UNIVERSIDADE DE LISBOA
FACULDADE DE CIÊNCIAS
DEPARTAMENTO DE BIOLOGIA ANIMAL

Ecosystem services and drivers of change in mangroves and seagrasses in Maputo Bay, Mozambique

Alice Resende Santos

Mestrado em Ecologia e Gestão Ambiental

Dissertação orientada por:
Professora Alexandra Marçal
Professor José Paula

2021

ACKNOWLEDGMENTS

It is with a great deal of pleasure that I convey my deepest gratitude for the support and commitment of those involved in bringing about this dissertation, without whom it would not be possible.

I wish to express my sincere appreciation to my advisor, Professor Alexandra Marçal Correia, who could not have guided and support me better; her help, as well as her kindness and knowledge, made everything smoother and inspiring.

To my co-advisor, Professor José Paula, I am thankful for the opportunity of writing this dissertation within the COBIONET project and for always making himself available.

To my colleague Marta Bento, doing her Ph.D. within the same project, I'm grateful for being always willing to help me; also, a quick mention to Henrique Niza, that even though we crossed paths very briefly, was extremely helpful and shared all the material he could to guide me.

Likewise, it is important to acknowledge some of the people behind the PORTWIMS project, such as Professor Vanda Brotas, who helped me make the connection with Plymouth Marine Laboratory. I am very thankful to all the people I got to know there, amongst them Dr. Melanie Austen, whose guidance meant very much to me, but especially Dr. Stefanie Broszeit, who was extremely supportive, always available, and allowed me to look at things from a different perspective.

To all the master course professors, a show of gratitude for all the knowledge and skills passed along the way, as they proved to be very resourceful.

Withal, my accomplishments have not been mine alone, since over time many were the people inspiring me, giving me strength and encouragement. Hence, this dissertation is dedicated to them as well.

To my big and amazing family, a huge thank you. Most importantly to my parents Vitor and Lurdes, to whom I will forever be in debt, for their unconditional love and undeniable support. Also, a special note to my sister Rita and my cousin Ana, as they always walk alongside me.

Most warmly, to my boyfriend Mário for always understanding me and listening to my concerns over and over again. He was the most patient and loving person by my side.

To my friends, especially Bárbara, it is whole-heartedly appreciated the motivation and understanding given. They always had the right words and solutions for my outbursts. Yet, I owe a special note to Catarina and Juliana, their companionship throughout the first year of the master was my biggest motivation, much because of their enthusiasm and character.

It was a challenging year, full of unpredictable situations, but with great people standing beside me, everything was easier. This work is not only mine, but it also has a piece of you all.

ABSTRACT

The African coast has a high diversity of species and ecosystems, that provide ecosystem services (ES) and assure the subsistence of local populations. However, the supply of these ES is often endangered due to ecosystem degradation caused by direct and indirect drivers of change, which threaten people's livelihoods and food security.

This master thesis (integrated in the COBIONET project, funded by FCT/AGA KHAN Development Network) aimed to identify, classify and quantify ES provided by Maputo's Bay (MB) mangrove forests and seagrass meadows, with a special focus on marine macroinvertebrates (MMI). The condition of both ecosystems and their link with the main direct drivers of change (e.g. alien species; climate change; land-use and land-cover changes; pollution; overexploitation (deforestation and overfishing)) and indirect drivers of change (e.g. overpopulation) was also assessed, allowing the understanding of how they may influence mangroves and seagrasses ES, as well as MMI ES. This led to the development of potential scenarios for the supply of MMI ES in the MB, and its connection with local food security.

The work culminated with a conceptual model highlighting the connections between the drivers of change, the condition of the ecosystems, the main ES provided by the MMI from mangrove forests and seagrass meadows, and the expected management goals linked to a sustainable use of marine resources. The results from this thesis provided baseline information about the complexity of the MB, representing a practical starting point of exploration that may be used for future studies.

Keywords: conceptual model; digital data; food security; future scenarios; marine macroinvertebrates.

RESUMO

A costa africana tem uma grande diversidade de espécies e ecossistemas, que fornecem serviços de ecossistema (ES – *Ecosystem Services*) e garantem a subsistência de vasto número de pessoas. No entanto, o fornecimento desses ES é frequentemente ameaçado por diversas pressões que levam à degradação do meio, colocando em causa a subsistência das comunidades locais e a sua segurança alimentar.

Esta dissertação de mestrado, integrada no projeto COBIONET, financiado pela Fundação FCT / AGA KHAN, teve como principais objetivos a compreensão dos ES das florestas de mangal e pradarias marinhas da baía de Maputo (MB – Maputo Bay) e sua associação à condição destes habitats e principais pressões diretas e indiretas que os afetam, bem como a sua relação com os ES proporcionados pelos macroinvertebrados marinhos (MMI – *Marine MacroInvertebrates*) que neles habitam. Este estudo pretendeu ainda levar a cabo uma abordagem holística identificando lacunas de conhecimento e integrando avanços sobretudo relacionados com os ES dos MMI, de modo a desenvolver um modelo conceptual de ES que ligasse as pressões e condição dos ecossistemas com o fluxo de ES dos MMI e os diferentes objetivos de gestão. Pretendeu-se ainda compreender a importância dos MMI para a segurança alimentar das populações locais da MB, englobando práticas tradicionais e o uso sustentável desses recursos em florestas de mangal e pradarias marinhas. Utilizando dados digitais disponíveis, este estudo pretendeu fornecer uma ferramenta com informações de base para os decisores identificarem ações de mitigação e conservação aplicadas aos MMI das florestas de mangal e pradarias marinhas da MB. A condição dos mangais e pradarias marinhas, avaliada através da razão entre a área da Reserva Marinha Parcial da Ponta do Ouro (POPMR) e da área marinha total na província de Maputo (ZEE de Maputo), revelou-se longe dos níveis desejáveis. Por outro lado, o estudo das principais pressões diretas e indiretas, revelou uma elevada utilidade para compreensão da dinâmica geral da baía, dando uma perspetiva dos possíveis futuros cenários da área, se as pressões em questão não forem eliminadas ou mitigadas.

Em termos de pressões diretas, foram consideradas: (1) espécies exóticas de MMI: apenas uma foi descoberta, porém já causa insatisfação entre os pescadores; (2) alterações climáticas: avaliadas através da variação da temperatura da superfície do mar (SST – *Sea Surface Temperature*) e do nível do mar (SL – *Sea Level*) ao longo do tempo, as quais revelaram estar a subir apesar de algumas oscilações; (3) alterações no uso e ocupação do território (LUCL – *Land Use Land Cover*) - estudo efetuado com ferramentas de mapeamento, que evidenciou uma crescente cobertura urbana e agrícola em detrimento da cobertura (semi)natural, a qual inclui florestas de mangal; (4) sobreexploração, a qual foi dividida em desflorestação e sobrepesca, ambas a aumentar. Relativamente à desflorestação, as florestas de mangal periurbanas foram consideradas mais vulneráveis devido à dependência das comunidades locais deste recurso. A sobrepesca trouxe à luz o problema da intensa captura acessória (*bycatch*) e a provável situação de exploração insustentável dos *stocks* de algumas espécies, da qual é exemplo a alta procura de espécies de camarão, tanto na pesca artesanal como na semi-industrial; e (5) poluição, um problema que pode ter várias fontes e cujas verdadeiras consequências não estão bem estudadas ao nível da MB, causando assim motivo de preocupação. Em relação às pressões indiretas, considerou-se apenas a sobrepopulação, sendo um problema exponencialmente crescente na área de estudo e que pode funcionar como um catalisador para todas as demais pressões diretas referidas.

No que toca à identificação, classificação e quantificação do ES proporcionados pelas florestas de mangal, pradarias marinhas e os seus MMI, o mapeamento foi utilizado como *proxy* para a identificação do local onde os ES em estudo poderiam ser encontrados com maior probabilidade; o mapeamento foi

desenvolvido com recurso ao *software* ArcGIS, e apesar das suas incontornáveis vantagens, foi uma ferramenta que revelou ter algumas limitações, já que algumas porções de floresta de mangal não foram identificadas, principalmente no estuário Espírito Santo. Quanto ao processo de identificação e classificação, este seguiu a *Common International Classification of Ecosystem Services* (CICES), dando ao mesmo tempo correspondência à *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES) para uma perspetiva mais ampla; já para a quantificação, foram aplicados diferentes indicadores para compreender a oferta de ES, processo que revelou algumas falhas, atendendo à escassa quantidade de dados disponíveis.

Foi confirmado o potencial das florestas de mangal e das pradarias marinhas em termos de serviços de provisão, regulação e manutenção, e culturais. Na seção de regulação e manutenção os ES destacaram-se, principalmente devido ao potencial destes ecossistemas para mitigar os efeitos de muitas das pressões diretas identificadas, bem como por serem importantes áreas de viveiro (*nursery*), inclusive para espécies de MMI: as florestas de mangal são vitais para a proteção de espécies edíveis como o caranguejo *Scylla serrata* e camarões, principalmente o *Fenneropenaeus indicus* (camarão-branco); as pradarias marinhas estão intimamente ligadas à apanha do ouriço-do-mar e amêijoas, também estes edíveis.

Ao nível de regulação e manutenção, o ES *"*ciclo hidrológico e regulação do fluxo de água" foi quantificado e considerado decrescente, refletindo a diminuição gradual da área de floresta de magal, que funciona como barreira natural.

Quanto à seção de serviços culturais, o ES "as características dos sistemas vivos que permitem a investigação científica ou a criação de conhecimento ecológico tradicional" mostrou-se crescente, refletindo o aumento do número de publicações científicas; o ES "características dos sistemas vivos que são ressonantes em termos de cultura ou património*"* foi globalmente decrescente quando se considerou o número total de hóspedes que permaneceram em Maputo ao longo do tempo, embora os visitantes internacionais tenham apresentado um maior crescimento do que os visitantes nacionais.

Relativamente aos MMI, é importante primeiro reconhecer que todas as informações resultaram de uma base de dados digital (BD) fornecida pela equipa do projeto COBIONET. No contexto da sua distribuição, os phyla Arthropoda e Mollusca demonstraram ser predominantes, sendo o primeiro mais presente em florestas de mangal e o segundo em pradarias marinhas. No que toca aos seus ES, a secção de provisão destacou-se pela sua importância na segurança alimentar, que é um dos pontos fundamentais desta dissertação e um importante Objetivo de Desenvolvimento Sustentável da Agenda 2030 da ONU para o Desenvolvimento Sustentável.

Em termos de provisão, o potencial dos MMI foi identificado e estudado através de indicadores de produção, no que diz respeito à pesca artesanal e semi-industrial, tendo as licenças de pesca artesanal também sido contabilizadas. A pesca artesanal, com um número crescente de licenças, tem aumentado a sua produção ao longo dos anos, porém, tem como alvo comum à pesca semi-industrial espécies de camarão, revelando a sua importância como fonte proteica e económica para a baía. Destacam-se as espécies *Fenneropenaues indicus* (camarão-branco) e *Metapenaeus monoceros* (camarão-negro), cujos *stocks* estão provavelmente em declínio, refletindo a sobreexploração deste recurso – realidade corroborada pela crescente procura desta iguaria já ter levado à expansão de área de pesca, a qual está já a ser praticada parcialmente dentro da POPMR, ao largo da península de Machangulo.

Para o estudo dos ES de regulação e manutenção foi aplicado a riqueza específica funcional, estimada com base na informação contida na base de dados compilada durante este estudo. Os ES possíveis de serem quantificados foram os seguintes: "manutenção de populações e habitat de viveiro"; "processos

de decomposição e fixação e os seus efeitos na qualidade do solo"; "ciclo hidrológico e regulação do fluxo de água"; e "regulação da condição química da água salgada por processos vivos". Os resultados mostraram que a oferta de todos os ES estava a aumentar indicando, aparentemente, que embora os MMI enfrentem muitas pressões, o seu efeito ainda não é visível a esta escala.

Os ES culturais passíveis de serem avaliados foram "características dos sistemas vivos que permitem a investigação científica ou a criação de conhecimento ecológico tradicional", "características dos sistemas vivos que permitem a educação e o treino" e "características dos sistemas vivos que possibilitam atividades promotoras da saúde, da recuperação ou do disfrutar por meio de interações ativas ou imersivas". Todos revelaram estar em crescimento, os dois primeiros devido à crescente riqueza específica ao longo do tempo em termos de MMI, e o último pelo crescente número de licenças para a pesca recreativa e desportiva.

Com toda a informação recolhida, o trabalho resultou no desenvolvimento de um modelo conceptual, com destaque nas ligações entre as pressões diretas e indiretas, o estado/condição dos ecossistemas, os principais ES fornecidos pelos MMI das florestas de mangal e pradarias marinhas da MB, e objetivos de uma gestão sustentável relacionados com a segurança alimentar e estado ecológico. Os resultados obtidos serão úteis para estudos futuros, representando um ponto de partida prático de exploração da MB ou áreas de estudo que reúnam condições semelhantes.

Palavras-chave: cenários futuros; dados digitais; macroinvertebrados marinhos; modelo conceptual; segurança alimentar.

ÍNDICE

LIST OF ABBREVIATIONS

CAs	Conservation Areas
CBD	Convention on Biological Diversity
CCI	Climate Change Initiative
CGLS	The Copernicus Global Land Service
CICES	The Common International Classification of Ecosystem Services
CITES	Convention on International Trade in Endangered Species of Wild Flora and Fauna
DB	Data Base
EBM	Ecosystem-based approach to management
EEZ	Exclusive Economic Zone
ES	Ecosystem Service(s)
ESA	The European Space Agency
ESCM	Ecosystem Services Conceptual Model
FAO	Food and Agriculture Organization
FS	Food Security
GBIF	Global Biodiversity Information Facility
GDP	Gross Domestic Product
HO	Habitat Occupation
IMO	International Maritime Organization Convention
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MA	The Millennium Ecosystem Assessment
MB	Maputo Bay
MMI	Marine Macroinvertebrate(s)
MPAs	Marine Protected Areas
MSY	Maximum Sustainable Yield
MZ	Mozambique
NO	Number of occurrences
NCPs	Nature’s Contributions to People

PO	Place of occurrence
PPMR	Ponta do Ouro Partial Marine Reserve
SL	Sea level
SST	Sea surface temperature
SDGs	Sustainable Development Goals
SR	Specific richness
STP	São Tomé and Príncipe
T	Future trend
TBT	Tributyltin
TG	Trophic Guild
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. ECOSYSTEM SERVICES

The first references to ecosystem services (ES) date back to the decades of 1960 and 1970 (e.g. King, 1966; Hueting, 1970; Odum & Odum, 1972; Westman, 1977), but in practical terms, the interest and ground-breaking works on ES strongly increased from 1990 onwards (e.g. de Groot, 1992; Pearce & Pretty, 1993; Bingham *et al.*, 1995; Costanza *et al.*, 1997; Daily, 1997).

In 2000 the United Nations (UN) called for The Millennium Ecosystem Assessment (MA). Initiated in 2001, MA's goal was to assess the consequences of ecosystem changes for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of ecosystems. The MA (2005) report became a seminal tool gathering cutting edge scientific information on the condition and trends of the world's ecosystems and the services they provide, tremendously increasing the global consciousness that humans depend on nature and biodiversity.

The ES concept is now regularly used, although its definition can have slight variations, which appeared and evolved due to the fact that different contexts of use and the urge of meeting different needs of various stakeholders gained voice. Therefore, there is no global definition of ES and interested groups or stakeholders with different motivations may have a particular view of the concept (Fisher *et al.*, 2009; Newton *et al.*, 2018).

1.1.1. ES definition

As stated previously, there is no global definition of ES, but the definition proposed by the MA (2005) is the most widely used. It follows Costanza *et al.* (1997) and Daily (1997) by including both natural and human-modified ecosystems as sources of ES, as well as the term "services" to encompass both the tangible and the intangible benefits humans obtain from ecosystems, which are often separated into "goods" and "services", respectively. The MA defines ES as "the benefits people obtain from ecosystems" (MA, 2005), which reflects an anthropocentric vision where ES are essential for human well-being and their study allows the understanding of the links between humans and ecosystems.

Once ecosystems and their links could be traced and framed within the concept of ES, other initiatives approaching this concept began to emerge. One of these is the Economics of Ecosystems and Biodiversity (TEEB), which fundamentally follows the MA definition except that it makes a finer distinction between services and benefits and explicitly acknowledges that services can benefit people in multiple and indirect ways. TEEB gives emphases that ES value may be viewed in economic terms and captured into decision-making. In this context ES are defined as "the direct and indirect contributions of ecosystems to human well-being"(TEEB, 2010).

The Common International Classification of Ecosystem Services (CICES), as the name implies, is directed towards a systematic classification of ES. The premise of CICES is the need for international standardization in the way ES are described and assessed by developing accounting methods that allow ES comparisons among different studies. CICES defines ES as "the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them" (Haines-Young & Potschin, 2013).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is the follow up of the MA, and it was established by the UN to strengthen knowledge foundations on ES for a better policy through science, for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (Díaz *et al.*, 2015). The IPBES is deeply rooted in cultural aspects and the intrinsic value of nature including direct biological connections to symbolic components and the perceptions of different social groups such as indigenous people and local communities. The IPBES approach advanced a new nomenclature, "Nature's Contribution to People" (NCPs, which include ES, but is not limited to them), described as "all the contributions, both positive and negative, of living nature to people's quality of life" (Díaz *et al.*, 2015, 2018).

Although each initiative has a slightly different view of ES definition, they are all based on the same fundamentals. The inherent subjectivity of the concept is intelligible in many works since each chooses the framework most adequate to its aim, if well established and justified, there is no right or wrong approach.

The most preceptive way to grasp the concept of ES contributing to human well-being is through the provisioning of different benefits, such as food. Nevertheless, one must keep in mind that there are several dimensions of well-being, such as freedom, justice, security, and health (Cruz-Garcia *et al.*, 2017). Hence, this concept not only depends on objective dimensions but also on subjective ones, related to emotional states (Summers *et al.*, 2012). Therefore, ES also consist of non-material benefits, such as spiritual or religious values (Díaz *et al.*, 2015, 2018).

ES are intertwined in three complex domains: ecology, economy, and sociology. Ecology recognizes that a healthy ecosystem generally provides a larger set of services and more consistently over time; economy corresponds to the association of value to each service provided by nature; and sociology refers to the role that environment plays in society (Fisher *et al.*, 2009).

1.1.2. ES assessment

An ES assessment is a systematic evaluation of the condition, trends, and future trajectories of ecosystems and their services. In common with other global environmental assessments, it is a collective deliberative process to produce and synthesize scientific knowledge to support informed decisions (Mace *et al.*, 2012) – ,a key step for global conservation and sustainability (MA, 2005).

Worldwide efforts to conduct global, regional, national, and even local ecosystem assessments are still in demand. Thus, the development of methods for ES quantification, mapping and economic valuation are vital tools to generate outputs useful to support decision making.

A thorough ES assessment must cover the following steps: assessment of ecosystems condition; exploring ecosystem's drivers of change; ES identification, classification, and quantification; and may further include ES mapping and valuation.

Ecosystem condition & drivers of change

The assessment of ecosystem condition refers to the analysis of the physical, chemical and biological condition of ecosystems quality at a particular point in time and the impacts of major drivers of change to which they are exposed (Hatziiordanou *et al.*, 2019).

For decision support, the most comprehensive and informative approach for the assessment of ecosystem condition should include direct mapping and assessments in combination with information about the direct (also known as pressures) and indirect drivers of change that induce these conditions. Such an approach provides information on both the current environmental state and expected changes due to constant, increasing or decreasing drivers of change (Burkhard & Maes, 2017). This is of paramount importance to support policies that aim to reduce the impact of drivers of change and contribute to a better condition of ecosystems and their services.

To better assess and describe ecosystems condition, the selection of suitable and pertinent data and indicators is fundamental to generate valuable outcomes. In cases where impacts or condition cannot be quantified, drivers of change are not only important for the understanding of the overall dynamics of the ecosystem but may also function as proxy indicators of their condition (Burkhard *et al.*, 2018).

