bay compared to other contexts described in the background. At the local level, stakeholders indicated mosquito issues and a hiding location for thieves, but also agreed with the secondary stakeholders that these are inherent characteristics of the wetland phenomenon that communities must adapt to. This suggests that while the perceived importance of ES is influenced by socioeconomic and site-specific conditions, a general awareness of their functions exists amongst primary and secondary stakeholders.

In contrast to the negative perceptions, there were limited trade-offs mentioned by the stakeholders, possibly due to a conceptual gap in terms of differing understanding of the terminology or a general lack of trade-offs in the study area. Some stakeholders identified unsustainable mangrove cutting as a threat to biodiversity and coastal protection. Thus, the overuse of provisioning services creates trade-offs with regulating and supporting services. This reflects Machava-António's (2022) findings on mangroves in Maputo Bay being weakened by their surrounding pressures, such as harvesting, which confirms the stakeholders' statements. Other trade-offs included tree cover and the fishery's obscurity, as mentioned by one primary stakeholder, highlighting a trade-off between supporting services for flora and fauna and supporting services for communities. Overall, these findings indicate that the trade-offs in Maputo Bay are mainly driven by external factors and not by a direct relationship between the ES, meaning that indirect trade-offs dominate. Indirect trade-offs that are context-specific and embedded within the social systems are more difficult to identify and attribute to ES (Su & Liu, 2023), which may limit stakeholders' ability to discuss them with certainty and explain the limited responses received from stakeholders. Temporal trade-offs, where short-term benefits over long-term ones are prioritized, were also shown to be present, albeit not discussed as potential trade-offs. These temporal trade-offs include extensive overuse of provisional services, which is more prominent in peri-urban/rural areas. This finding agrees with the overarching literature, indicating that these ES synergies are linked to differing priorities (Ureta et al., 2025; da Costa & Ribeiro, 2017).

6.3 TEMPORAL CHANGES OF MANGROVES

As previously mentioned, certain primary stakeholders showed disagreement with the mangrove cover map presented in Fig. 2, saying that it is inconsistent in comparison with their research and observations. It should be noted that there is a possibility that these respondents could have misunderstood the map, given that it has a 1 km buffer around the mangroves. On the other hand, it is also clear that multiple interpretations of temporal changes exist, creating various perspectives. From an open data perspective, the model shows an overall loss over the past eight years. Similarly, websites such as GMW and authors who conducted similar studies, like da Costa & Ribeiro (2017), support the statement of a temporal decrease in mangrove cover. In contrast, while certain primary and secondary stakeholders agreed, the majority pointed out an overall increase. This creates a mismatch between macro and micro-scale observations (Li et al., 2019), which can, in general, lead to interventions that oversimplify or misinterpret the local state of mangroves, as one stakeholder mentioned.

The RF perspective in this case provides a zoomed-out, general version of the study area. A comprehensive macro-scale view is highly valued in research where identification of spatial patterns serves a significant role (Hutchison et al., 2014; Li et al., 2019; Amaral et al., 2023). However, the reality is captured by factors such as the indices used, human interpretation, and the resolution of the images, all of which can influence the outcome of the model. Since the resolution used in the RF model was 31 meters, mangrove systems smaller than 0.09 ha were not detected, leading to missed details that could have been picked up by the stakeholders who disagreed with the mangrove extent of the map.

In contrast to the RF model, the stakeholders were speaking from experience, drawn from observations, localized studies, and fieldwork. However, this creates further contradictions. While some mentioned an overall decrease, others mentioned an overall increase in mangrove cover. Similarly, while some pointed out an increase in Inhaca, others reported a decrease. A possible explanation could be that the stakeholders were specifying the decrease in different locations within the areas. While these differences exist, stakeholders base their responses on perceived dynamics rather than on the two images used in the RF model, which potentially overlook changes that occurred between the years. In a broader context, Pasetto et al. (2018) mention this limitation as a *temporal gap*. These findings highlight the existence of different perceptions of mangrove cover change and the importance of combining both macro- and micro-scale levels for conservation research.