ES identification and classification

Answering the question "are ecosystems healthy so they can keep sustainably providing ES?" is complex. Foremost, it is crucial to identify key ES provided by a particular ecosystem, so they can be classified, quantified, and mapped; after, ES value can be assessed either qualitatively or quantitatively.

Once the ES at focus are selected, their classification becomes necessary, which is done according to the adopted initiative, such as the ones presented below.

Millennium Ecosystem Assessment (MA)

The MA (2005) classification meets along ecosystem functional lines, using categories of provisioning, regulating, cultural, and supporting services, recognizing that some of the categories may overlap. Provisioning, regulating, and cultural services directly affect people, whereas supporting services refer to ecosystem processes (functions).

Provisioning services, consist of the products obtained from ecosystems, such as food and fuel; regulating services are the benefits obtained from the regulation of ecosystem processes, like air quality maintenance and climate regulation; cultural services are the nonmaterial benefits people obtain through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences, including spiritual and religious values, as well as recreation activities and ecotourism; supporting services are those that are necessary for the production of all other ES, differing from the remaining in a sense that their impacts on people are either indirect or occur over a very long time (MA, 2005).

The Economics of Ecosystems and Biodiversity (TEEB)

TEEB (2010) proposes a typology of twenty-two ES divided into 4 main categories: provisioning (e.g. food and water), regulating (e.g. air quality regulation and climate regulation), habitat (e.g. maintenance of life cycles of migratory species and genetic diversity), and cultural and amenity services (e.g. aesthetic information and opportunities for recreation and tourism). An important difference, in relation to the MA (2005), is the omission of supporting services such as nutrient cycling and food-chain dynamics, which are seen as a subset of ecological processes. Instead, habitat services are identified as a separate category to highlight the importance of ecosystems, and that availability of the services is directly dependent on the state of the habitat which provides them (TEEB, 2010).

The Common International Classification of Ecosystem Services (CICES)

The CICES classification proposes a hierarchical structure based on five categories (section > division > group > class > class type); the most inclusive one (section) divides biotic and abiotic services into three major clusters of classification: provisioning, regulation and maintenance, and cultural.

This hierarchical structure is designed to allow users to go to the most appropriate level of detail required for their study but also to be able to group or combine results when making comparisons or more generalized reports. Moving down from ‘section’ through to ‘division’, ‘group’ and ‘class’, the ‘services’ are increasingly more specific but remain nested within the broader categories that sit above them; therefore, it implies a sense of ‘taxonomy’ in elements within the same ’group’ or ‘class’, as they are conceptually more similar to each other in the ways they are used by people than to services elsewhere in the classification. At any level in the hierarchy, the categories are intended to be exclusive so that CICES can be regarded as a classification system, rather than an arbitrary nomenclature (Haines-Young & Potschin, 2013).

Overall, the provisioning section covers all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water); regulation and maintenance services focus on how all living organisms can mediate or moderate the environment which affects human health, safety, or comfort, together with abiotic equivalents; and the cultural section encompasses all the non-material, and normally non-rival and non-consumptive outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people (Haines-Young & Potschin, 2013).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

The IPBES classification distinguishes three broad groups of NCPs, regulating, material and nonmaterial, comprising a total of 18 NCPs. Importantly, this classification recognizes that many of the NCPs may not fit squarely within just one of the three broad groups. By doing so, IPBES defends that there is a representation of different facets of the complex flows from nature to a good quality of life, ranging from indispensable direct biological connections (e.g., oxygen, water), to symbolic components that give meaning to the identity of different social groups and their relationships with nature (Díaz *et al.*, 2018).

Regulating contributions, which can be related to regulating ES category of the MA, are the functional and structural aspects of organisms and ecosystems that modify environmental conditions experienced by people, and/or sustain and/or regulate the generation of material and non-material benefits. These NCPs include water purification, climate regulation, and soil erosion regulation, and are often not experienced directly by people (Díaz *et al.*, 2018).

Material contributions, which largely fit within the provisioning ES category as defined in the MA, integrate the substances, objects or other material elements from nature that sustain people’s physical existence and infrastructures needed for the operation of a society or enterprise. They are typically physically consumed in the process of being experienced, such as when plants or animals are transformed into food, energy, or materials for shelter or ornamental purposes (Díaz *et al.*, 2018).

Non-material contributions are subjective or psychological quality of life, individually and collectively. The entities that provide these intangible contributions can be physically consumed in the process (e.g., ritual fishing or hunting) or not (e.g., individual trees or ecosystems as sources of inspiration). These contributions can be related to many cultural ES, as defined in the MA (Díaz *et al.*, 2018).

ES quantification

ES quantifications includes different approaches, generally multidisciplinary, namely: biophysical quantification, involving ES measurement in biophysical units, which are used to expresses quantities; socioeconomic quantification, which relies on human preferences towards ES in non-monetary units, and/or human welfare derived from the use or consumption of ES, generally, also monetary units;

computer modelling which provides simplified representations of the environment that allow biophysical, ecological, and/or socioeconomic characteristics to be quantified and explored. When applied to ES assessment these models can be important tools for quantifying the relationships that underpin ES potential, flow and demand and, in some cases, produce maps representing these factors; Bayesian belief networks, a simplified, pragmatic approach based on graphical probabilistic models that can be used to provide initial estimates of ES delivery; and expert knowledge quantification, an approach with interdisciplinary involvement of experts to efficiently provide information on ES when other sources are lacking, generating results and validating data and maps (Burkhard & Maes, 2017).

The key to achieve a reliable ES quantification depends on the availability and quality of the data, as well as in choosing suitable, relevant and, most preferably, harmonized indicators. These are generally divided into: state indicators, describing the ecosystem that is providing the ES and its capacity (e.g. how much? total biomass); biodiversity indicators, describing species and/or their interactions (e.g. functional biodiversity; specific richness); pressure indicators, describing human or natural drivers of change affecting ES (e.g. pollutants deposition); flow indicators, describing the flow of ES (e.g. biomass harvested per year); performance indicators, describing how much of the ES can potentially be used in a sustainable way (e.g. maximum sustainable yield); socio-economic indicators, describing ES demand, value and human well-being (e.g. energy consumed and its value) (de Groot *et al.*, 2010).

Mapping ecosystems and their ES

ES production and flow are spatially explicit and temporally dependent, therefore, it is important to assess how much of a service is produced, but also when and where, as any value assigned to any service will vary across space and time (Swetnam *et al.*, 2011).

Given the spatial and temporal variable nature of ES, mapping them for planning purposes is becoming increasingly important and widely recognized as a complementary action with much potential for the aggregation of complex information, that ultimately can be used by decision-makers as a powerful tool for the support of landscape sustainability assessments (Swetnam *et al.*, 2011).

The landscape is highly influenced by land use, as such usually results in land cover changes, generally referred to as land-use land-cover (LULC) changes. These LULC changes are amongst the main effects of human activities on the environment which can impact the capacity of ecosystems to provide goods and services to humans, that at maximum should match the demands of the society for a self-sustaining anthropogenic use (Burkhard *et al.*, 2012).

Gathering land cover information is vital to carry any mapping process, and for that, many approaches can be used, such as remote sensing, land surveys and geographic information systems (GIS) with data from monitoring, statistics, modelling or interviews.

1.1.3. ES integration in conceptual models

Knowledge about ecological processes that lead to ES is still evolving, so that research aims to understand the linkages between ecosystem functioning and the delivery of ES. These linkages underpin ES synergies and trade-offs between different ES, and sustain the existence of ES bundles. Considering these connections implies looking at multiple ES simultaneously to support their management and the sustainable use of resources (Olander *et al.*, 2018).

In recent years there have been significant changes in the focus of environmental policy. The first is a shift towards an ecosystem-based approach to management (EBM); the second is a move away from a sector by sector management towards integrated management and planning (Cavanagh *et al.*, 2016; Knights *et al.*, 2013); third is the increasing recognition that an ecosystem service approach helps understanding the societal implications of management decisions (Börger *et al.*, 2014; Cavanagh *et al.*, 2016; Daily *et al.*, 2009). Therefore, the ES approach is now included in many international agendas, namely the UN and the EU Biodiversity Strategy 2020 and 2030.

Operationalizing the ES concept entails the holistic view of the natural system, and the organization of the flux of interactions related to particular ecological and socio-economical goals. Another relevant aspect of the ES approach is the enrolment of stakeholders related to any activity or business affiliated to the ecosystem under analysis. Subsequently, the idea of fully assessing how management decisions and policies enhance, sustain, or degrade the benefits nature provides to people is becoming more embedded in stakeholders, politicians and the society in general (Olander *et al.*, 2018).

One tool that can support ES assessment and management, as it serves as an auxiliary practical guidance, is the use of Ecosystem Services Conceptual Models (ESCMs). There are many types of ESCMs, and different levels of complexity between them are expected since models can adapt to the aim of a project or the level of knowledge and data behind it. Hence, ESCM can be exploratory, general or specific (Olander *et al.*, 2018).

Exploratory conceptual models are preliminary models that illustrate major relationships but are most often incomplete and unrefined. These preliminary models are often quickly developed with the input of experts, practitioners, and stakeholders that bring together a range of perspectives (e.g., cultures, roles, socio-economic status) and knowledge (e.g., ecology, economics, medicine). These models help stakeholders and experts to get on the same page and communicate priorities, though they can be challenging to produce when teams are unfamiliar with the ecosystem or related human well-being aspects of a system. In these situations, exploratory conceptual models provide a starting point for further examination (Olander *et al.*, 2018).

General conceptual models are completed and refined models that capture the cascade of changes through the system and that fully articulate, in generalized categories, the benefits for and impacts on human well-being. These models are designed to be the parent model for a type of intervention (e.g., salt marsh restoration) that can be adapted to different contexts. In addition to helping stakeholders and experts get on the same page, these general models are particularly useful for providing consistency in application/implementation and, often, a key set of services and indicators to include. They also provide a user-friendly starting point for those not knowledgeable about ES, and they can increase efficiency of implementation (Olander *et al.*, 2018).

Specified conceptual models are complete and refined versions of either exploratory or general models that are adapted and specified for a particular place and decision context. These models are more likely to follow best practices and to include measurable indicators and will most often be used in decision making as they will be targeted to relevant decision context. These models can be developed directly from an exploratory model when no general model exists, but it will be most efficient to adapt them from a general model when possible (Olander *et al.*, 2018).

Overall, ESCMs can underpin both simple and complex methods while helping to improve consistency and credibility (Olander *et al.*, 2017). In other words, ESCMs are flexible and powerful instruments to help break down a complex biological system. They consist of result chains, influence diagrams, and logic models, which can be used as a starting point to be readily used by stakeholders and conservation managers. Furthermore, ESCMs provide a decision-specific resource that can simplify and streamline incorporation of ES into decision making.

1.1.4. ES context dependency

Ecosystems are different from one another and provide their own unique resources, which can be renewable or non-renewable (MA, 2005). Due to different factors such as socio-cultural characteristics, financial capacity and customs and norms, each outlying community of a certain ecosystem may have different perceptions of its services. In addition, a community is made up of individuals with unique interests, who will act according to what is most appropriate within their civic habits (Scholte *et al.*, 2015).

Of paramount importance is the development level of the country at issue (Chaikumbung *et al.*, 2016). For instance, most times developed countries tend to receive ES benefits through the market and not directly from nature (Casado-Arzuaga *et al.*, 2013), deeply contrasting with developing countries. These countries meet ES benefits over immediate needs (Naylor & Drew, 1998), in addition to being communities where policy makers themselves may not be able to ensure sufficient food for all individuals, meaning that lack of food security can be a reality (Unnevehr, 2003). For these reasons, developing countries' communities are more sensitive to changes in the ecosystems, and are susceptible to face more adverse circumstances in which there is no alternative means to protect themselves.

Regarding all the above, projects and studies that assess ecosystems and their services from developing countries, directly in the field or remotely, are extremely relevant to assess the degree of dependence of peripheral communities on ecosystems.

1.2. FOOD SECURITY

Much has changed since 1974, when the Food and Agriculture Organization (FAO) first began reporting the extent of hunger in the world (FAO, 2020). The world population has grown steadily, with most people now living in urban areas; technology has evolved at a dizzying pace, while the economy has become increasingly interconnected and globalized. This has led to major shifts in the way food is produced, distributed and consumed worldwide. But these transformations have also brought about worrying developments in malnutrition (FAO *et al.*, 2019), as well as disparities in its distribution.

In 2015, the countries of the UN committed to the 2030 Agenda for Sustainable Development, establishing 17 Sustainable Development Goals (SDGs) divided in smaller targets provided with the right indicators (DESA, 2015). The SDG goal number 2, "Zero Hunger", aims not simply to "eradicate hunger", but also to "end hunger and ensure access by all people, in particular the poor and people in vulnerable situation to safe, nutritious and sufficient food all year round" (SDG Target 2.1) and to "eradicate all forms of malnutrition" (SDG Target 2.2) (DESA, 2015; FAO *et al.*, 2019).

Nowadays, food security is defined by FAO as a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life"(FAO, 2020). In the frame of the SDGs, it is therefore imperative to make sure no one suffers from hunger, and at the same time recognize that there are many people who, while not "hungry" in the sense that they suffer physical discomfort caused by severe lack of dietary energy, may still experience food insecurity. That means they have access to food to meet their energy requirements, yet are uncertain if it will last, and may be forced to reduce the quality and/or quantity of the food they eat in order to get by. This moderate level of severity of food insecurity can contribute to various forms of malnutrition and has serious consequences for health and well-being (FAO *et al.*, 2019).

After decades of steady decline, the trend in world hunger – as measured by the prevalence of undernourishment – reverted in 2015, as the number of people who suffer from hunger has slowly increased, resulting in more than 820 million people in the world still hungry today, underscoring the immense challenge of achieving the Zero Hunger target by 2030 (FAO *et al.*, 2019).

Achieving food security is a grand challenge for society. Climate change and an expanding global population act in concert to make global food security even more complex and demanding. Thus, it is vital to explore solutions which are complementary and do not oppose to other SDGs. One must keep in mind that the desire to raise productivity and yields has historically led to a degraded environment, reduced biodiversity and caused reduction in ES, with the greatest impacts affecting the poor (Poppy *et al.*, 2014).

The contemporary situation makes clear that it is urgent to study ES and the benefits they provide to secure nutritious food for local communities and thereby contribute to achieve the SDGs until 2030. Preventing ES overexploitation and minimizing negative impacts on the ecosystems by researching and working with citizens is, more than ever, fundamental.

1.3. MANGROVES AND SEAGRASSES

Mangroves are distinctive tidally influenced tropical and subtropical wetland ecosystems consisting of forests of trees, shrubs, epiphytes, and ferns. These habitats are found in sheltered depositional coastal environments and estuaries where fine, often nutrient rich sediments collect. They are generally confined to tidal areas between the low and high tide marks, and along the tidal margins of rivers (Aksornkoae & Kato, 2011). Their distribution is predominantly governed by climate, soil structure and salinity, as well as tidal amplitude. Research with focus on mangrove habitat ecology and implied resources has excelled, with focus on distribution and abundance of faunal elements – in so doing, the importance of these ecosystems for providing goods and services for human coastal populations has excelled (Barbier, 2007).

Seagrasses are marine flowering plants, which form extensive meadows in shallow coastal waters on all continents except Antarctica (Green *et al.*, 2003) and may occur in the intertidal and shallow subtidal on sedimentary sea beds. Seagrasses have received considerable attention in the past and seagrass beds have been identified as one of the most productive areas in the oceans, with various trophic levels, and complex species-dominance structures and succession patterns (Alfaro, 2006).

The complex dynamics within biologically rich habitats, such as mangroves and seagrasses, has received considerable attention in the past (e.g. Green *et al.*, 2003; Lee *et al.*, 2014). Both mangroves and seagrasses regulate freshwater infiltrations, retain large quantities of organic and inorganic matter, as well as pollutants, producing an environment of crystalline water low in nutrients that promote the growth of adjacent corals; those, in turn, serve as a physical buffer for ocean currents and ripples, developing a suitable environment for seagrasses and mangroves (Lee *et al.*, 2014; Moberg & Folke, 1999). In fact, these ecosystems are essential for most of the coastal communities, as they are associated to a high productivity and biodiversity, providing goods and services, not only food security related, but also aesthetic, cultural, recreative and coastal protection. Consequently, the good function of mangroves and seagrasses is fundamental to secure the mentioned benefits to local communities.

1.4. MARINE MACROINVERTEBRATES

In the tropics and sub-tropics, estuarine environments with mangrove and seagrass habitats provide important structures and resources for diverse communities of benthic organisms (Alfaro, 2006). In fact, due to their abundance, diversity, interaction with high number of trophic levels in ecological networks and occupation of a huge variety of ecological niches, marine macroinvertebrates (MMI) are vital components of mangroves and seagrasses (Alfaro, 2006).

Marine macroinvertebrates play an important role not only in ecological terms but often to human well-being as well. For instance, MMI are relevant components in the human diet greatly contributing to food security of local communities, especially in developing countries such as Mozambique (Gillespie & Vincent, 2019). Throughout this work the phyla Annelida, Arthropoda, Cnidaria, Echinodermata and Mollusca will be addressed for their role in each ecosystem (mangroves and seagrasses) and their importance to food security of local communities in the Maputo Bay.

1.5. MAPUTO BAY

Maputo Bay (MB) is the largest coastal embayment in Mozambique (MZ) and a major feature along the eastern African coastline; such dimensions allied with the richness of diverse natural environments and their derived ES set out to be key factors in supporting the livelihood of a large human population.

According to Mumby *et al.*, (2000) the major coastal habitats of the MB consist of: mangroves; submerged aquatic vegetation, mainly seagrass meadows but also macroalgae; sand, including sand bars, spits, sandy beaches and dune systems; corals; and rocky formations (outcrops of sandstone). These ecosystems, together with the MB's shape and the presence of Inhaca and Portuguese islands provide protective barriers against strong wave action; addedly, the six rivers that flow into this coastal embayment also provide the necessary freshwater for local communities and the establishment of healthy ecosystems (Barbosa *et al.*, 2001).

The capital of Mozambique, Maputo, sited on the western margin of the Bay, constitutes the main and largest urban area of the country, and the prime centre for commerce, industry and trade, also being a major hub with the outside world (da Silva & Rafael, 2014). Though of political and commercial importance this reality comes with some disadvantages, as the urban fabric carries the weight of new or amplified anthropogenic related drivers of change that are likely to harm the ecosystem condition and consequently the ES availability.

1.6. DIGITAL DATA

One of the greatest challenges while conducting a study, relies on data availability and gathering. Researchers can compile data in many ways from sampling and surveys, field studies to museum collections and other studies. In truth, all the methods mentioned are reliable and widely used. However, beyond these there is an increasing array of high quality digital data stored in digital repositories (e.g. GBIF, FAO, national statistical institutes, etc) that can be used in downstream studies (Ladouceur & Shackelford, 2021), such as ES assessments. In fact, according to Borgman *et al.* (2006, 2007) data is becoming scientific capital and e-Science promises to increase the pace of science via fast, distributed access to computational resources, analytical tools, and digital libraries.

Digital data can be used for different purposes, and generally involves compiling, standardizing, and synthesizing data from different sources. The advantages of using metadata from digital sources are many, e.g., allowing the identification of knowledge gaps which can be addressed through an informed process, the use of broader spatial and time scales, the development of desk-based projects when the study area is difficult to assess, and overall leading towards better/more complete outcomes (Ladouceur & Shackelford, 2021). These 'long-term' datasets can be used either alone, or in combination with newly generated data to produce new knowledge, discovery and innovation. Subsequent data and knowledge obtained from such studies can be integrated and reused by the community after the data publication process.

1.7. OBJECTIVES

This thesis fits into the emerging theme of ES, whose concept focuses on the contribution of biodiversity and ecosystems to the sustainable development of humanity, advocating a sustainable use of goods and services in conjunction with the promotion of human well-being.

The main objective of this dissertation was to identify the most important ES associated with mangroves and seagrasses in the Maputo Bay, Mozambique, and relate their condition and drivers of change with the ES provided by marine macroinvertebrates. This assessment further intended to have a holist approach on blue ES by addressing knowledge gaps targeting marine macroinvertebrate ES and by providing an ES conceptual model relating drivers of change with marine macroinvertebrates ecological characteristics, flow of ES, and different management goals. Emphasis was placed on the importance of MMI to food security of the MB´s local communities, encompassing traditional practices and the sustainable use of these resources in mangroves and seagrasses. This model intends to provide a tool with baseline information for decision-makers to identify marine macroinvertebrates mitigation and conservation actions applied to MB´s mangroves and seagrasses.

Specifically, this study addresses the following questions:

- What is the condition and the main drivers of change in MB´s mangroves and seagrasses?
- What are the main ES provided by mangroves and seagrasses in MB?
- What are the ES provided by MMI in MB´s mangroves and seagrasses?
- What are the knowledge gaps related to marine macroinvertebrate ES in MB´s mangroves and seagrasses?
- How do MMI ES relate to food security in MB´s mangroves and seagrasses?
- Which mitigation and conservation actions can be taken to promote food security related to MMI in MB´s mangroves and seagrasses?

2. METHODOLOGY

2.1. THE STUDY AREA

2.1.1. Geographical setting

With an area of 2,280 km^2 (approximately 90 km in coastal length by 32 km width), the MB opens to the Indian Ocean, lying between the latitudes 25°72'10" S – 26°28'30" S and longitudes 32°49'10" E – 32°85'40" E (Datum WGS84).

In terms of regional integration, the Macaneta Peninsula encloses the Bay to the north-west, with Portuguese and Inhaca Islands forming the eastern arm; from Inhaca southward, the main coastal features include the Machangulo Peninsula, Bembe River Estuary and Maputo River Estuary. As for the western shore, it comprises the Espírito Santo and Incomati Estuaries, as well as the associated Xefina Islands (**Figures 2-1** and **2-2**).

In detail, the Bay integrates three major estuaries and a smaller one. The three main ones are the Incomati Estuary (Incomati River), Espírito Santo Estuary (Infulene, Matola, Umbeluzi and Tembe Rivers) and Maputo Estuary (Maputo River); Bembe Estuary (Bembe River) is less known since it's smaller and therefore the flow into the bay is less noticeable (da Silva & Rafael, 2014).

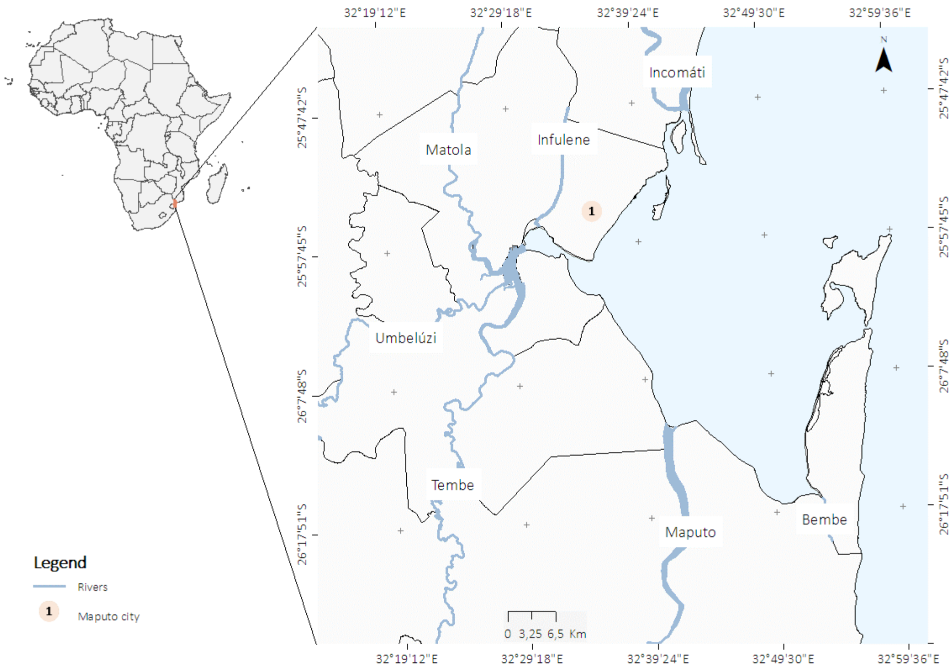


Figure 2-1| Geographic enclosure of MB, with a highlight on the rivers that disembogue into it.

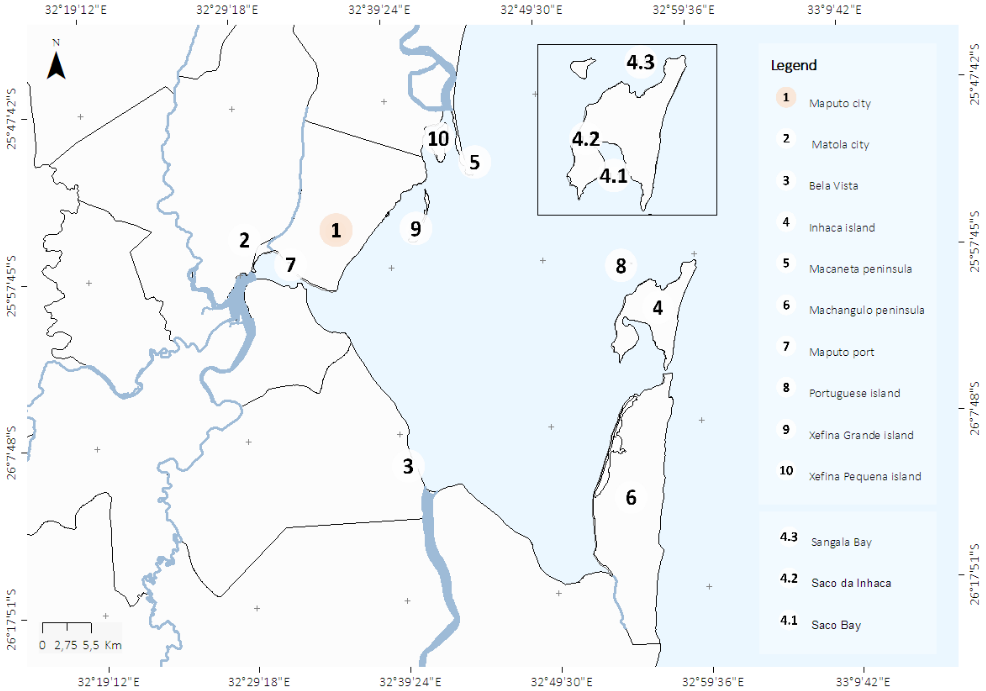


Figure 2-2| Map of MB and important points of reference that will be mentioned thenceforth.

According to Kalk (1995), there are six species of mangroves in MB: *Avicennia marina*, the most widespread mangrove species inhabiting both the inner and outer fringes of mangrove forests; *Rhlizophora mucronata* which occurs in creeks throughout the Bay and tolerates less variation in salinity; *Ceriops tagal*, a middle species in the zonation of mangroves, along with *Bruguiera gymnorhiza*; *Xylocarpus granatum*, a less common species in the Bay with the exception to Incomati Estuary where it is widespread; and *Lumnitzera racemosa*, the uppermost mangrove species occurring right after the limit of the terrestrial vegetation, usually in areas where there is seepage of freshwater.

Seagrass meadows in MB, locally called "Tanhi" in the language xiRonga, include nine seagrass species distributed in three families: from Cymodoceaceae family, *Cymodocea rotundata*, *C. serrulata*, *Halodule uninervis*, *Syringodium isoetifolium*, *Thalassodeudron ciliatum* and *T. leptocaule*; from Hydrocharitaceae family, *Halophila ovalis* and *Thalassia hemprichii*; and from Zosteraceae family, *Zostera capensis* (Bandeira, 2002). According to Bandeira (2002), the major seagrass meadows are located near Inhaca island, and include *T. ciliatum*/ *C. serrulata* in its west side, and *T. hemprichii*/ *H. uninervis* at north and south bays (Sangala and Saco, respectively). At the Saco Bay's mouth, *Zostera capensis* can be also found, linking it to the Machangulo peninsula, where seagrasses become quite inconspicuous given the extensive mangrove forests. The western and southern parts of MB are less suitable for seagrasses, given the existence of fine sediment plumes produced by the discharges of the several rivers, where mangroves thrive (Bandeira, 2002).

With exception of the urban areas of Maputo and Matola cities, as well as the surrounding adjacent population centres, over 70% of the coastal belt of the Bay is a natural vegetated landscape especially at Inhaca island and Machangulo Peninsula. In addition to that, MB includes two important conservation areas (**Figure 2-3**): Ponta do Ouro Partial Marine Reserve (POPMR) and Maputo Special Reserve (MSR), which includes only terrestrial grounds. Both reserves are very important for the conservation of biodiversity, socio-economic development, and the well-being of local communities, especially in rural areas. Currently, these areas attract tourists and their potential rely on the trade-offs between the availability of infrastructures to support the tourism industry and the maintenance of their integrity (Goñi *et al.*, 2011).

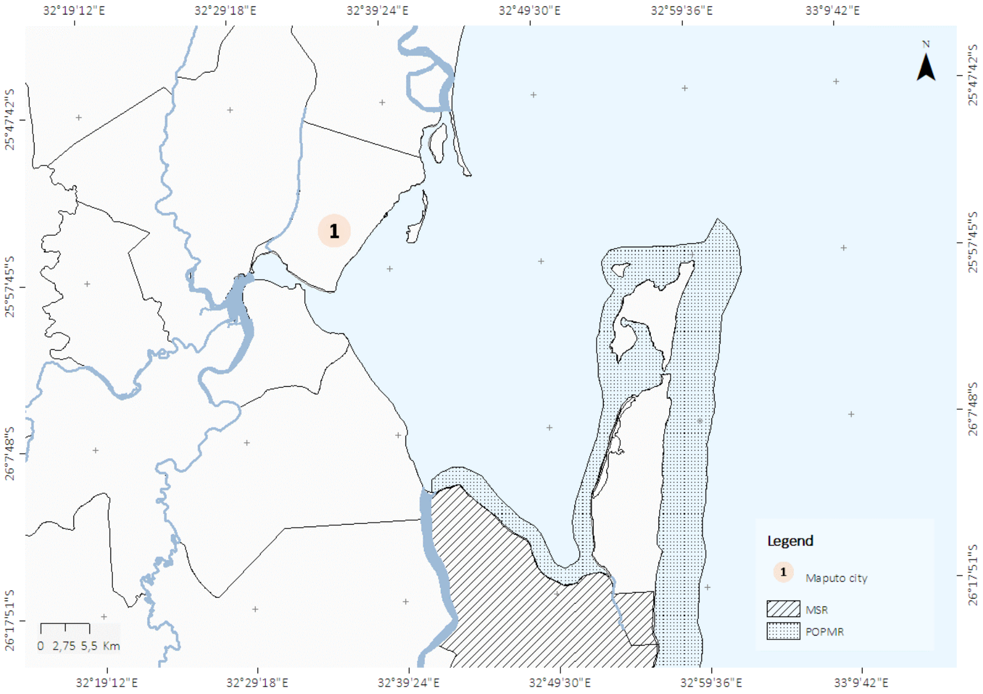


Figure 2-3| Protected areas involving Maputo Bay. Maputo city (1) is emphasized in a warmer colour as a landmark. MSR - Maputo Special Reserve. POPMR - Ponta do Ouro Partial Marine Reserve.

2.1.2. Social and economic context

Maputo City, the capital of the country, is an urban area with a high density of tall buildings, being the heart of the business/ financial sector and concentration of government offices; to the north and west of this area spread extensive residential areas, housing the majority of the population. There, habitations are usually of small size and less complex. However, the fast-urban expansion promises a rapid transformation of these suburban areas (da Silva & Rafael, 2014).

Mozambique is recognized as a country that has enough natural resources in its territory to escape poverty, as well as to develop and grow economically. Productive activities around MB are mainly agriculture, industry, trade and fisheries, being the main industrial sector within the coastal zone located in the Matola satellite city that extends to the Espírito Santo estuary where the Maputo Port is located (**Figure 2-2**) (CMM, 2008).

MB is the second largest fishing ground in Mozambique and supports both extensive artisanal fisheries, where the fleet consists of 3-7 m wooden boats propelled by sailing, rowing or with outboard engines: and semi-industrial fleets capturing several types of fishing products. Semi-industrial fishery accounts for 2 000 fishers, employs about 7,046 people and provides direct annual input to the local economy, estimated in 1.5-2 million USD (Anderson, 2009).

2.2. CONDITION AND DRIVERS OF CHANGE IN MB´S MANGROVES AND SEAGRASSES

2.2.1. Mapping ecosystems

The present section refers to the ecosystem mapping process, with the steps carried out for every map used in this study. GIS tools were used, more precisely ArcMap, an application from ArcGIS (ESRI, 2020) maintained by the Environmental Systems Research Institute (ESRI).

The spatial dataset for mapping mangrove forests and seagrass meadows, added as layers, were downloaded from the UN Environmental World Conservation Centre website at https://data.unep-wcmc.org, and manually obtained from Bandeira et al. (2014), respectively. The datasets, used for each ecosystem, were as follows: Global Distribution of Mangroves USGS (Dataset ID: WCMC-010): the dataset shows the global distribution of mangrove forests derived from earth observation satellite imagery, composed of one set of polygon occurrence data, with a temporal range from 1997 to 2000 and the reference system WGS 1984 (version 1.4 – March 2021); Global Mangrove Watch (Dataset ID: GMW-001): the dataset shows a global baseline map of mangroves using satellite imagery, composed of one set of polygon occurrence data for 1996, 2007, 2008, 2009, 2010, 2015 and 2016, and the reference system WGS 1984 (version 2.0); Seagrass Meadows in Maputo Bay: the dataset shows the distribution of seagrasses in the MB adapted from the map provided in Bandeira *et al.* (2014), composed of one set of polygon occurrence data, with an unknown temporal range and spatial reference. When another type of information was deemed useful (e.g. points of reference), it was inserted manually in the software – in this case, coordinates needed to be known beforehand, along with their respective geodetic datum (GD) and projected coordinate system (PCS). The GD defines the size and shape of the Earth, as well as the orientation and origin of the used geographic coordinate system (GCS) through a set of constants, whereas the PCS is based on GCS that is transferred into a flat, two-dimensional surface (Burkhard & Maes, 2017). Other important elements of each map were the following: Hydrographic network, retrieved from the Humanitarian OpenStreetMap Team at https://export.hotosm.org/: the dataset shows the main rivers of the MB, composed of one polygon; Maputo Special Reserve and Ponta do Ouro Partial Marine Reserve, retrieved from the Foundation for the Conservation of Biodiversity (BIOFUND) at https://www.biofund.org.mz: the datasets shows the cover of the protected areas, each one composed of one polygon; Exclusive economic zone (EEZ), retrieved from Flanders marine institute (VLIZ) at http://www.marineregions.org/: the dataset shows the maritime boundaries and exclusive economic zones (200NM), composed of one polygon; Maputo administrative boundaries, retrieved the humanitarian data exchange (HDX) at https://data.humdata.org: the datasets shows the administrative boundaries of Mozambique, composed of a set of polygons; World map (country scale), retrieved from ArcGIS at https://www.arcgis.com: the datasets shows the administrative boundaries of each country, composed of a set of polygons, with the reference system WGS 1984.

Once all the intended files were obtained and uploaded to ArcMap, a standardization process was applied so the data would have equal properties, thus creating images able to overlap correctly in future maps. In other words, the GD (WGS84) and PCS (UTM zone 37S) of all files were made the same, so equal coordinates would correspond to the same point in the globe, leading to the generation of rectified and most precise maps.

The output of this mapping process generated simple images of the studied ecosystem's locations, only providing background information to better understand the areas where different ES types may be present as a proxy – see **section 2.3.**

2.2.2. Ecosystem's condition

A thorough review of digital databases and scientific literature was accomplished to gather data on different MB ecosystem condition parameters. Due to the lack of data to compare and standardize quality scales, only one indicator had the potential to be applied for the MB condition assessment: the area of the Marine Protected Areas (MPAs). More concretely, the estimation of the ratio between the area of POPMR and the total marine area in the province of Maputo (Maputo's EEZ). The resulting ratio was compared to a standard value proposed by the Aichi target 11, within the strategic goal C (to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity), stating that "*by 2020, at least 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ES, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes"* (CBD, 2013) . This reference value (10% of MPAs) was used to assess the MB condition, and therefore its mangroves and seagrasses.

It should be noted that all the EEZ information was retrieved (from VLIZ, 2019), at the country scale. The area parallel to the coastline of Maputo's province was then selected permitting the application of the condition indicator specifically to the area corresponding to the MB. It is important to safeguard that the generated area approximates the corresponding EEZ directly in contact with the province where the study area and the encircled MPA belong.

2.2.3. MMI of MB's mangroves and seagrasses

Available digital data was compiled to evaluate the occurrence (i.e. existence of an organism or a defined group of organisms considered to be taxonomically homogeneous, at a particular place at a particular time) and distribution of MMI in MB´s mangroves and seagrasses, which were used as proxy indicators to assess MMI condition (adapted from MAES, 2018). The MMI database (DB) used for this study, was provided by the team of the COBIONET project (Niza *et al.*, 2021). Data sources for the DB included biodiversity repositories such as the Global Biodiversity Information Facility (GBIF), museum collections and scientific literature; the dataset was already georeferenced (with every entry associated with a latitude and longitude), standardized according to a Darwin Core format, and validated.

The original DB had data from two countries, Mozambique (MZ) and São Tomé and Príncipe (STP) so the DB was handled to fit the intended analysis. Thus, all STP data were discarded, leaving only the MZ data, which was further subjected to a second selection where only the entries lying between the physical/ geomorphological boundaries of the MB were accounted for. The latitudes considered were between -26.10083 and -25.86053, whereas the longitudes between 32.48915 and -25.86053.

Two scatterplots of the MMI registered at the MB (y) over time (x) were produced to characterize the final DB in terms of all the individuals represented.

The distribution pattern of MMI at the Phylum level in both ecosystems was mapped to visualize their occurrence within the study area by applying pie charts representing the relative proportion amongst phyla in each ecosystem. Further, to add detail to the MMI spatial distribution, all occurrences from each Phylum in both mangroves and seagrasses were also mapped.

2.2.4. Drivers of change

Direct drivers of change

Direct drivers are those which unequivocally influence ecosystem processes, and for this reason, are further explored in this dissertation. The assessment of direct drives of change (pressures) encompassed the review of digital databases, scientific literature and reports related to Mozambique, more specifically MB, to gather data on five main pressures: alien species, climate change, land use land cover (LULC) changes (related with habitat destruction), pollution and overexploitation.

Alien species

The literature search focused on invasive MMI and culminated in a single article (Simbine *et al.*, 2018). Since the available data was insufficient, no indicators were applied.

Climate change

The datasets referring to Sea Surface Temperature (SST) and Sea Level (SL), were downloaded from the permanent service for Mean Sea Level (PSMSL) at https://www.psmsl.org/data/obtaining/stations/986.php and the Nasa Earth Observations (NEO) at https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MYD28M&year=2020. The datasets used from each source were as follows: PMSL – Maputo MSL, and consists of a .cvs file, dating from 1961 to 2001; NEO – sea surface temperature (1 month - AQUA/MODIS), and consists of a .cvs file, dating from 2002 to 2010. To better understand if any climate change sign has been registered over time in the MB region, for each variable, a scatterplot was produced where the dependent variable was SST or SL, and the independent variable was time (in years). Subsequently, a linear regression was applied to the data of each scatterplot to obtain an overall perspective on the evolution of each dependent variable over time.

Land use/ Land cover (LULC)

LULC data are often derived from remote sensing or habitat mapping. The spatial datasets mapping the LULC, added as layers, were downloaded from the European space agency (ESA) at http://www.esa-landcover-cci.org/?q=node/175 and the Copernicus global land service (CGLS) at https://land.copernicus.eu/global/products/lc. The datasets used from each source were as follows: ESA – 300 m annual global land cover time series from 1992 to 2015: the dataset shows the different types of land cover at a global scale, and consists of a raster file, dating from the years of 1992 to 2015; CGLS – Global Land Cover viewer for maps and area statistics: the dataset shows the different types of land cover at a global scale, and consists of a raster file, dating from the years of 2016 to 2019.