Most stakeholders associated mangrove decrease with lower performance of the ES, especially the regulating and supporting. Invertebrates, fish, and the ability to protect against coastal hazards decrease, as mentioned by various stakeholders. In areas where mangrove cover has increased, stakeholders mentioned high performance of ES, highlighting mainly the supporting services, where they have observed that areas with mangroves have been less impacted by erosion and floods compared to areas without mangroves. This shows the relation between mangrove cover and the potential of the ES to exist and be used by the communities.

6.4 PRESSURES AND THREATS TO MANGROVES AND THEIR ECOSYSTEM SERVICES AND POTENTIAL PATHWAYS

To address the third RQ, the overall findings showed that the threats are site-specific. Urban expansion and implementation challenges were the most mentioned threats, especially in the city. In rural and peri-urban areas, cutting and implementation challenges were shown to be the most significant threats. These differences can be tied back to changing socioeconomic needs, which dictate how mangroves are used. For example, in Maputo City, various authors, such as Rodrigues (2024), agreed with the stakeholders' responses that there is a need for expansion to accommodate the incoming population. These findings can be connected to the RF model that suggests a decrease within Maputo City and its surrounding peninsula. Conversely, cutting becomes an issue in rural/peri-urban areas due to greater demand for mangrove products, as noted by some secondary stakeholders. Other threats, such as pollution in terms of solid waste, unsustainable cutting, and natural threats such as extreme weather events like rainfall and hailstorms, were also mentioned. However, these were mostly isolated within specific places and affected specific mangroves, such as those located near factories or in geographically exposed areas such as the Maputo River, where degradation is clearly visible in the RF model.

The aforementioned threats should not be treated in isolation. Many stakeholders pointed out multiple natural and anthropogenic threats within the same areas, highlighting their interconnections. This finding relates to the literature, where mangrove pressures are described as interactive and consist of uneven spatial distributions, which lead to mangroves having different vulnerability levels (Fan et al., 2024). The findings also confirm that external interactions with different ES are also prone to creating threats to the mangrove system. For example, certain primary and secondary stakeholders noted that regulating services are weakened by the overuse of provisional services in urban areas. Nevertheless, it should be noted that the term “threat” is a simplified concept that includes many underlying drivers. One example includes path dependencies stemming back to the colonial era, where parts of the city expanded into mangrove ecosystems to accommodate more residents (da Costa & Ribeiro, 2017; Dürrangel et al., 2025). Another example includes the status quo that other secondary stakeholders mentioned, where residents’ perceptions of mangroves being permanent and unchanging dominate over action. To reduce the threats, the result suggests moving beyond current drivers and looking at deeper, historical, institutional, and cognitive factors that shape them.

In addition to addressing the third RQ above, stakeholders also proposed solutions that can reduce mangroves' susceptibility to threats. The solutions primarily focused on shifting from national or regional to more localized interventions and regulations, such as sustainable cutting. In fact, conservation is oftentimes not about restricting communities from utilizing an ecosystem completely, but to use it more sustainably and controlled (Lugo et al., 2014). Arguably, such a shift could help reduce forms of maladaptation in certain rural areas, where certain stakeholders mentioned that a strong dependence on provisioning and supporting services is associated with reduced regulating services. Other stakeholders suggested the need for, or continued support of, community engagement/involvement in mangrove safeguarding. Evidence shows that community involvement strengthens conservation, benefiting *both* the community and beneficiaries (Roslinda et al., 2021). In the context of Maputo Bay, both the stakeholders and the literature prove that these initiatives are already strong and have proven effective in areas such as Maputo National Park (Peace Parks Foundation, 2025; Massango, 2023), but less effective in other, unspecified areas mentioned by the stakeholders. However, while the promotion of bottom-up approaches is beneficial, it is not easily implemented in practice, especially since certain stakeholders mentioned that the status quo and perceptions of mangroves being permanent systems persist. This challenge is globally evident in conservation research, where authors mention tokenism, local power dynamics, and distrust between the higher and lower levels as additional factors that lead to the status quo and persistent inequalities in benefit distribution (Gargule, 2022).

Additional solutions mentioned by stakeholders included sustainable land-use planning, favoring densification over urban expansion. Densification reduces pressure on mangroves by limiting the demand for land use in sensitive areas (Gijsman et al., 2021), where mangals are located. However, this approach also comes with increased demand for resources and institutional capacity, as well as the need to accommodate diverse viewpoints from stakeholders. Mucova (2025) further mentions that institutional capacity and long-term promotion of projects can also be constrained by the limited funding given to Mozambique. While none of the stakeholders brought up these overarching issues, it is important to highlight them as possible reasons for the existing threats to mangroves, adding another layer to the "threat" terminology.