The obtained data ranged from 1992 to 2019, resulting from the compilation of two different files, one from 1992 to 2015 and another from 2016 to 2019. However, while analysing both files together, it became evident that due to differences in both resolution and classification of origin, they were not compatible and therefore comparable. Hence, the data from ESA, which covers the longer time range was selected for further analysis.

Given the impacts of LULC change on ES, gaining insight on how soil occupation has developed over time in terms of urbanization, agriculture and natural environment was the target. To do so, the same methodology used in **section 2.2.1** was applied at a starting point – these steps and the following ones can be consulted in **Figure 2-4**.

After the standardization, all raster files (one for each year) were converted to the datum D_WGS_1984 and projected to WGS_1984_UTM_Zone_37S, and each pixel was reclassified to strictly represent one of the following classes: (1) (semi)natural land-cover, (2) agricultural land-cover, (3) urban land cover, and (4) bare land cover; (0) zero stood for eventual pixels with no data, later proven to not exist. For the final step, all raster files were handled to obtain the areas of the main classes (multiplying the area of one pixel by the total number of pixels from each class).

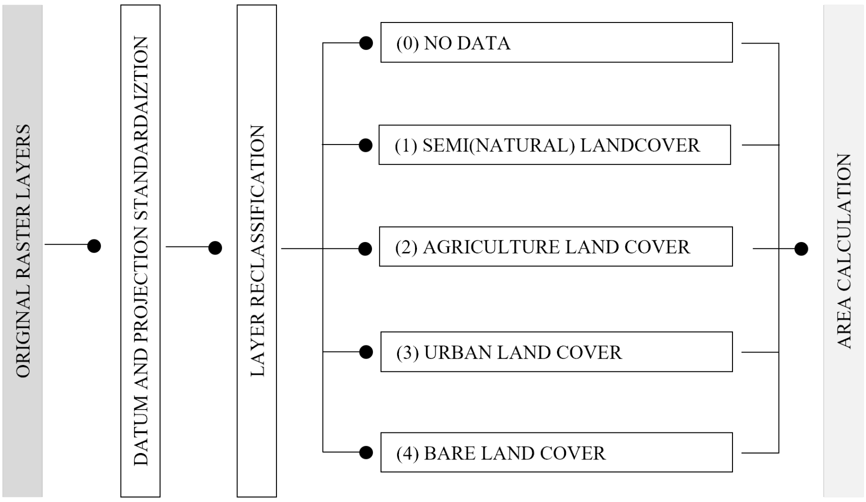


Figure 2-4| Steps for the datum and projection standardization, raster reclassification and area calculation of each LULC layer from 1992 and 2015.

Pollution

The search carried out only brought forward the findings available in Bandeira & Paula (2014). For this reason, no indicators were applied in this section. Nevertheless, to better grasp the complexity of the study area, the information found was compiled into a table, summarizing the main sources of pollution in MB, as well as the main problems behind them.

Overexploitation

Mangrove deforestation and MMI fisheries were the two main pressures within overexploitation with potential for further analysis. Thus, this driver of change was divided into two subsections.

Deforestation

The deforestation analysis aimed at understanding the evolution of MB´s mangrove forests over time. Therefore, the methodology behind it is the same as in the section LULC, but a different file was used here because raster files from LULC did not differentiate mangrove cover within the class (1) (semi)natural land-cover. Specific data used to assess mangrove deforestation ranged from 1996 to 2016 and were the same as in **section 2.2.1.**

Overfishing

According to the *Instituto Nacional de Investigação Pesqueira* (National Fisheries Research Institute), subordinated to the *Ministério do Mar, Águas Interiores e Pescas* (Ministry of the Sea, Inland Waters and Fisheries), three types of fisheries must be accounted for in MB: (1) artisanal fisheries; (2) semi-industrial fisheries of shrimp; and (3) recreation and sport fisheries (IPP, 2009).

As a practical matter, recreation and sport fisheries were established as a non-interfering factor for the fishing effort as, in comparison with artisanal and semi-industrial fisheries, it only makes up for a very small parcel of the total catches. Since this type of fishery is considered to contribute to recreational activities, it was addressed through the spectre of cultural ES.

To understand the impact that fishing can have on MB´s wildlife, concretely on MMI, various official reports were consulted (António et al., 2017; Ministério das Pescas, 2012; Sousa, 1989). To assess the possibility of overfishing in the MB, data on Maximum Sustainable Yield (MSY) and fishing effort are required, however, the gross of the information available consisted of fishing licenses and data catches (production in tons). Therefore, fishing licenses functioned as a proxy indicator of the state of MMI stocks, following the assumption that more licences represent higher fishing effort and more severe impact on MMI stocks which can become unsustainable – meaning that the number of individuals of a species can drop to concerning levels, putting the health of the ecosystem and the reassurance of food security at risk. Data catches provided vital information about by-catch, a reality that ended up being explored as it represents a threat and a complex problem to marine biological communities worthy of debate.

Indirect drivers of change

Whereas a direct driver unambiguously influences ecosystem processes, an indirect driver operates more diffusely, by altering one or more direct drivers; indirect drivers are usually demographic, economic, socio-political, scientific and technological, and cultural and religious.

This work focused on the demographic aspect of the MB since this area has been facing a rapid urbanization process. Specifically, the population development in the entire province of Maputo was assessed over time, recurring to data census from 1997, 2007 and 2017 (INE, 1997, 2007, 2017). This information was used to construct a scatterplot. This was followed by the application of an exponential model to the linear regression representing the tendency of the data over time (an exponential function was chosen as population growth tends to have an exponential behaviour). Also, with the population numbers for all districts within the province of Maputo, the population density was calculated, by the ratio between the population number of each district and its respective area.

To better understand the dynamics among population density, LULC changes and mangrove deforestation over time in the MB surrounding area, three maps were created using the same methodology as in **section 2.2.1**, one for 1996, another for 2007 and another for 2015. These years were chosen as they represent three decades of information and had almost all the data needed regarding the three parameters in analysis. **Table 2-1** explains the adopted methodology for the year selection; LULC and mangrove cover were already available for the three years considered; only population density information was lacking for the years of 1996 and 2015, which was estimated. To estimate population density for each district, population numbers were calculated through a scatterplot of the available census information, along with the application of an exponential model to the non-linear regression of each scatterplot. All equations characterizing the non-linear regressions representing the tendency of the data over time can be consulted in **Table 6-1, ANNEXES**. The equations were then used to obtain population number estimates which were used to calculate the population density in both 1996 and 2015.

Table 2-1| Timeline from 1992 to 2019 with data available on LULC, mangrove forest cover and population density. The dark grey corresponds to the years with accessible information; light grey indicates that the available information was estimated, and it only applies to population density; the squares with a diagonal line mark refer to discarded information. 1996, 2007 and 2015 are encircled in black as they were the selected years with overlapping data and similar time intervals between them, being the most suitable for map construction and visual analysis.

TIME	*92*	*93*	*94*	*95*	*96*	*97*	*98*	*99*	*00*	*01*	*02*	*03*	*04*	*05*
LULC	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
Mangroves					▓									
Population density	░	░	░	░	░	▓	░	░	░	░	░	░	░	░

TIME	*06*	*07*	*08*	*09*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
LULC	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▨	▨	▨	▨
Mangroves		▓	▓	▓	▓					▓	▓			
Population density	░	▓	░	░	░	░	░	░	░	░	░	▓	░	░

2.3. ASSESSMENT OF MB´S MANGROVES AND SEAGRASSES ES

2.3.1. ES identification and classification

To assess mangroves and seagrasses in terms of ES supply a thorough literature research was done to identify them and compile information on their dynamics and potential. This process led to the construction of different tables comprising provisioning, regulating and maintenance, and cultural ES of mangroves and seagrasses. The listed ES were categorised following CICES initiative, giving correspondence to IPBES as well, so that they could be viewed from two different perspectives.

2.3.2. ES quantification and future tendencies

When assessing ES there is a big variety of indicators that can be applied, being that their selection and further application will depend on the type of data available for analysis. During this process, a thorough bibliographic search was done to find suitable indicators which are listed in **Table 2-2**.

It is of note the fact that the indicators selected to assess provisioning ES of mangrove and seagrass were based on MMI information which are described in greater detail in **section 2.4.2.**

The regulation and maintenance ES “Flood control and coastal protection” was estimated by calculating the MB´s mangrove area in 1997 and 2017 to detect changes over time. The areas were calculated as in LULC by multiplying the area of one pixel by the total number of pixels of the mangrove forests extension in each year.

Cultural ES were quantified through the indicators “scientific studies (no per year), and “average stays in Maputo Province” (days per year), detailing stays “by national visitors” (no per year) and “by foreign visitors” (no per year). The number of scientific studies was obtained by counting the number of written papers about the MB mangroves and seagrasses in each year; the papers search was done through SCOPUS, an abstract and citation database, using the following keywords: seagrass(es), mangrove(s), and Maputo Bay. Average stays and visitor numbers were obtained from INE (2020) and directly analysed.

Table 2-2| Selected indicators suitable to assess the quantification and future tendencies of ES provided by mangrove forests and seagrass meadows of MB.

ES SECTION	***INDICATORS***	***SOURCE***
Provisioning	See section 2.4.2	-
Regulation and maintenance	Changes in mangrove area over time (km^2)	Worthington *et al.* (2020)
Cultural	Scientific studies (no per year)	Scopus, Elsevier (2021)
	Average stays in Maputo Province (days per year) ↳ by national visitors (no per year) ↳ by foreign visitors (no per year)	INE (2020)

2.4. ASSESSMENT OF MMI ES IN MB'S MANGROVES AND SEAGRASSES

2.4.1. ES identification and classification

Similarly to **section 2.3.1**, to assess MMI in terms of ES supply a thorough literature search was done to identify and classify MMI ES in MB. This process led to the construction of different tables related to provisioning, regulating and maintenance, and cultural ES. Again, ES were categorised following the CICES initiative, giving correspondence to the IPBES typology.

2.4.2. ES quantification and future tendencies

ES indicators were selected according to the available data and can be consulted in **Table 2-3**. However, the indicators used to quantify the regulation and maintenance services provided by MMI were developed here using an independent approach applied to the DB analysis – the process behind it is explained in more detail throughout the following paragraphs and resumed at the end of this section in **Figure 2-5**.

Table 2-3| Selected indicators to assess the quantification and future tendencies of ES provided by the MMI present in MB´s mangrove forests and seagrass meadows; (*) indicators originated through the DB analysis and had no previous source. SR – species richness.

ES SECTION	***INDICATORS***	***SOURCE***
Provisioning	Artisanal fishery production (tons/ year)	António *et al.* (2017); Ministério das Pescas (2012); Sousa (1983)
	Semi-industrial fishery (shrimp) production (tons/ year)	
Regulation and maintenance	*Score level of species capable of providing "maintaining nursery populations and habitats (including gene pool protection)" ES by contributing to habitat modification, bioerosion, nutrient cycle and food web stability	*
	*Score level of species capable of providing "decomposition and fixing processes and their effect on soil quality" ES by contributing to bioturbation	*
	*Score level of species capable of providing "hydrological cycle and water flow regulation" ES by contributing to the hydrological flux	*
	*Score level of species capable of providing "regulation and chemical condition of salt water by living processes" ES by contributing to the water quality	*

Table 2-3| (cont.) Selected indicators to assess the quantification and future tendencies of ES provided by the MMI present in MB´s mangrove forests and seagrass meadows; (*) indicators originated through the DB analysis and had no previous source. SR – species richness.

ES SECTION	*INDICATORS*	*SOURCE*
Cultural	Diversity of life from which to learn (SR)	*
	Licences for recreation and sport fishing (no)	António *et al.* (2017)

The first step consisted in the assessment of the different functions performed by MMI taxa and its association with MMI's services – to avoid falling into intricate particularities of MMI's interactions, a guideline was developed using the information available involving MMI's functional groups, i.e., habitat occupation (HO) and trophic group (TG), and it is presented in **Table 2-4**.

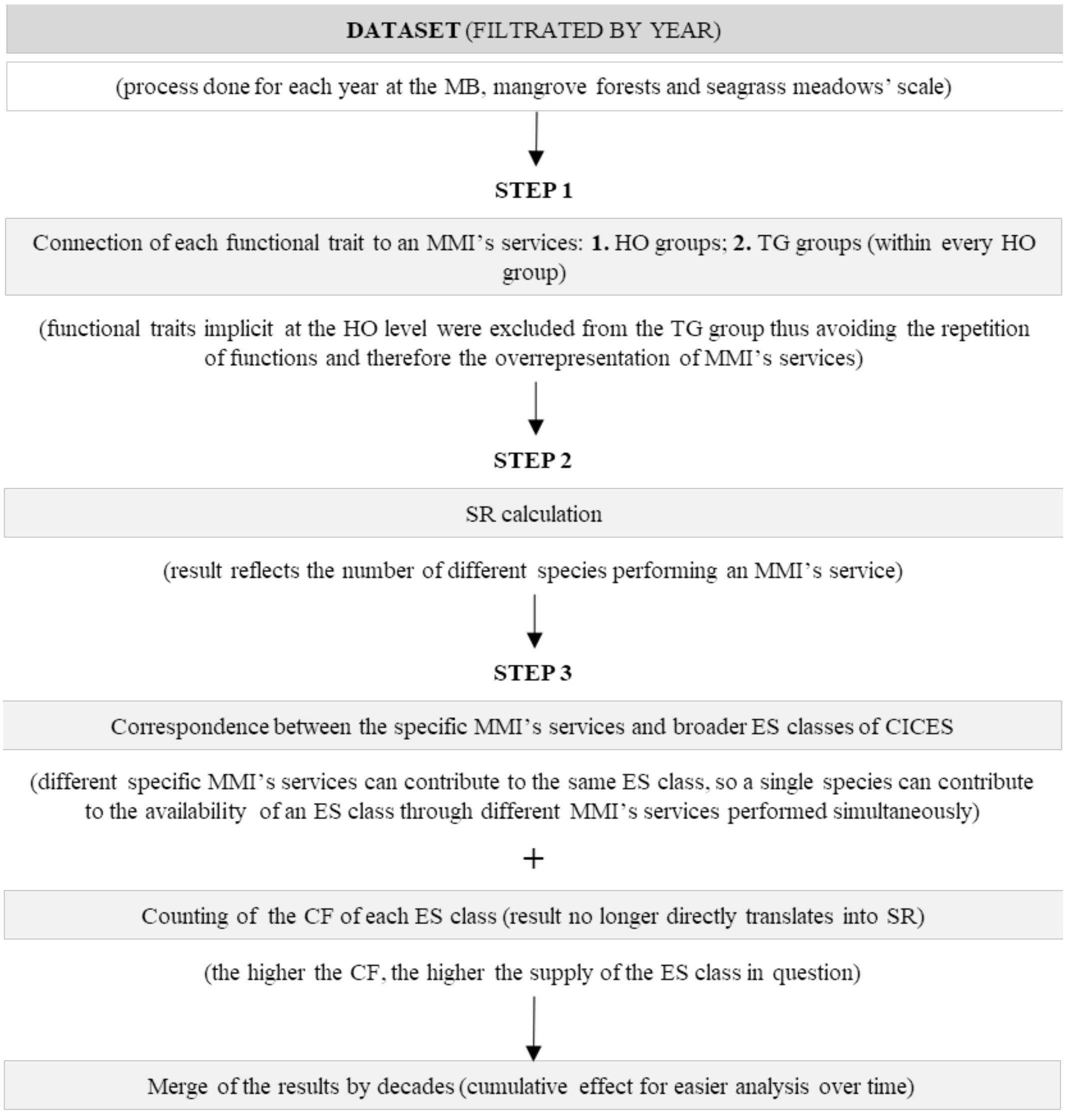
Secondly, species richness (SR) was used for MMI's services quantification, when it directly translated into the contribution for a specific MMI's service, i.e., the number of taxa presenting functional traits that provided that service. This procedure was done for each year, initially at the HO level, and next at the TG level within each HO group. The common functions between the HO and TG groups for each taxa were excluded at the TG level, since by being implicit in the broader group it would be accounted for twice, translating in an MMI's services overrepresentation.

With all the functions and corresponding MMI's services attributed and quantified, there was a need to classify them within CICES classes. However, by being too specific, different MMI's services could fall in the same ES class, meaning that a single species could contribute to the availability of an ES through different specific services performed at the same time. Hence, the third step consisted of the attribution of the different MMI's services to broader ES classes, where the final number would correspond to a Contribution Factor (CF), and not directly to SR. The higher the CF, the higher the contribution to an ES class.

During this process, the dataset was analysed at the MB, mangrove forests and seagrass meadows scale, per year. However, the results were summarized by decades; this cumulative effect had the purpose of obtaining more robust numbers to better illustrate the CF of each ES class overtime.

Table 2-4| Determination of the MMI's functions associated with habitat occupation (HO) and trophic guild (TG), and the corresponding ES (identified in bold). Here, "nutrient cycle" and "food web stability" ES were not included, as they were considered common to all groups.

HO	***CHAIN OF EVENTS AND RESULTING MMI'S ES***
Benthos	(1) *sediment movement and alteration, burrowing → (2) **bioturbation** → (3) **changes in hydrological flux** _(*This type of movements can also cause resuspension of particulate organic matter (POM) and pollutants that interfere with water quality, however in this case this phenomenon was considered vestigial and thus not accounted as an MMI function.)_
Nekton *Zooplankton*	(1) live in the water column, affecting the quantity of light able to penetrate through water → (2) **habitat modification**; (3) light affects photosynthesis processes and nutrient concentrations → (4) **water quality.**
TG	***CHAIN OF EVENTS AND RESULTING MMI'S ES***
Chemosymbiosis *Parasite* *Predator* *Scavenger*	No additional functions were determined.
Deposit feeder *Microphage* *Surface deposit feeder*	(1) sediment movement and alteration → (2) **bioturbation**. (1) consumption of sunk POM → (2) less POM reduces the likelihood of a eutrophication event and a consequent algae bloom → (3) **water quality** control **and habitat modification**. *(Though this type of feeders may incite habitat modifications, such consequent is not a direct consequence of their behaviour which in fact can be controlled before happening – for this reason the habitat modification function was not accounted for in this situation.)*
Suspension feeder *Filter feeder*	(1) consumption of suspended POM in the water column → (2) → less POM reduces the likelihood of a eutrophication event → (3) **water quality** control. (1) consumption of suspended POM in the water → (2) → less POM enables more light to penetrate the water column → (3) **habitat modification**.
Epifauna feeder	(1) degradation of the hard substratum, hence being capable of **bioerosion**.
Infauna feeder	(1) sediment movement and alteration → (2) **bioturbation** and burrowing → (3) changes in **hydrological flux** (burrowing allows water penetration and circulation).
Grazer *Phytoplanktivore*	(1) Ingestion of biofilm and algae or phytoplankton → (2) prevention of algae blooms / high concentrations of phytoplankton → (3) **habitat modification** and **water quality** control.
Zooplanktivore	(1) Ingestion of zooplankton → (2) Lower zooplankton concentration in the water column → (3) light can penetrate through the water more easily → (2) **habitat modification**.



DATASET (FILTRATED BY YEAR)

(process done for each year at the MB, mangrove forests and seagrass meadows' scale)

STEP 1

Connection of each functional trait to an MMI's services: **1.** HO groups; **2.** TG groups (within every HO group)

(functional traits implicit at the HO level were excluded from the TG group thus avoiding the repetition of functions and therefore the overrepresentation of MMI's services)

STEP 2

SR calculation

(result reflects the number of different species performing an MMI's service)

STEP 3

Correspondence between the specific MMI's services and broader ES classes of CICES

(different specific MMI's services can contribute to the same ES class, so a single species can contribute to the availability of an ES class through different MMI's services performed simultaneously)

+

Counting of the CF of each ES class (result no longer directly translates into SR)

(the higher the CF, the higher the supply of the ES class in question)

Merge of the results by decades (cumulative effect for easier analysis over time)

Figure 2-5| Scheme with the methodology behind the assessment of the regulating and maintenance ES and their future tendencies.