To tackle this, authors like Masum (2014) mention incremental changes where an enabling environment is created, and involvement of external experts and organizations for additional resources. While the national/regional strategies mention the involvement of different stakeholders and institutions, the stakeholders interviewed seem to have different and sometimes contradictory perspectives about mangrove dynamics and their drivers, signaling back to the need for enhanced and integrated coordination through knowledge sharing.

6.5 POSSIBILITIES FOR FUTURE RESEARCH

While this study examines the complex environment of mangrove ES, its limitations lead to simplifications of reality. As a result, a fully comprehensive approach cannot be justified. To get a more comprehensive view of multiple perspectives, it is important to further expand on this research area by integrating quantifiable ES studies, additional ES, stakeholders, and narrower site-specific studies. For example, the lack of quantifiable evidence on mangrove performance in Maputo, as indicated by several stakeholders, could set a base for future research that investigates how services perform and interact with the surrounding environment. Building on this approach, a combination of quantified methods of ES performance and pressures, together with the interviews, could reduce interpretation bias, allowing for more objective comparison across time and scales. Expanding on a few focused studies, like Magalhães (2018), which quantified how urban pressures affect carbon storage in the Maputo City area, future research could apply similar methodologies to other ES.

In addition to quantifying ES, it is also important to incorporate all aspects of the MA. While this study focused on regulating, supporting, and provisioning services, it excludes cultural services. Cultural interests of mangroves are rising in Mozambique, and as mentioned in the background, mangrove tourism is becoming recognized (Government of Mozambique, 2018). Moore et al. (2022) mention that cultural services are generally underrepresented because they are difficult to measure, yet they highlight a clear link between mangroves and human well-being. This represents an opportunity that could have been explored in detail in Maputo Bay. Addressing this could help clarify human-nature relationships more effectively by capturing how different stakeholders value mangroves from a subjective lens (Moore et al., 2022), moving beyond the material dependence that this study focused on. Essentially, this could have added another lens as to why mangrove ES are valued differently across Maputo Bay.

Focusing solely on mangroves within a bigger system represents another simplification within this study. Expanding the analysis to investigate the interactions between the different vegetation types connected to the mangrove ecosystem could improve the identification of distinct ES and direct trade-offs. A study done by Huxham et al. (2018) investigates the impact of one vegetation type on another, stating that vegetation such as seagrass helps mangroves to reduce wave energy and protect from fluvial floods. Similar studies, like the one by Huxham et al. (2018), could improve the insights on ES performance within the Maputo Bay area.

As several stakeholders stated, more focus should be placed on localized studies that narrow the scope of the research area. As mentioned before, focusing on a narrower geographical area allows for a more detailed assessment of ES and their interactions. It also combines the viewpoints of a wider range of stakeholders compared to this study. Arguably, this could have generated more detailed and potentially quantifiable outcomes, which can more accurately detect the needs of the mangroves and communities.

7. SUMMARY AND CONCLUSION

Mangroves in Maputo Bay provide multiple services to local communities, including fisheries, materials such as charcoal and fuelwood, and enhanced coastal protection. However, the usage and perceived importance of these services depend on socioeconomic, geographical, and biophysical factors, thereby also leading to dynamic performance and importance of ES. Similarly, factors such as resource dependence and proximity to the low-lying areas shape social vulnerabilities and adaptive capacities, whereas geographical exposure and anthropogenic threats shape ecological vulnerabilities to mangroves. Due to these dynamics, mangrove ES are also impacted by site-specific pressures and trade-offs, where climatic events dominate the southern part of Maputo Bay and anthropogenic pressure dominates the urban areas of the bay. This shows that mangrove ES are not fixed across all contexts, therefore, to gain an in-depth understanding of their functions, it is important to conduct more site-specific analyses that can identify the precise underlying drivers of the dynamics and threats to mangroves.