2.5. ES CONCEPTUAL MODEL

To create a fair ES conceptual model (ESCM) adapted to MB management goals, a few fundamental steps were taken based on Olander *et al.* (2018). At first, a specific outcome was established by adapting the model to an exact site and context – i.e., to understand the role of MMI in mangroves and seagrasses, ultimately considering food security of the local communities as an outcome.

Secondly, the kind of model to develop was chosen considering that: the present dissertation was based on linking existing scattered information and data; all the understanding of the study area and its systems was attained remotely; and as far as stakeholders are concerned, all the information gathered was the product of literature search – the possibility of direct contact with them was too farfetched. In this setting, the exploratory conceptual model (sensu Olander *et al.*, (2018) ESCM connotation i.e. exploratory, general, or specific) was considered the most adequate to provide baseline information for decision-making.

Thirdly, model assumptions entailed the clarification of hypotheses and the refining of the model, leading to a process of adding missing nodes and removing extraneous ones. Such was followed by a fourth step, the search for corroborating evidence (for each assumption), which consisted of assessing and documenting what is generally known about the relationships in the model, providing an initial indication of magnitude and direction of change where it is known, and refining model relationships (add/drop nodes and arrows as needed to represent what has been learned).

The fifth step was based on evidence assessment and the confidence behind each relationship described in the model; at this stage, all the results obtained during the course of this study were integrated to further enhance the model, and expert-based discussions were conducted, which further specified gaps that should be prioritized in the research agenda. Such actions culminated in the sixth and last step where the visualization of the model and the discussion of the confidence in the existing evidence and the concerns about the gaps identified were pointed out. This contributed to an understanding of the benefits and risks behind the results.

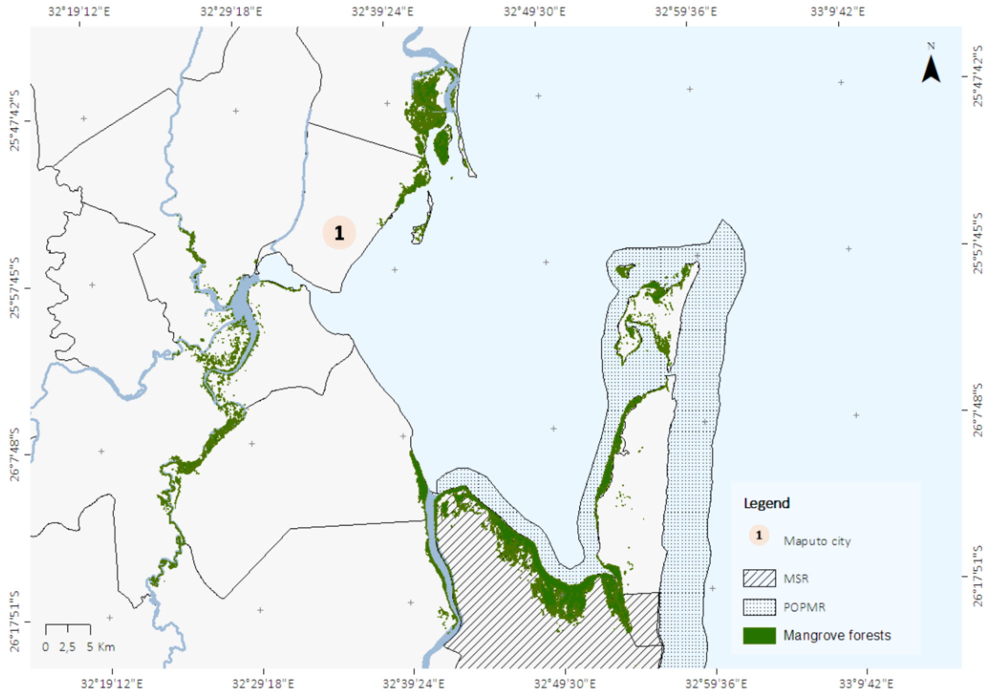
It is important to note that the first sketches of the conceptual model were developed in an expert-based knowledge workshop given by Professor Melanie Austen and Dr Stefanie Broszeit. Later, two online meetings took place, again counting with expert-based knowledge, where opinions and corrections were exchanged, aiming to refine the ESCM.

3. RESULTS

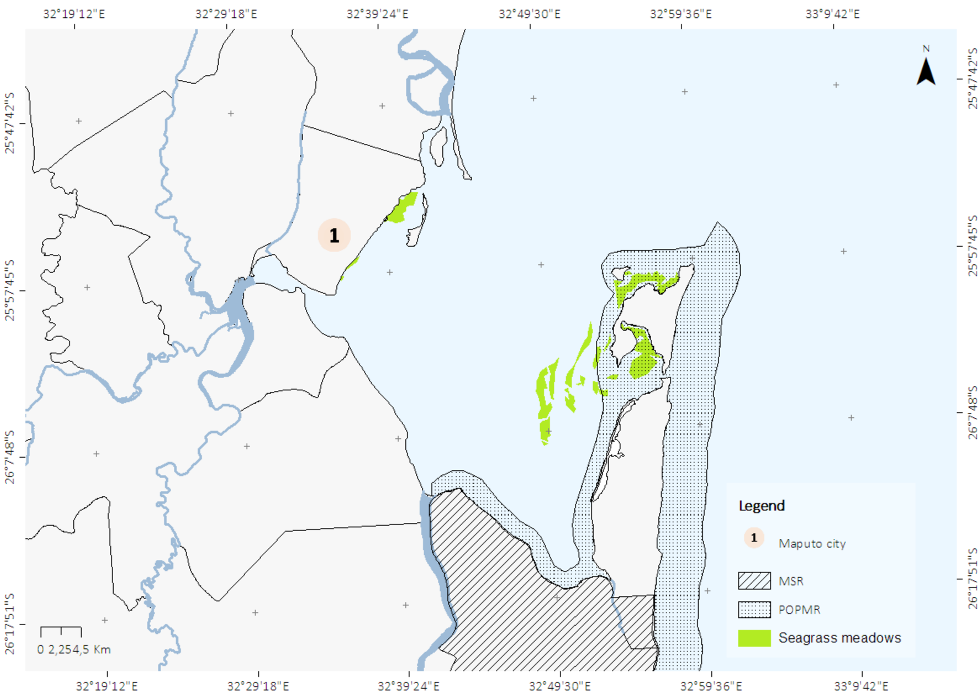
3.1. CONDITION AND DRIVERS OF CHANGE IN MB´S MANGROVES AND SEAGRASSES

3.1.1. Mapping ecosystems

Mangrove forests (**Figure 3-1**) bordered the banks of all estuarine systems. At north, by the Incomati river, mangrove forests revealed being quite dense. At Espírito Santo estuary, although present, mangroves became more prevalent upstream by the Matola and Tembe rivers side. In the south of the bay, mangrove formations stretched from around Bela Vista (Maputo river estuary mouth) towards Bembe river and Machangulo Peninsula, where, along with the Inhaca island, the most eastern mangrove formations of the bay were found.



Seagrass meadows (**Figure 3-2**) in the Bay area were mainly found around the Inhaca Island, extending to the Machangulo Peninsula and the middle of the Bay, and at north of Maputo City around Costa de Sol and Bairro dos Pescadores.



3.1.2. Ecosystem’s condition

Table 3-1 lists the total marine area of Maputo Province and the integrated MPA area, where the total marine area corresponds to the EEZ parallel to the province’s coast and the MPA’s area is translated by the area of the POPMR.

The condition indicator expressed as the ratio between both areas was 0.661% which is very apart from the 10% considered by the Aichi Target 11.

Table 3-1| Area of both Maputo Province’s marine area and marine protected area, and the ratio between them.

MARINE AREA	***AREA (KM^2)***	***RATIO (%)***
Marine area of Maputo Province	110878	0.661
Marine protected area of Maputo Province	678	

3.1.3. MMI of MB’s mangroves and seagrasses

Figure 3-3 illustrates each phylum representation in the dataset, where its overall proportion, number of occurrences (NO), which includes individuals from the same species, and SR is displayed. Mollusca had the biggest representation in the dataset making up to more than half of it (57%), followed by Arthropoda (34%), Echinodermata (6%), Cnidaria (3%) and Annelida (0%). Here, although the phylum Annelida was present, its representation was virtually zero in comparison with the other phyla. Also, for all phyla except Annelida and Cnidaria more than half of the registers corresponded to individuals from the same species, highlighting a big discrepancy between NO and SR.

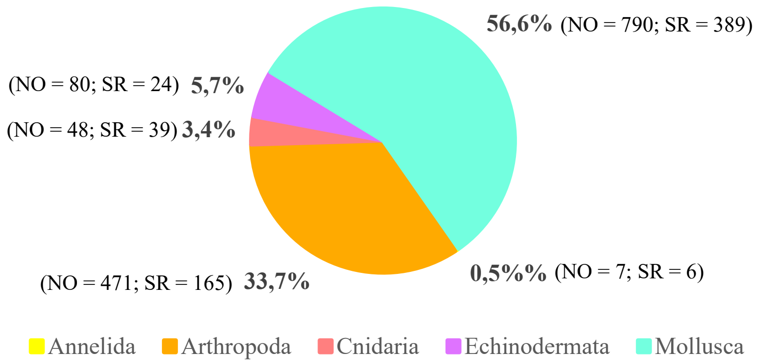


Figure 3-3| Characterization of the dataset, where each phylum representation is made in terms of proportion (%), number of occurrences (NO) and species richness (SR).

Mangroves from MB presented a total of 735 occurrences of MMI and a SR of 333, whereas seagrasses showed 109 occurrences and a SR of 59. **Figures 3-4** and **3-5** illustrate MMI's data availability over a period of approximately 100 years in MB´s mangroves forests and seagrass meadows. Both scatterplots express the NO of MMI registered in the BD.

Although both graphics revealed various MMI oscillations over time, the mangrove ecosystem seemed to have more robust data (**Figure 3-4**), with four small pics lower than or close to 50 occurrences, and two other ones that stand out: the highest pic at the beginning of the 1960s with approximately 275 occurrences, and the other, around the 2010s with almost 150 occurrences.

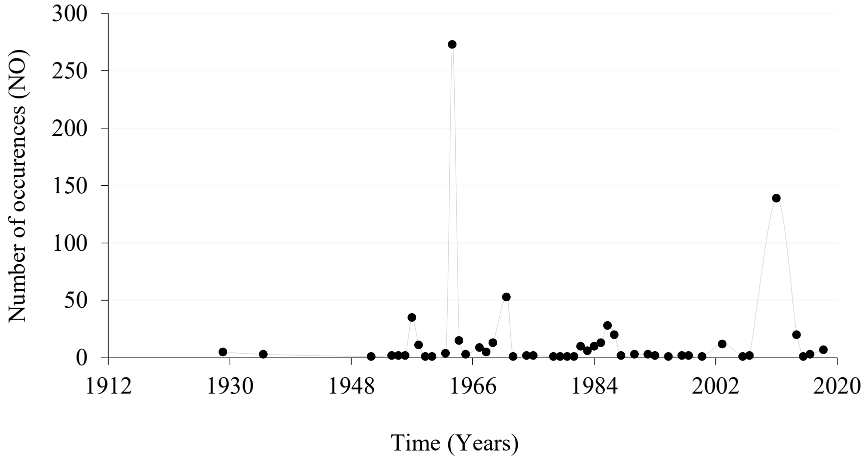


Figure 3-4| MMI data collection in MB´s mangrove forests over time, where the dots correspond to the number of occurrences (NO) registered each year (N).

Figure 3-5 shows that in seagrass meadows there was a small pic of MMI occurrences in the late 1980s, and a higher one in 2010 of almost 15 and 60 occurrences individuals, respectively. However, this growing tendency suffered a shift from that point on with almost no occurrences.

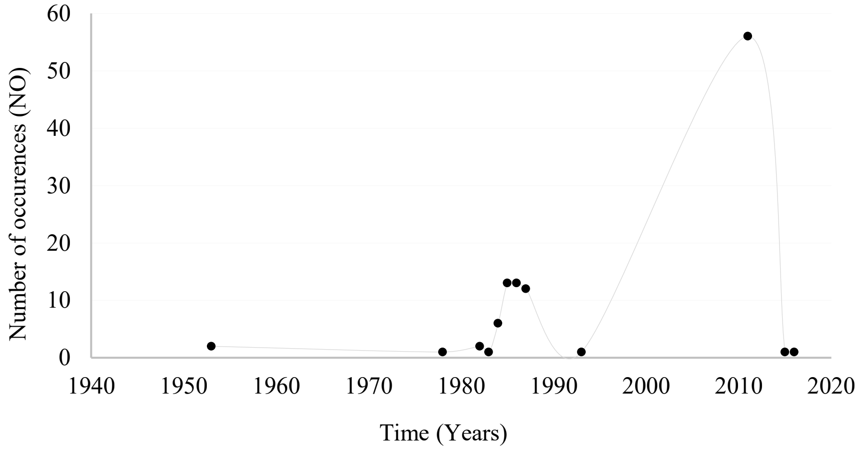


Figure 3-5| MMI data collection in MB´s seagrass meadows over time, where the dots correspond to the number of occurrences (NO) registered each year (N).

The distribution pattern of MMI at the phylum level in MB´s mangrove forests and seagrass meadows are presented in **Figures 3-6** and **3-7**, respectively; the pie charts also show the relative proportion amongst phyla in each ecosystem in different parts of the study area. Both figures have outliers (land points), all just including the phylum Arthropoda. These outliers are an artefact of the pie charts (**Figures 3-8** and **3-13** will make this clear) due to the occurrences in the shore or the river mouth – points close to land can sometimes seem to be misplaced due to a software default, as in this case. Although not representing the entire bay, pie charts characterize a small quadrant that, if close to the shore, may seem to be represented in the terrestrial domain.

Figure 3-6 reveals that at the western part of the bay the prevailing MMI phylum was Arthropoda, although towards the north, at the Incomati estuary, the phylum Mollusca gained presence; between Incomati and Espírito Santo estuaries, the phylum Echinodermata was also found. At the eastern point of the Bay, at Inhaca island, all phyla were present, except the phylum Annelida, yet Mollusca and Arthropoda phyla were more predominant, by this respective order.

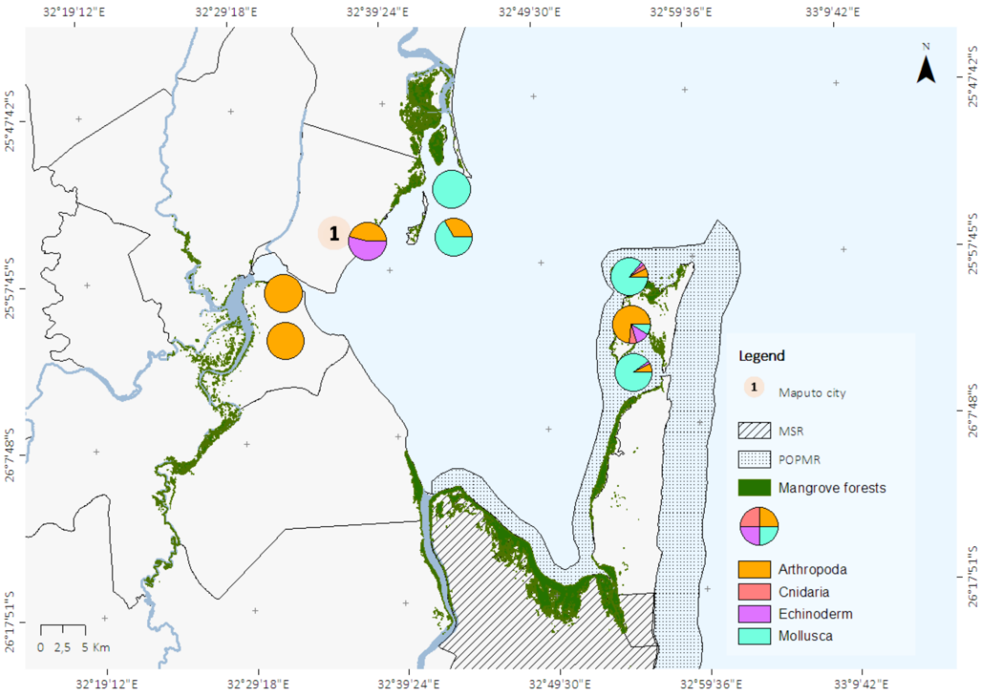


Figure 3-6| Distribution and relative proportion of each MMI phylum found in MB´s mangrove forests.

Although according to the obtained data, seagrasses could be found at the north of Maputo city and in the middle of the bay closer to the east side, only those inside the POPMR around Inhaca and Portuguese islands were found to be places of occurrence for MMI (**Figure 3-7**). Mollusca was the most represented phylum; in fact, in the most southern part of Inhaca it was the only phylum present; Echinodermata was the second most frequent phyla, whereas Annelida, Arthropoda and Cnidaria, while present, were far less frequent than the first two.

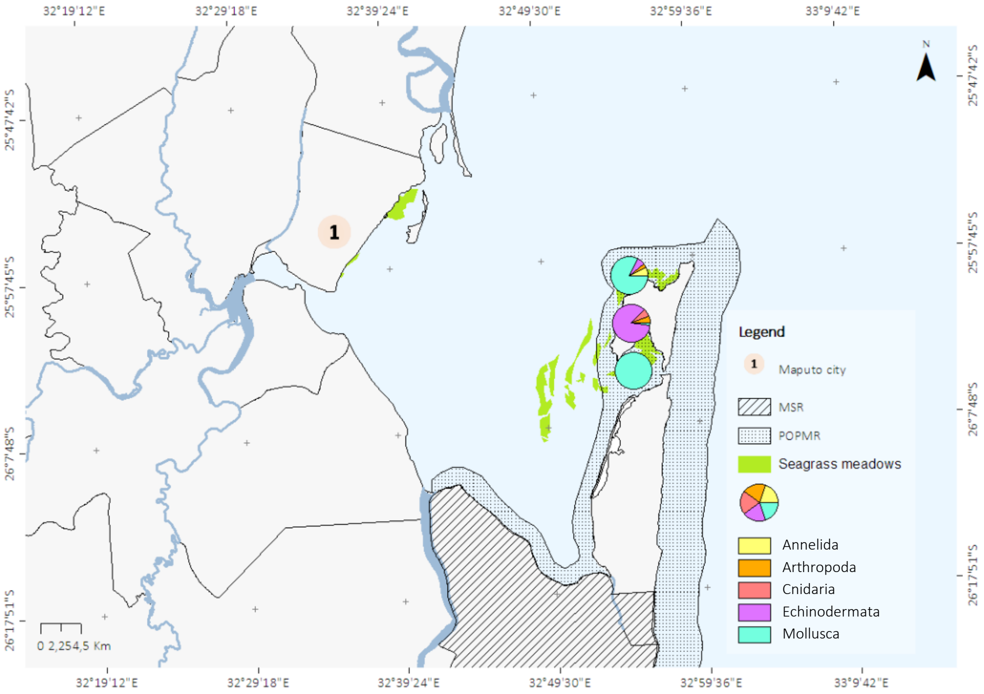


Figure 3-7| Distribution and relative proportion of each MMI phylum found in MB´s seagrass meadows.

Figures 3-8 and **3-9** add detail to the MMI spatial distribution, by focusing on all the occurrences of a single phylum at a time, being the first one dedicated to mangrove forests and the second one to seagrass meadows. Each dot represents a location of one or more individuals (from the same phylum); here these dots will be referred to as places of occurrence (PO).

No Annelida was represented in mangrove forests, and for all four other phyla, the highest concentration of PO was observed at Inhaca island and its surroundings (all turned west, facing the Bay, and none at the east, facing the Indian Ocean), all inside the POPMR.

Figure 3-8 (A) revealed two Arthropoda PO by the river, corresponding to the supposed outliers in the pie charts; **(B)**, which illustrates Cnidaria, only showed PO at Inhaca island (not even in the Portuguese island), one of them at Saco de Sangala and four at the west of the Saco da Inhaca; **(C)**, representing Echinodermata; and **(D)**, representing Mollusca, presented similar spatial distributions, with the exception that the last one had some PO in the Xefina islands.

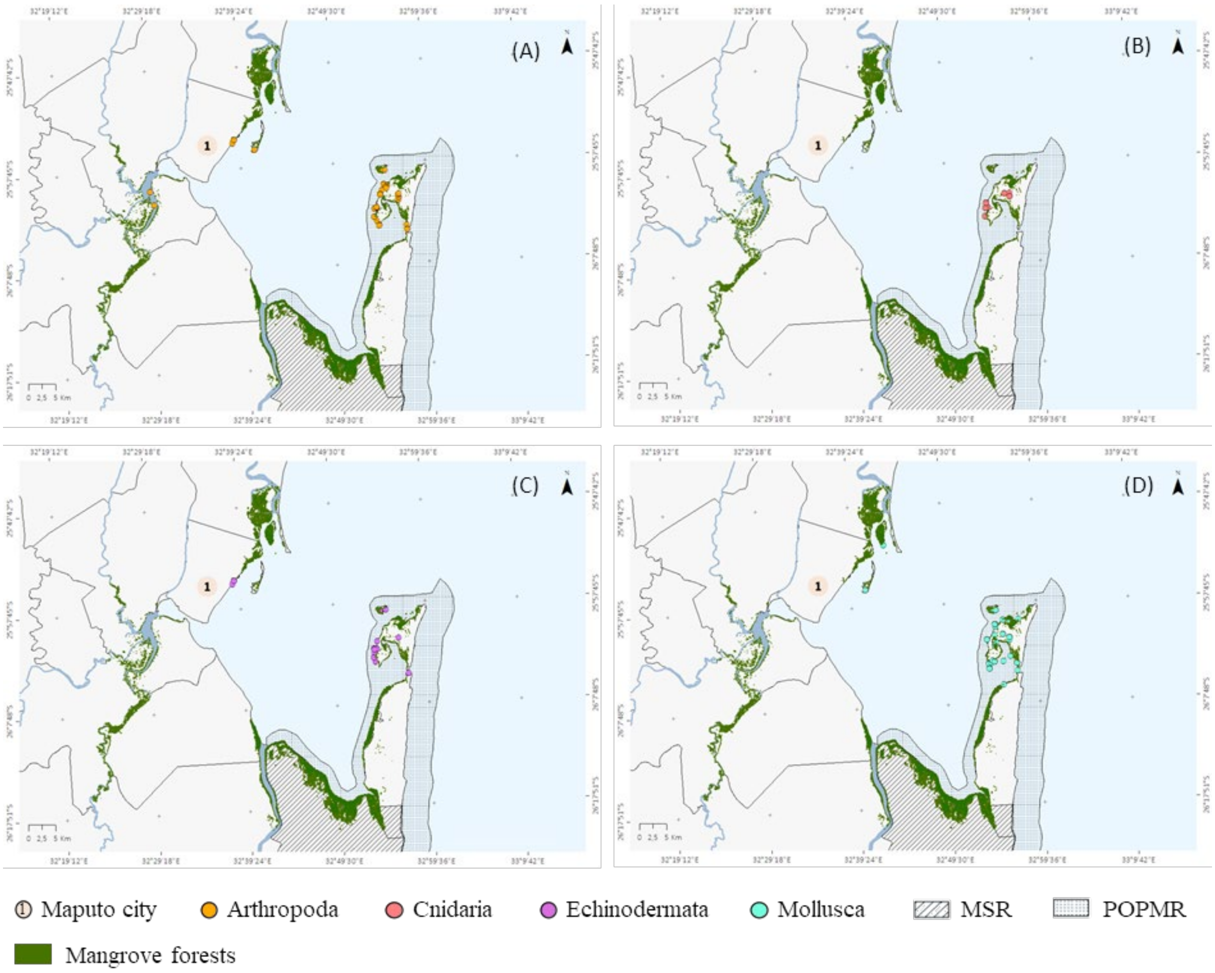


Figure 3-8| MMI distribution in MB's mangrove forests by phyla, namely: (A) Arthropoda, (B) Cnidaria, (C) Echinodermata, (D) Mollusca. Each dot corresponds to a different site (pair of coordinates).

In what concerns seagrasses, except for Annelida, all four other phyla had less PO than in mangroves, often being less than three. **Figure 3-9 (A)** showed only one Annelida PO, between Inhaca and the Portuguese islands; **(B)** revealed Arthropoda PO, one at the Portuguese island and another in the west side of Inhaca; **(C)** gave out the information that the only Cnidaria PO was at the west of Saco da

Inhaca; **(D)** revealed an almost identical distribution of Echinodermata to Arthropoda, only the first had two PO at the Portuguese island; and **(E)**, illustrated a contrasting distribution of Mollusca, which was far wider than the others phyla, with more PO in the Saco Bay.

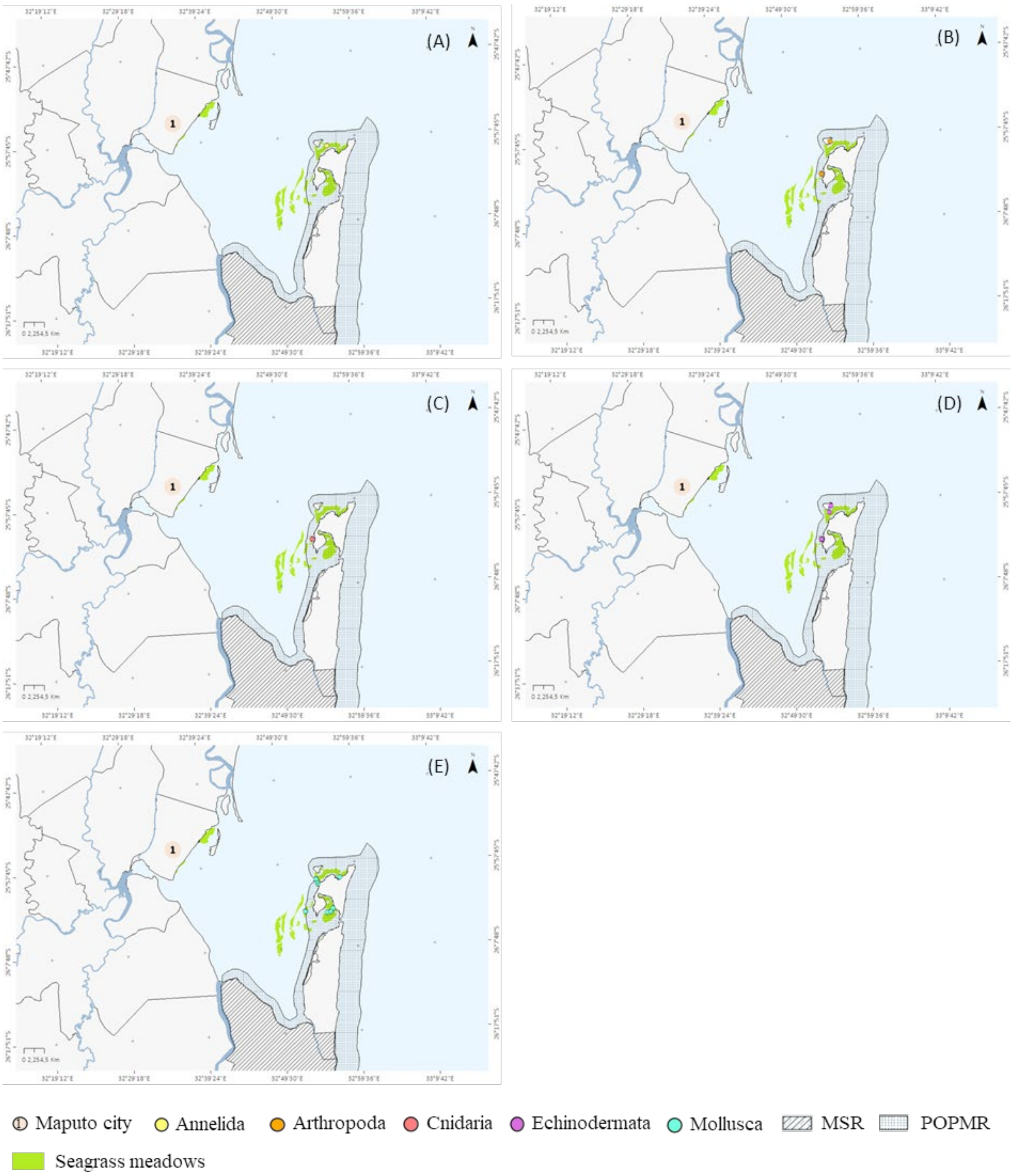


Figure 3-9| MMI distribution in MB's seagrass meadows by phyla, namely: (A) Annelida, (B) Arthropoda, (C) Cnidaria, (D) Echinodermata, (E) Mollusca. Each dot corresponds to a different site (pair of coordinates).

3.1.4. Drivers of change

Threats to mangroves

Figure 3-10, schematically presents the major threats to MB`s mangrove forests. The degradation of this ecosystem was linked to four direct drivers of change: climate change, overexploitation, LULC changes, and pollution.

Overexploitation included fishing production, as well as deforestation, the last one directly related to the destruction of mangrove forests for fuel and wood; LULC changes presented three distinct threats, namely, urban development, saltpans and shrimp aquaculture (now abandoned), which culminate in the same problem: land reclamation by deforestation to accommodate different projects; lastly, pollution, mainly assigned to port-based (e.g.: accidental spills) and land-based (e.g.: agricultural, industrial and domestic effluents, or urban sewage) activities.

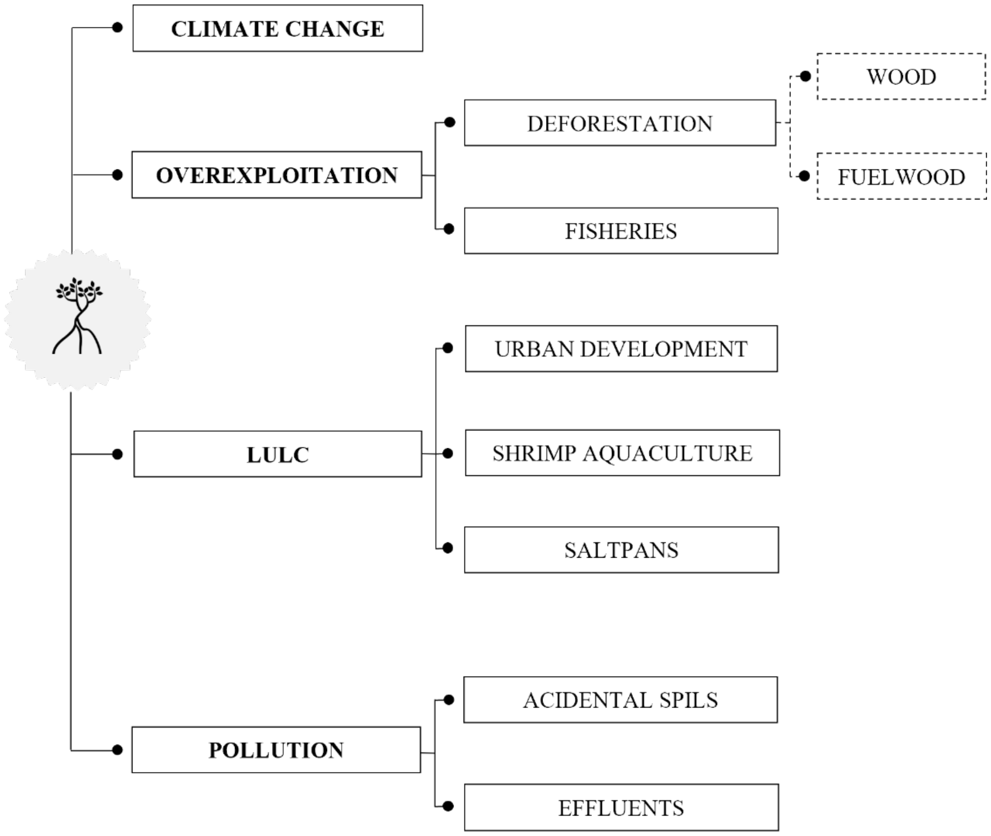


Figure 3-10| Main threats imposed to MB´s mangrove forests. Adapted from Paula *et al.* (2014).

Threats to seagrasses

The effect of drivers of change in MB´s seagrass meadows was more pronounced in two locations: Portinho, in the harbour area near the main village of Inhaca island, and at the northwest of the bay, between Bairro dos Pescadores and Xefina Grande island (**Figure 3-11**).

On Inhaca island, besides natural disturbances (related to sand accretion or sedimentation that can be enhanced by climate change), anthropogenic stressors were related to three distinct sources: trampling, motorboats, and the construction of a jetty. As for the northwest of the bay, apart from the natural sedimentation, sand excavation linked to clam harvesting was the major anthropogenic stressor.

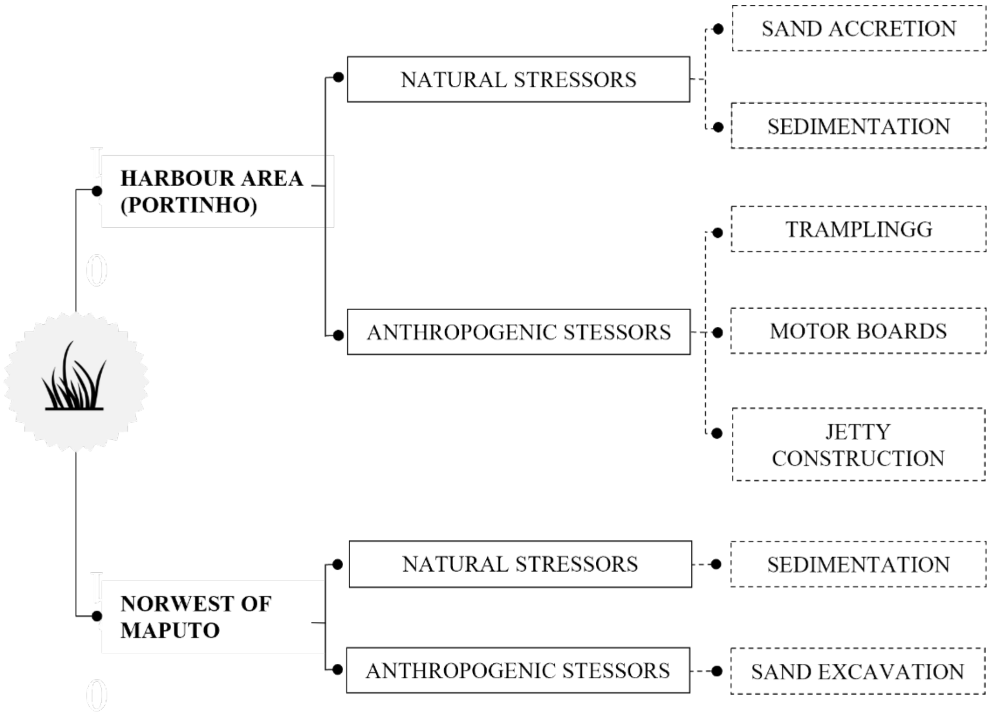


Figure 3-11| Main threats imposed to MB´s seagrass meadows. Adapted from Bandeira *et al.* (2014).

Direct drivers of change

Alien species

The only reference (Simbine *et al.*, 2018) to alien MMI species in MB, revealed the presence of a new *penaeid* shrimp species in 2007, *Metapenaeus dobsoni*, which had never been recorded in the area, or along the Mozambican coastal waters.

Climate change

A quick analysis of **Figure 3-12** reveals that at the beginning of the century the mean sea surface temperature (SST) was close to 14.8 ºC and since then, although with several oscillations, it increased to approximately 15.9 ºC in 2017. However, around 2020 the mean SST dropped to approximately 15.1 ºC. Even so, SST is likely to keep rising, according to a linear tendency line, which indicates a mean SST increase of 0.4 ºC in the MB in the last 20 years.

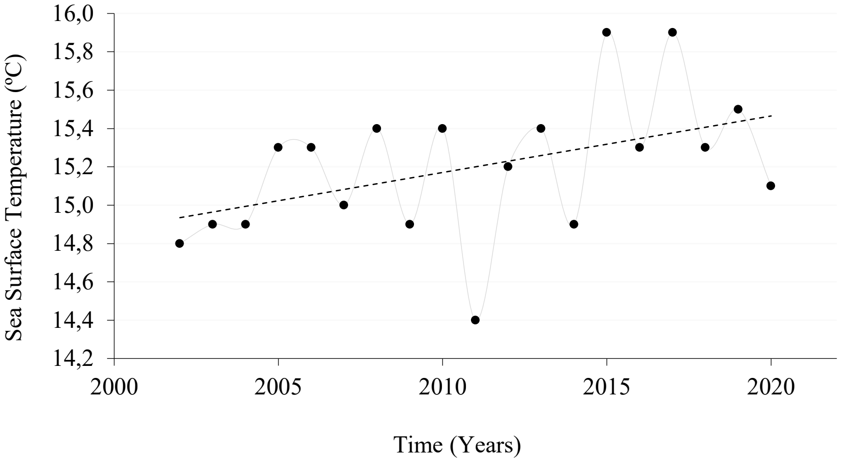


Figure 3-12| Scatterplot of the MB´s mean sea surface temperature over time (full line, where the dots correspond to known values) and respective linear tendency line (dashed line). Source: NEO, (2020).

Figure 3-13, shows the MB´s mean sea level (SL) over time. SL was approximately 6.95 m in the 1960s and, although, with many small oscillations through time, it increased to approximately 7.15 m at the beginning of the 21st century. The SL tendency line indicates a slight SL rise in 40 years, but if the SL registered in 2002 represents the actual SL trend in the last 18 years (there was no available data on MB´s SL after 2002), the SL rise may be higher than presented here.

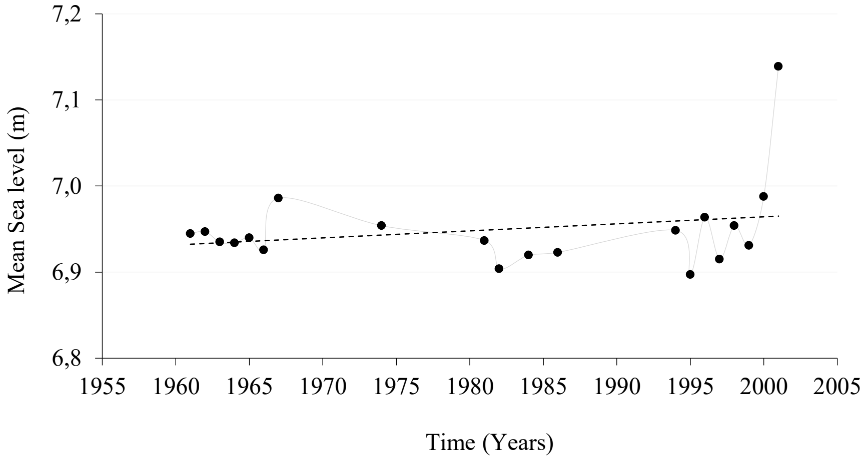


Figure 3-13| MB´s mean sea level over time (full line, where the dots correspond to known values) and respective tendency line (dashed line). Source: PSMSL (2005).

Land use/ Land cover

Figure 3-14 describes the LULC of Maputo province in 1992 and 2015, respectively. The comparison between them provides a general idea of the major changes that occurred in the area over time. In both cases, the majority of the land had a (semi)natural cover, although there was a decrease from 87.26% in 1992 to 84.52% in 2015; the agricultural cover was the second most common type, followed by an urban cover, both with an increase of 11.88% and 0.50% to 13.92% and 1.17%, respectively; bare cover remained practically the same over the years.