This study also shows a scale mismatch between the RF model and the ground data, with contradictions both between mangrove locations and temporal changes. While the model showed an overall decrease, stakeholders' answers varied, depending on locations and overall observations. In a broader context, this shows the importance of acknowledging the differences between these scales and validating national or regional-level trends with multiple stakeholders in order to ensure that conservation efforts also capture local needs. Different scales serve great importance where macro-scale identifies overall patterns and micro-scale identifies detailed realities, but they also bring risks such as subjectivity and generalization, highlighting the importance of a balanced and multi-scalar approach.

External threats to mangroves are similar to ES, site-specific, and heavily influenced by the social system and external climatic factors such as hailstorms. On a national level, there is a high awareness of mangroves and their importance, as indicated by various strategies that exist to safeguard them. While some stakeholders mentioned the success of these strategies, many others mentioned ongoing challenges, making it difficult to implement them uniformly across the bay. These altered views underscore the importance of continued knowledge sharing between different local and higher-level stakeholders.

Overall, this shows the importance of integrating multiple perspectives into conservation efforts. Further, this also underscores the complex nature of mangroves and the need for continued research that explores the interconnection between different vegetation types and their effects on ES, the incorporation of multiple ES, and more site-specific, detailed analysis.

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9. APPENDIX

Appendix 1: Interview guide in English.

Date and time:

 Received and agreed to the information about the data and the interviewing process.
Pseudonym to be used in the data analysis:
Primary or secondary stakeholder:
Profession (not used in the data analysis):

PART 1: BACKGROUND INFORMATION (*ONLY USED FOR CATEGORIZING RESPONSES*)

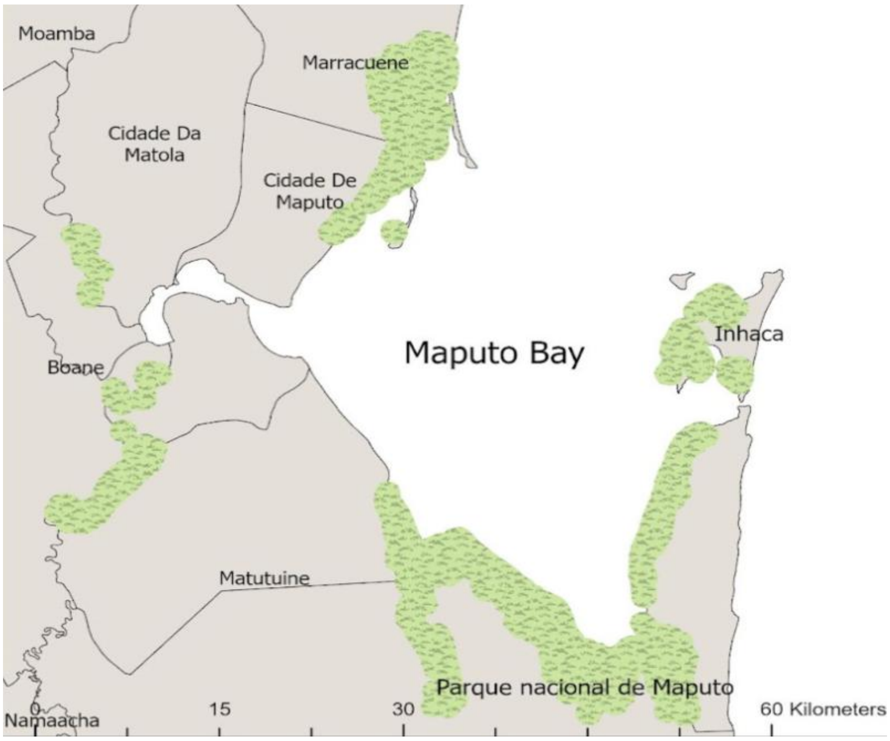
1. **How long have you been involved with or living near the mangrove areas?**
   - 0-5 years
   - 5-10 years
   - 10+ years

2. **To what extent are you familiar with mangroves in Maputo Bay?**
   1. Very familiar
   2. Familiar
   3. Somewhat familiar
   4. Slightly familiar
   5. Not familiar at all

*Note: parts 2 – 6 below refer specifically to the **Maputo Bay** area. If a participant selects option 5, follow-up questions may be adapted accordingly.*

PART 2: MANGROVE DYNAMICS

3. Have you noticed any areas where Mangroves have expanded or decreased over the past 8 years? (see map)



4. Have you in any way been affected by the change in mangrove extent? If yes, in what ways? (directly or indirectly (i.e., seen in news)

PART 3: ECOSYSTEM SERVICES

5. In what ways, if any, do biodiversity in mangrove areas, in terms of fish, plant, and other animal species, contribute to people's livelihoods and daily needs?

6. Are mangroves used for timber, fuelwood, and/or construction materials? If so, have you used or relied on these resources?

7. Do you perceive that the mangroves have reduced the impacts of coastal hazards (such as erosion, floods, or cyclones)?

PART 4: TRADE-OFFS

8. Have you experienced or thought of any conflicts between using mangroves for timber, fuelwood, and/or construction material and preserving them for coastal protection or biodiversity? – explain this one

9. Do you think the way that mangroves are being used and harvested affects their ability to provide protection or other benefits?

10. Do any of the ecosystem services provided by mangroves (such as biodiversity, timber provision, or coastal protection) have unwanted side effects? If yes, please elaborate.

PART 5: THREATS

11. What are the main threats that mangroves face?

- ☐ Urban expansion/infrastructure development
- ☐ Logging
- ☐ Climate change (sea-level rise, cyclones)
- ☐ Pollution
- ☐ Policy gaps / Implementation challenges
- ☐ Other (please elaborate):

PART 6: ADAPTIVE CAPACITY AND RESILIENCE

12. Are you aware of any implemented or ongoing rules or policies that govern how mangroves are managed in Maputo? If yes, please elaborate.

13. How would mangrove decline affect locals' livelihood and daily needs? Do they have any alternatives when mangrove resources decline?

END OF THE INTERVIEW.

Thank you very much for your participation.

JOKER QUESTIONS (POSSIBLY INCLUDED AS FOLLOW-UPS)

(*Follow-up to Q6*) Has the availability of timber, fuelwood, and/or construction materials provided by mangroves changed over the last 8 years?

(*Follow-up to Q7*) Have you noticed differences between areas with and without mangroves during cyclones? (e.g., during cyclone Idai, or Kenneth?)

(*Follow-up to Q8*) Do you believe that some groups benefit more than others from mangrove services?

(*Follow-up to Q12)* If you could change one thing about mangrove management in Maputo Bay, what would it be?

Appendix 2: Interview guide in Portuguese.

Data e hora:

□ Recebi e concordei com a informação sobre os dados e o processo de entrevista.
Pseudónimo a usar na análise de dados:
Stakeholder primário ou secundário: Profissão (não utilizado na análise de dados):

PARTE 1: INFORMAÇÃO DE CONTEXTO (*USADA APENAS PARA CATEGORIZAR RESPOSTAS*)

14. Há quanto tempo está envolvido ou vive perto das áreas de mangai?

- 0-5 anos
- 5-10 anos
- 10+ anos

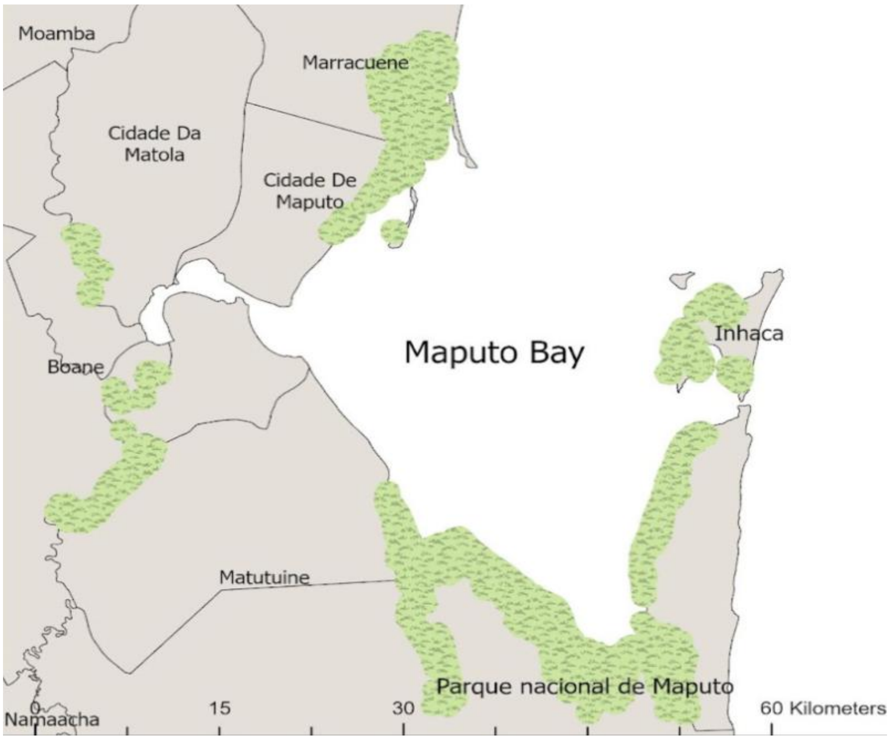
15. Até que ponto está familiarizado com os mangais na Baía de Maputo?