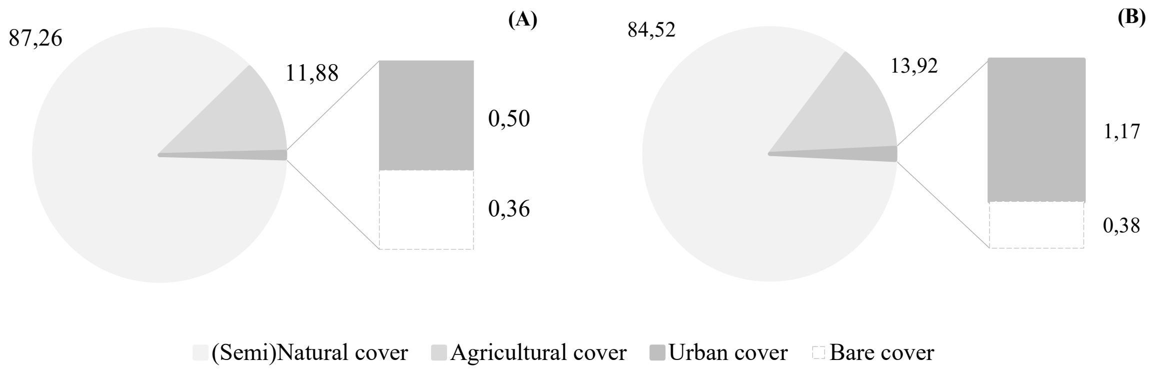


Figure 3-14| Land use, land cover (LULC) at Maputo district in 1992 (A) and 2015 (B), where (semi)natural, agricultural, urban and bare cover are discriminated. Source: ESA (2017).

Pollution

According to **Table 3-2**, MB´s pollution was identified as land-based or related to port activity in 1993. Recent data on MB´s pollution was not found. While port-based pollution affected mostly the port water quality and associated biota and fisheries, land-based pollution provoked a wider range of problems, as some forms of pollution have the potential to affect the entire bay. This type of pollution was linked to anthropogenic sources like agriculture, industry, and urbanization running along river basins, to the shore close to urbanized areas (e.g. Costa do Sol) and estuaries; plastics had further impact in the eastern part of the MB, namely in Machangulo peninsula and Inhaca island, which are protected since 2009 by the POPMR.

Table 3-2| MB´s types of pollution followed by their location and related problems. Light grey cells emphasize the key types of land-based pollution that led to the other ones here discriminated. Adapted from Fernandes *et al.* (1993).

	TYPES OF POLLUTION	*LOCATION*	*CONSEQUENT PROBLEMS*
LAND-BASED POLLUTION (URBAN SEWAGE)	*Agricultural sewage*	Along river basins (Infulene river is the most affected)	• Increase in agriculture activity, turning rivers into the main pathways for fertilizers and pesticides to enter the coastal and marine environments.
	Industrial sewage	Mainly at Maputo and Matola cities (discharges into Espírito Santo estuary through Matola and Infulene rivers)	• Runoff of heavy metals, such as mercury, lead, chromium, manganese, nickel, and zinc in the bay.
	Domestic sewage		• Nutrients discharged.
	Stormwater (episodic events)	All bay	• Chemicals discharges (agriculture and industrial sewage). • Nutrient discharges (agriculture and domestic sewage) that can lead to eutrophication. • Increase in sewage, solid waste and marine litter runoffs.
	Eutrophication	Mainly at Costa do Sol	• Abundance of benthic microalgae.
	Microbial pollution	Estuaries and beaches	• Beaches unsafe for swimming; sanitary and food security problems related to bivalves.

Table 3-2| (cont.) MB´s types of pollution followed by their location and related problems. Light grey cells emphasize the key types of land-based pollution that led to the other ones here discriminated. Adapted from Fernandes *et al.* (1993).

	TYPES OF POLLUTION	*LOCATION*	*CONSEQUENT PROBLEMS*
LAND.BASED POLLUTION	*Solid waste and marine litter*	Machangulo peninsula and Inhaca island	• Increase in plastic pollution.
PORT-BASED POLLUTION	*Antifouling*	Port area and surroundings	• "Imposex" (reversal of sex organ development) and "intersex" (indeterminate biological sex) in certain marine gastropods.
	Ballasting		• Introduction of alien species.
	Dredging activities and sediment pollution		• Turbidity and bathymetric changes affect benthic marine habitats; fluctuations in water quality by the re-suspension of bottom sediments that can remobilize contaminants such as heavy metals and nutrients.
	Oil spills		• Water contamination. • Animal deaths. • Less or no fisheries.

Overexploitation

Deforestation

Figure 3-15 shows the total area of MB´s mangrove forests over time, which did not change consistently. However, there was a clear area drop, from 80.5 Km^2 in 1996 to 77 Km^2 in 2007; this decline was followed by an increase to almost 80 Km^2 until 2010 when it finally dropped again to a new low of approximately 76.5 Km^2 by the last register in 2016. In sum, around 4 Km^2 of mangrove forest were lost in MB over the course of 20 years.

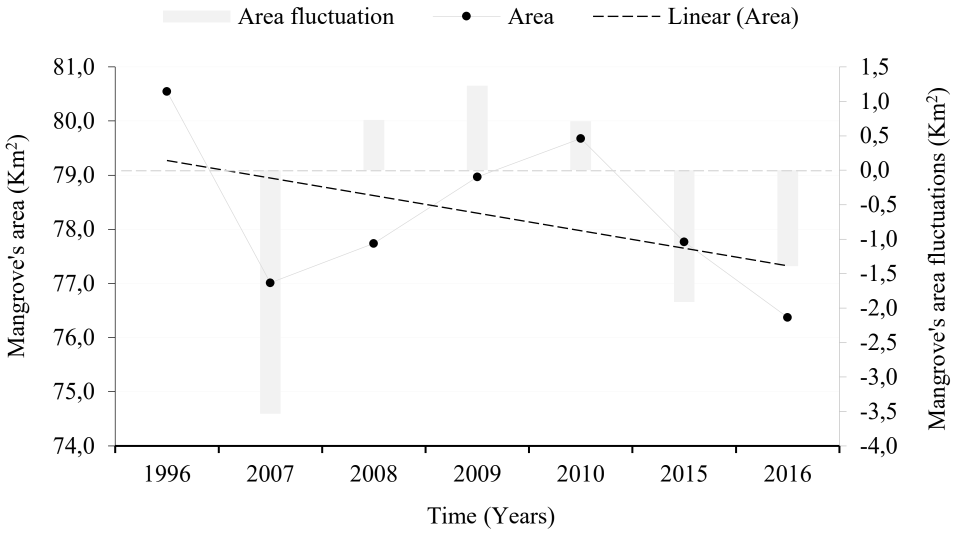


Figure 3-15| Area of MB´s mangrove forests over time represented by the full line, where the dots correspond to known area values calculated through ArcGIS using the available shapefiles; the dashed line corresponds to the linear tendency line; the light grey columns illustrate the calculated area variations between years with known values; the dashed line in light grey marks the 0 from the area fluctuation scale for visual reference. Adapted from Worthington *et al.* (2020).

Fisheries

Figure 3-16, presents the number of licenses attributed to artisanal fishery both on national and MB scales. At the national level, the highest number of licenses was reached in 2015 (20 368). The decrease (ca. 5 000) of licences from 2015 to 2016 (16 411) was followed by an increase in 2017 (18 197). A similar pattern was observed in MB, with a maximum of licenses in 2015 (2 679), except that in 2014 the number of licences was also high (2 678). Overall, in MB there was a tendency for an increase in the number of artisanal fishery licenses.

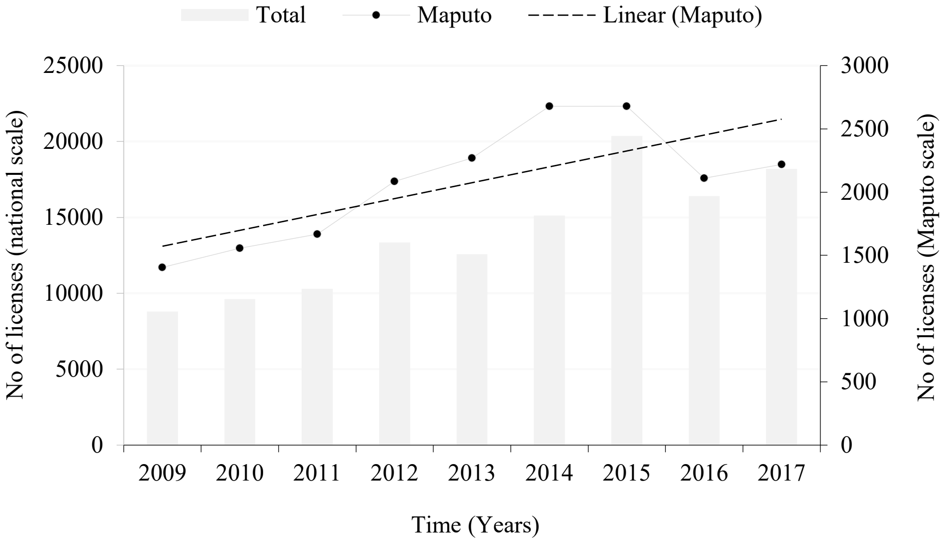


Figure 3-16| Number of licenses attributed to artisanal fishery over time, both on a national scale (grey columns and axle?) and at Maputo Province scale (the full line where each dot represents a known value, and the dashed line represents the linear tendency. Source: António et al. (2017).

Figure 3-17 emphasizes the weight of shrimp captures lead by artisanal and semi-industrial fisheries, where to catch a single kilogram (Kg of shrimp, 3 and 4 Kg of bycatch were produced, respectively. As bycatch represents different biomass from the target species, it can end up being discarded; in the case of the MB´s artisanal fishery, to catch 1 Kg, 0.5 of the 3 Kg of bycatch were waste and 2.5 Kg were used; in the semi-industrial fishery the case was more drastic as to capture 1 Kg of shrimp, more than double (2.4 Kg) of the bycatch weight (4 Kg) was discarded, salvaging only 1.6 Kg.

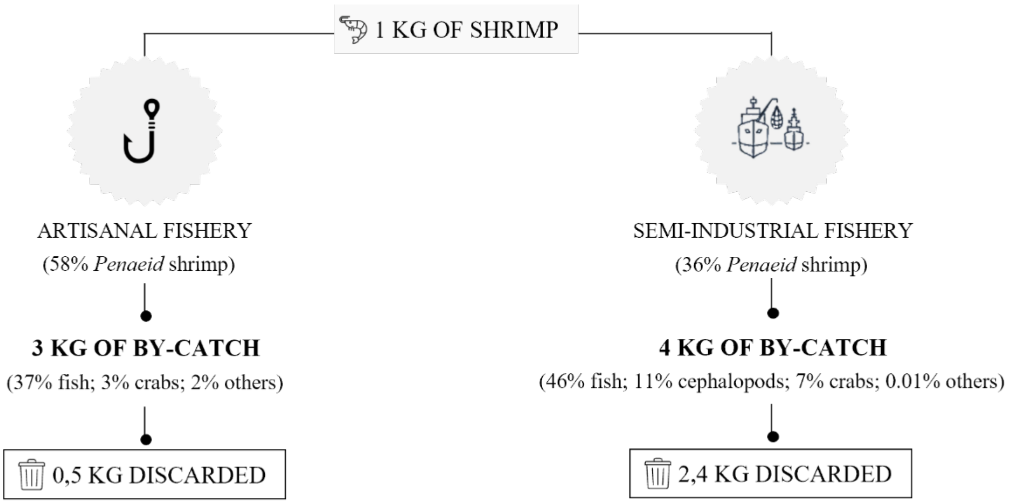


Figure 3-17| The impact of shrimp captures in MB in terms of bycatch, where artisanal and semi-industrial fisheries are compared in terms of the captures' composition (adapted from Machava *et al*. 2014).

Trends of direct drivers of change

Table 3-3 describes the future trends (represented by the up or downward arrows) of all direct drivers of change affecting the bay, its mangrove forests and seagrass meadows, as well as MMI inhabiting there, based on the analysis of the indicators applied during this study. Accordingly, both SST and SL are rising; artisanal fishing production and mangroves deforestation is also rising; and last, agricultural and urban covers are increasing to the detriment of the (semi)natural cover.

Table 3-3| Future trends (T - represented by the up or downward arrows) of major direct drivers of change: climate change, overexploitation and LULC, affecting the bay, its mangrove forests and seagrass meadows, as well MMI.

DRIVER OF CHANGE	***INDICATOR***	***T***
Climate change	Sea surface temperature	▲
	Sea level rise	▲
Overexploitation	No of licences for to artisanal fishery	▲
	Mangrove deforestation	▲
LULC	(Semi) natural cover	▼
	Agricultural cover	▲
	Urban cover	▲

Indirect drivers of change

Large temporal demographic dynamics were observed around the MB area from 1997 to 2017 (**Table 3-4**). The population of Maputo province has grown, thus so its population density (**Figure 3-18**). The same is true for every district, which presented growing population numbers and density, particularly Matola, Marracuene, Boane and Maputo city.

In 1997, Maputo city, the capital, had the highest number of inhabitants (966,837), as well as population density (2,760 inhabitants per square km). By 2017, the satellite city of Matola was in the lead with 1,616,267 inhabitants and a density of 4,353 inhabitants per square km, followed by Maputo city with a slightly lower population number of 1,101,170 inhabitants and a density of 3,144 inhabitants per square km. The population of these two cities combined made up about 75% of the entire province's population.

Table 3-4| Maputo population (number and density) for all Maputo Province and each of its districts, based on census data from 1997, 2007 and 2017. Adapted from INE (1997, 2007, 2017).

ADMINISTRATIVE LEVELS		***POPULATION***			***POP. DENSITY***			***AREA (KM^2)***
PROVINCE	*DISTRICT*	*1997*	*2007*	*2017*	*1997*	*2007*	*2017*	-
Maputo	*Boane*	56703	104128	210498	70	128	259	813
	Magude	42788	54195	63691	6	8	9	7036
	Manhiça	130351	160096	208466	55	67	87	2386
	Marracuene	41677	86177	230530	59	123	328	703
	Matola	424662	682691	1616267	1144	1839	4353	371
	Matutuíne	35161	37939	44834	7	7	8	5392
	Moamba	43396	57568	83879	9	12	18	4629
	Namaacha	31441	42694	48933	14	20	22	2175
Maputo C.	*Maputo C.*	966837	1094628	1101170	2760	3125	3144	350
	Total	1773016	2320116	3608268	74	97	151	23857

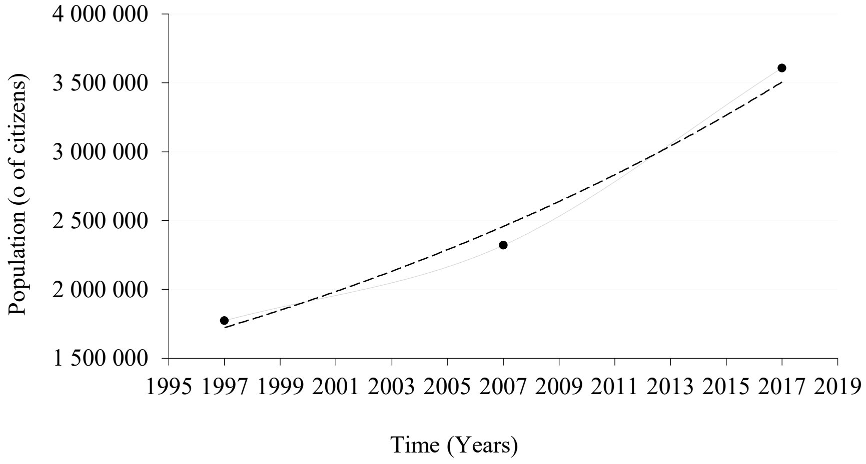


Figure 3-18| Scatterplot of the Census data and the modelled exponential tendency line of the population growth in Maputo province. Source: INE (1997, 2007, 2017).

Figure 3-19 illustrates the development of LULC over time in parallel with the population density downscaled to the growing urbanized areas; here downscaled population is interpreted through an arbitrary scale with the sole purpose of understanding its spatial distribution and development over time when comparing all situations. Mangrove forest cover was also discriminated to better detect any possible urban expansion in detriment to this ecosystem, at the same time giving detail to the (semi)natural cover.

By 1996 **(Figure 3-19: A)**, most of the urban cover was around Maputo and Matola cities, being the capital area the most heavily populated (in number and density); in the surroundings of the Incomati river, there was a small urbanized area with low population density, right in the middle of a mangrove forest (due to its reduced size, in the figure it can be undetected as the light colour can be confounded with the one intended for (semi)natural cover).

In 2007 **(Figure 3-19: B)**, Maputo city was still in the lead, but the population of both cities kept growing; agricultural cover increased considerably especially around the urban tissue. The urbanized area of Matola city began to stretch to the margin of the Matola river, where a portion of the mangrove forest exists, though its area seems to have remained the same; in the middle of the mangrove forest close to the Incomati river, both the area of the urban tissue and the population density grew, which probably translated into some mangrove deforestation.

By 2015 **(Figure 3-19: C)**, the population development patterns were the same as in the two previous decades, where agricultural cover, as well as the general urban tissue, kept growing. Both cities grew in terms of population density, mainly Matola, which (looking simultaneously at **Table 9**) outgrew the capital. Also, the small urban tissue near the Incomati river remained the same.

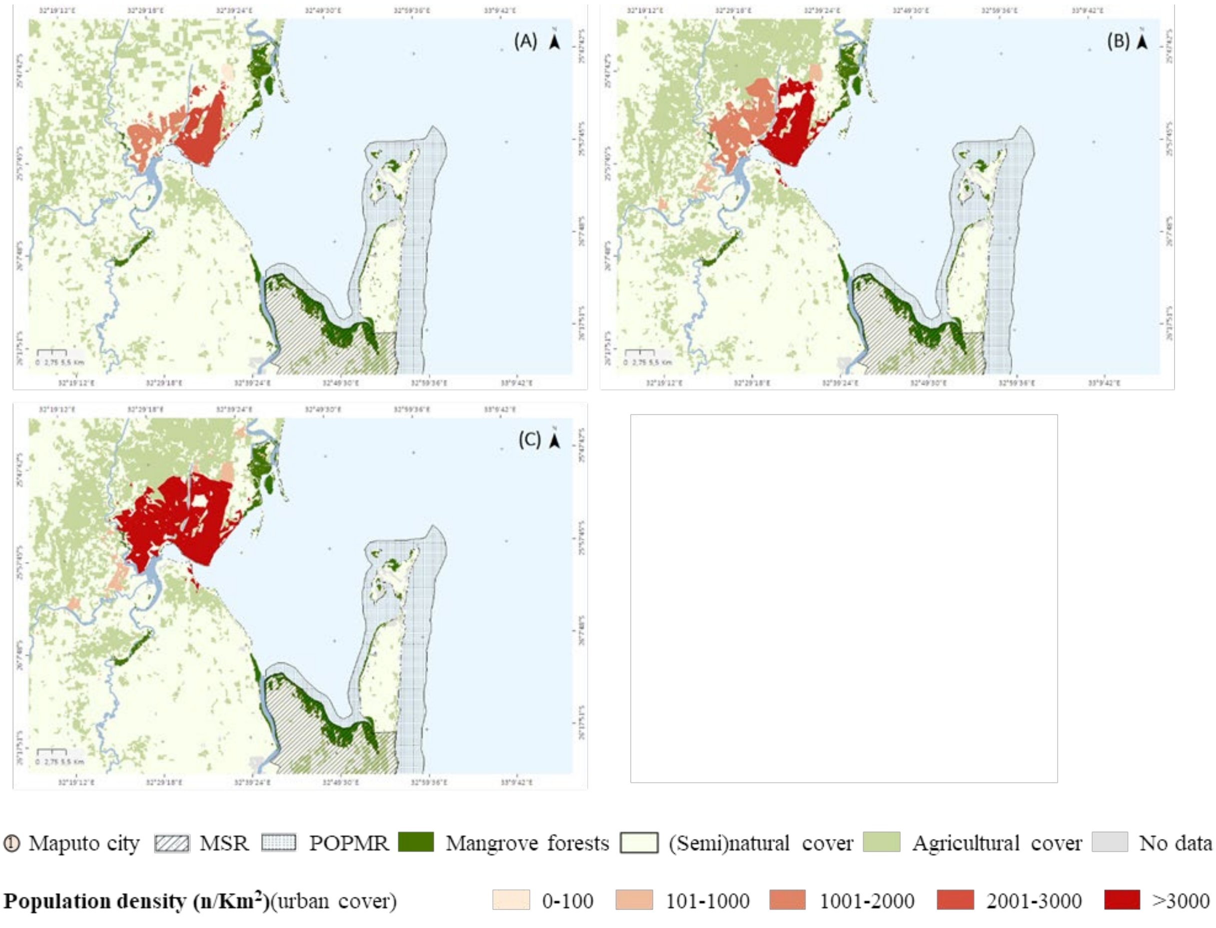


Figure 3-19| MB´s LULC in 1996 (A), 2007 (B), and 2015 (C), where (semi)natural (with a highlight in mangrove forests), agricultural, urban and bare cover are discriminated; urban cover is represented in warmer colours, giving parallel information of downscaled population density. Adapted from: ESA (2017); INE (1997, 2007, 2017); Worthington *et al.* (2020).