6. Muito familiar
7. Familiar
8. Algo familiar
9. Ligeiramente familiar
10. Não me conheço nada

*Nota: as partes 2 – 6 abaixo referem-se especificamente à **área da Baía de Maputo**. Se um participante escolher a opção 5, as perguntas de seguimento podem ser adaptadas em conformidade.*

PARTE 2: DINÂMICA DOS MANGAIS

16. Reparou em alguma área onde os mangais tenham crescido ou diminuído nos últimos 8 anos? (ver mapa)



17. Foi de alguma forma afetado pela mudança na extensão dos mangais? Se sim, de que formas? (direta ou indiretamente (ou seja, visto nas notícias)

PARTE 3: SERVIÇOS DE ECOSSISTEMA

18. De que forma, se alguma, a biodiversidade nas áreas de mangal, em termos de peixes, plantas e outras espécies animais, contribui para os meios de subsistência e necessidades diárias das pessoas?

19. Os mangais são usados para madeira, lenha e/ou materiais de construção? Se sim, já usaste ou confiaste nestes recursos?

20. Considera que os mangais reduziram os impactos dos perigos costeiros (como erosão, cheias ou ciclones)?

PARTE 4: TROCAS

21. Já experienciou ou pensou em algum conflito entre usar mangais para madeira, lenha e/ou materiais de construção e preservá-los para proteção costeira ou biodiversidade? – explica esta

22. Acha que a forma como os mangais são usados e colhidos afeta a sua capacidade de fornecer proteção ou outros benefícios?

23. Algum dos serviços ecossistémicos prestados pelos mangais (como biodiversidade, fornecimento de madeira ou proteção costeira) tem efeitos secundários indesejados? Se sim, por favor elabore.

PARTE 5: AMEAÇAS

24. Quais são as principais ameaças que os mangais enfrentam?

- ☐ Expansão urbana/desenvolvimento de infraestruturas
- ☐ Exploração florestal
- ☐ Alterações climáticas (subida do nível do mar, ciclones)
- ☐ Poluição
- ☐ Lacunas políticas / desafios de implementação
- ☐ Outros (por favor, elaborem):

PARTE 6: CAPACIDADE ADAPTATIVA E RESILIÊNCIA

25. Tem conhecimento de alguma regra ou política implementada ou em curso que regule a forma como os mangais são geridos em Maputo? Se sim, por favor elabore.

26. Como é que o declínio dos mangais afetaria o sustento e as necessidades diárias dos habitantes locais? Têm alguma alternativa quando os recursos de mangais diminuem?

FIM DA ENTREVISTA.

Muito obrigado pela sua participação.

PERGUNTAS SOBRE O CORINGA (POSSIVELMENTE INCLUÍDAS COMO SEGUIMENTOS)

(*Seguimento ao 6.º trimestre*) A disponibilidade de madeira, lenha e/ou materiais de construção fornecidos pelos mangais mudou nos últimos 8 anos?

(*Seguimento do Q7*) Notou diferenças entre áreas com e sem mangais durante ciclones? (por exemplo, durante o ciclone Idai, ou Kenneth?)

(*Seguimento ao Q8*) Acredita que alguns grupos beneficiam mais do que outros dos serviços em mangais?

(*Seguimento ao Q12)* Se pudesse mudar uma coisa na gestão dos mangais na Baía de Maputo, qual seria?