Trends of indirect drivers of change

Table 3-5 describes the future trends (represented by the up or downward arrows) of an indirect driver of change (overpopulation) affecting the Bay, its mangrove forests and seagrass meadows, as well as MMI inhabiting there, based on the analysis of the indicators applied during this study. Accordingly, both population number and density are increasing.

Table 3-5| Future trends (T - represented by the up or downward arrows) of a direct driver of change: overpopulation, affecting the Bay, its mangrove forests and seagrass meadows, as well MMI. Based on the analysis of the indicators applied during this study.

DRIVER OF CHANGE	***INDICATOR***	***S***
Overpopulation	Population number	▲
	Population density	▲

3.2. ASSESSMENT OF MB´S MANGROVES AND SEAGRASSES ES

3.2.1. ES identification and classification

Provisioning ES

Tables 3-6 and **3-7** present the identification and classification of the provisioning ES supplied by the mangrove forests and seagrasses of the bay, respectively.

Several provision ES were identified in mangroves (**Table 3-6**): wood and its derivates that can be used for many purposes, from fuel to construction materials and household utensils; in fact, even its tannins are purposeful. Seagrasses also contributed with different provisioning ES (**Table 3-7**): from the production of amulets and everyday utensils to alternative medicine practices and spiritual rituals. Both ecosystems, provided many fauna elements (MMI included) for nutritional purposes, ultimately contributing to food security.

Table 3-6| Identification and classification (CICES and its IPBES equivalence) of the provisioning ES supplied by the MB´s mangroves. Adapted from Paula *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			***IPBES***	***EXAMPLES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Biomass	Wild plants for nutrition, materials or energy	Fibres and other materials for direct use or processing	13 14	• Wood as a construction material. • Wood for household utensils. • Tannins to preserve and camouflage fishing nets.
		Used as a source of energy	11	• Fuelwood.
	Wild animals for nutrition, materials or energy	Wild animals used for nutritional purposes	12	• Fishing of *Scylla serrata*, the only commercial crab of the Bay and locally considered as a delicacy. • Fishing of *penaeid* shrimps (e.g. *Fenneropenaeus indicus*) of the Bay.
	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	12	• Shrimp aquaculture (even though now abandoned).

Table 3-6| (cont.) Identification and classification (CICES and its IPBES equivalence) of the provisioning ES supplied by the MB´s mangroves. Adapted from Paula *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			*IPBES*	*EXAMPLES*
DIVISION	*GROUP*	*CLASS*	*CODE*	
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1 13 14	• Mangrove replantation of *Avicennia marina* in Tsolombane (Matutuíne) (Bandeira *et al.*, 2016).

Table 3-7| Identification and classification (CICES and its IPBES equivalence) of the provisioning ES supplied by the MB´s seagrass meadows. Adapted from Bandeira *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			*IPBES*	*EXAMPLES*
DIVISION	*GROUP*	*CLASS*	*CODE*	
Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing	13 14	• Anti-fever treatment. • Dried and ground of leaves as amulets. • Baths to purify the body against bad spirits. • Leaves to fill pillows.
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals used for nutritional purposes	12	• Clam collection which can be for domestic consumption or to sell at Maputo City's markets and restaurants. • Sea urchin collection at Inhaca Island with the purpose of local consumption of their gonads (it is not intended for sale). • Other fish and MMI collection, such as crabs, shrimps, sea cucumbers and octopus (de Boer *et al.*, 2002).
Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1 13 14	• Seagrass meadows restoration program by replantation carried by Eduardo Mondlane University (UN, 2020).

Regulation and maintenance ES

Tables 3-8 and **3-9** show the identification and classification of the regulation and maintenance ES supplied by the mangrove forests and seagrass meadows of the bay, respectively. Both ecosystems had a key role to mediate waste and toxic substances, prevent extreme events, provide a nursing environment, regulate the quality of both water and sediment, and mitigating climate change.

Table 3-8| Identification and classification (CICES and its IPBES equivalence) of regulating and maintenance ES provided by the MB´s mangrove forests. Adapted from Paula *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			***IPBES***	***EXAMPLES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	3	• Treatment contamination from sewage, particularly important in eastern MB (Costa do Sol and Matola), where there is a high density of urban development.
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	9	• Erosion prevention and sediment regulation.
		Hydrological cycle and water flow regulation	6	• Flood control and coastal protection (e.g.: from high tide and storm events). • Water storage and retention (Queiroz *et al.*, 2017).
	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	1	• Nursing area of fish and many MMI (e.g. juveniles of the crab species *Scylla serrata* and *penaeid* shrimps such as *Fenneropenaeus indicus*).
	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	8	• Carbon sequestration.
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	3	• Climate regulation at a local and global level (Queiroz *et al.*, 2017).
		Regulation of temperature and humidity, including ventilation and transpiration	4	

Table 3-9| Identification and classification (CICES and its IPBES equivalence) of regulating and maintenance ES provided by the MB´s seagrass meadows. Adapted from Bandeira *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			***IPBES***	***EXAMPLES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	3	• Organic carbon absorption/ sink capacity. • Trapping of nutrients and promotion of their recycling.
Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	8	• Sediment stabilisation and therefore consolidation of seabeds and/by sediments deposition.
		Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	6	• Decrease of wave power and current.
	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	1	• Important nursery grounds for fish and MMI.
	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	8	• Organic carbon absorption/ sink capacity. • Trapping of nutrients and promotion of their recycling.
	Water conditions	Regulation of the chemical condition of salt waters by living processes	7	• Trapping of nutrients and promotion of their recycling.
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	3	• Climate regulation at a local and global level (Mtwana Nordlund *et al.*, 2016).
		Regulation of temperature and humidity, including ventilation and transpiration	4	

Cultural ES

Tables 3-10 and **3-11** present the identification and classification of the cultural ES supplied by the mangrove forests and seagrasses of the bay, respectively. Both ecosystems played an important role in intellectual and representative interactions, as both have been the subject of scientific research, as well as in spiritual and religious practices, at the same time that they promoted mental well-being.

Furthermore, seagrass meadows (**Table 3-11**) showed an extra potential for tourism as they are home to flag species such as turtles and dugongs, and provided a suitable environment for activities such as snorkelling and wildlife watching.

Table 3-10| Identification and classification (CICES and its IPBES equivalence) of cultural ES provided by the MB´s mangrove forests. Adapted from Paula *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			***IPBES***	***EXAMPLES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	6 16	• Fishing and boat cruises (Queiroz *et al.*, 2017).
		Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	6 16	• Wildlife watching. • Mental and physical relaxation through resting and reflection, functioning as therapy (Queiroz *et al.*, 2017).
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	6 15	• Natural central model system in research activities in MB area.
		Characteristics of living systems that enable education and training	6 15	
		Characteristics of living systems that are resonant in terms of culture or heritage	6 17	• The relation with mangroves that can generate personal satisfaction for the communities, such as strength to live, richness, pride and liberty (Queiroz *et al.*, 2017).
		Characteristics of living systems that enable aesthetic experiences	6 15 16	• Mangrove as part of the coastal scenery (Queiroz *et al.*, 2017).
Indirect, remote, often indoor interactions with living systems that do not require presence in the	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	6 17	• Local communities may recognize mangroves as a sacred space (Queiroz *et al.*, 2017).
		Elements of living systems that have sacred or religious meaning	6 17	• Intertidal religious practices.
		Elements of living systems used for entertainment or representation	6 13 17	• Mangroves are motive and inspiration for artistic creations (e.g. books and documentaries) (Queiroz *et al.*, 2017).

Table 3-11| Identification and classification (CICES and its IPBES equivalence) of cultural ES provided by the MB´s seagrass meadows. Adapted from Bandeira *et al.* (2014); other complementary sources are listed in the table in the examples section.

CICES			***IPBES***	***EXAMPLES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	6 16	• Snorkelling • Diving
		Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	6 16	• Wildlife watching (e.g. flag species such as dugongs and sea turtles)
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	6 15	• Skills or knowledge about the environment and nature.
		Characteristics of living systems that enable education and training	6 15	
		Characteristics of living systems that are resonant in terms of culture or heritage	6 17	• The relation with seagrasses that can generate personal satisfaction for the communities, such as strength to live, richness, pride and liberty (adapted from Queiroz *et al.* (2017)).
		Characteristics of living systems that enable aesthetic experiences	6 15 16	• Mangrove as part of the coastal scenery (adapted from Queiroz *et al.* (2017)).
Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	6 17	• Local communities may recognize seagrasses as a cultural icon promoting social cohesion.
		Elements of living systems that have sacred or religious meaning	6 17	• Intertidal religious practices
		Elements of living systems used for entertainment or representation	6 13 17	• Seagrasses are motive and inspiration for artistic creations (e.g. books and documentaries) (adapted from Queiroz *et al.* (2017)).

3.2.2. ES Quantification and future trends

Provisioning ES

The provision ES indicators referring to the MB´s mangroves and seagrasses were MMI specific. For this reason, and to avoid repetition, the quantification of MB´s provisioning ES can be consulted in section **3.3.2.** below.

Regulation and maintenance ES

The flood control and coastal protection ("Hydrological cycle and water flow regulation") ES in MB was quantified through the change of mangrove area between 1997 and 2017 (**Figure 3-15**) showing that the role of mangroves as natural barriers in MB is decreasing overtime.

Cultural ES

Regarding the MB´s cultural ES, the two ES assessed, "Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge" and "Characteristics of living systems that are resonant in terms of culture or heritage", were quantified through the application of different indicators integrating data from all the bay area.

The number of scientific publications was used as an indicator to quantify the "characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge" over time (**Figure 3-20**). The number of scientific publications increased from 1985 to 2020, with the highest registers in 2005 and 2017 with 9 and 8 published papers, respectively.

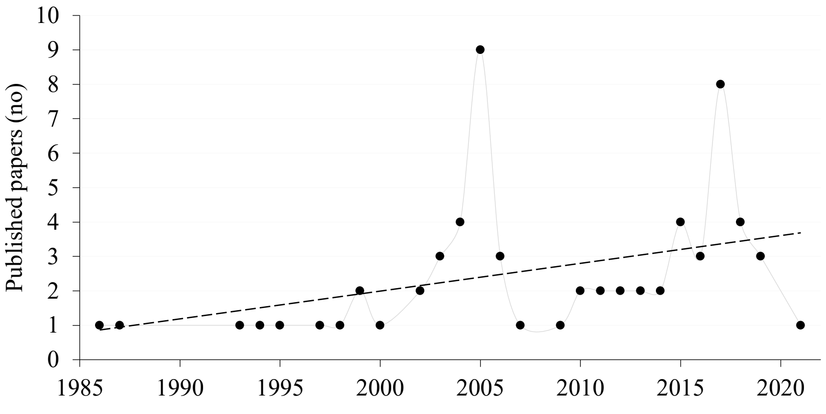


Figure 3-20| Scatterplot of the total published papers written about MB and its mangrove forest and seagrass meadows ecosystems. Each dot represents a known value of the published papers in that respective year; the dashed line represents the linear tendency of the data. Source: Elsevier (2021).

The "characteristics of living systems that are resonant in terms of culture or heritage" in MB was interpreted in light of the average stays in Maputo, which is a composite indicator estimated through the number of both national and international visitors, and the total number of guests over time.

Figure 3-21 shows that the first indicator at the scale of the national visitors was approximately 1.5 days per year remaining steady from 2012 to 2018. However, the mean average stays of the international visitors varied between 2.4 and 3.1 stays per year, with a maximum of 3.7 stays in 2018 and a minimum of 1.7 stays in 2014.

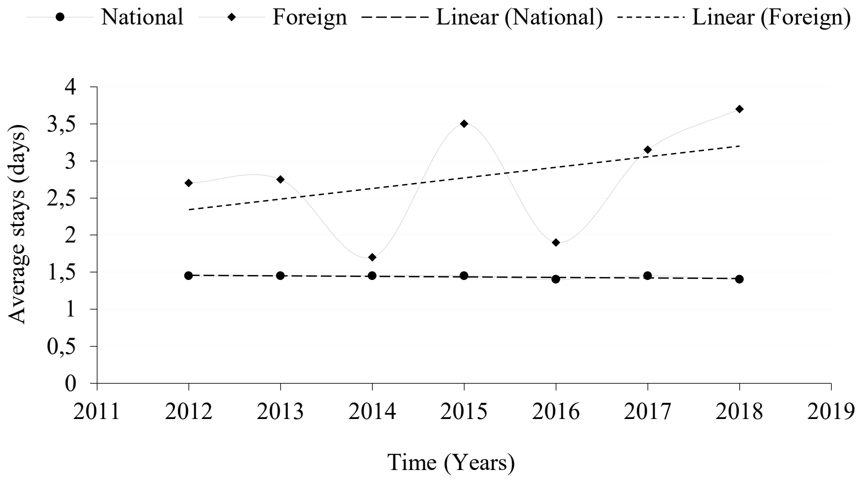


Figure 3-21| Scatterplot of the average stays (in days) at the Maputo Province, where each dot represents a known value of the visitors had in that respective year. National visitors are marked by circles, whereas the international visitors are marked by diamond shapes; both their linear tendency lines are shown as well, one by large dashes and another by narrow ones, respectively. Source: INE (2020).

The second indicator, referring to the total number of guests in Maputo through time (**Figure 3-22**), showed an overall decrease from 2012 to 2016, except for 2013 when there were approximately 900 000 guests. No data from 2017 to the present were found.

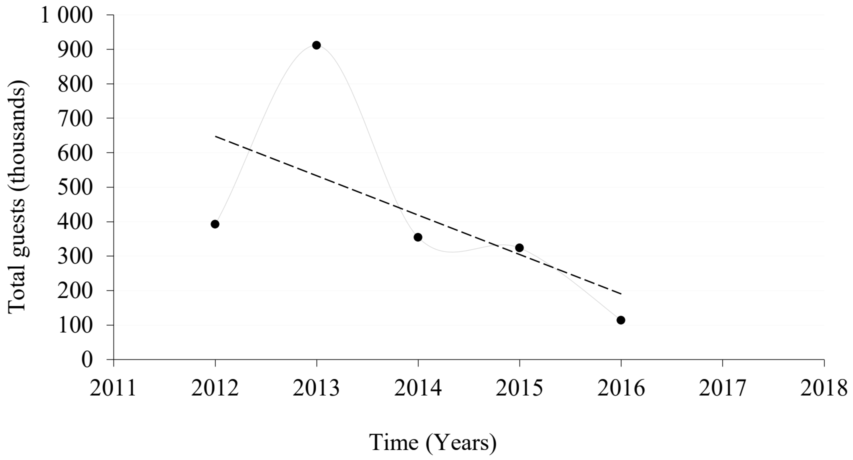


Figure 3-22| Scatterplot of the total guests (national and international) received in Maputo Province over time. Each dot represents a known value of the guests in that respective year; the dashed line represents the linear tendency of the data. This Figure is not fully complementary to the previous one, as the available data range only between 2012 and 2016. Source: INE (2020).

Future trends of MB’s mangroves and seagrasses ES

Table 3-12 describes the future trends (represented by the up or downward arrows) of MB´s regulation and maintenance ES and cultural ES provided by both mangrove forests and seagrass meadows jointly, based on the analysis of the indicators applied in this study. In accordance, the “hydrological cycle and water flow regulation" expressed as the services provided by mangroves as natural barriers is decreasing. The "characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge", conveyed by scientific publications referring to MB are increasing. Finally, the "characteristics of living systems that are resonant in terms of culture or heritage", reflected by: (1) the average stays in Maputo at the national level is steady, but then again the number of international visitors is increasing; (2) the total number of guests is decreasing.

Table 3-12| Future trends (T - represented by the up or downward arrows) of the MB´s regulation and maintenance ES and cultural ES. Based on the analysis of the indicators applied during this study.

ES SECTION	*CICES*	*IPBES*	*INDICATORS*	*T*
Regulation and maintenance ES	Hydrological cycle and water flow regulation	6	Mangroves as natural barriers	▼
Cultural ES	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	6 15	Scientific publications	▲
	Characteristics of living systems that are resonant in terms of culture or heritage	6 17	Average stays in Maputo (days)	
			↳ by national visitors	≅
			↳ by international visitors	▲
			Total number of guests	▼

3.3. ASSESSMENT OF MMI ES IN MB'S MANGROVES AND SEAGRASSES

3.3.1. ES identification, classification

Provisioning ES

MMI of the bay represent a very important source of protein, for that reason, this study focused on the class of "wild animals used for nutritional purposes" ES (**Table 3-13**), both in mangrove forests and seagrass meadows, where fishing activities were explored to understand the quantitative supply (**section 3.3.2** below) of provisioning ES provided by MB´s MMI.

Table 3-13| Identification and classification (CICES and its IPBES equivalence) of the provisioning ES supplied by the MMI of MB´s mangrove and seagrasses (adapted from (Bandeira et al., 2014; Paula et al., 2014).

CICES			*IPBES*	*MMI ES*
DIVISION	*GROUP*	*CLASS*	*CODE*	
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals used for nutritional purposes	12	• Edible marine invertebrates (shrimps, prawns, crabs, lobsters, cephalopods) through artisanal and semi-artisanal fisheries and harvesting

Regulation and maintenance ES

Table 3-14 illustrates the results obtained by linking each MMI functional group, considering both HO and TG, to MMI ES (see **Table 2-5**, **section 2.4.2**). Here only the "nutrient cycle" as well the "food web stability” ES were common to all MMI. Otherwise, there was a variability of regulation and maintenance ES provided by different MMI functional groups.

Table 3-14| Correspondence between different MMI functional groups related to habitat occupation (HO) and trophic guild (TG)and regulation and maintenance ES provided by MMI of MB´s mangrove forests and seagrass meadows.

FUNCTIONS	**HO**			**TG**												
MMI SERVICES	BENTHOS	NEKTON	ZOOPLANKTON	CHEMOSYMBIOSIS	DEPOSIT FEEDER	SURFACE DEPOSIT	SUSPENSION FEEDER	FILTER FEEDER	EPIFAUNA FEEDER	INFAUNA FEEDER	MICROPHAGE	GRAZER	PHYTOPLANKTIVORE	PREDATOR	SCAVENGER	ZOOPLANKTIVORE
Habitat modification		X	X		X	X	X	X			X	X	X			X
Bioerosion									X							
Bioturbation	X				X	X				X	X					
Nutrient cycling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hydrological flux	X									X						
Water quality		X	X		X	X	X	X			X	X	X			
Food web stability	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 3-15 shows MMI ES in the context of broader ES divisions (group and class), where most MMI services revealed to ultimately contribute to the ES class of “maintaining nursery populations and habitats”.

Table 3-15| Classification (CICES and its IPBES equivalence) into broader divisions (group and class) of previously identified regulation and maintenance ES provided by MMI of MB´s mangrove forests and seagrass meadows.

CICES		***IPBES***	***MMI Services***
GROUP	*CLASS*	*CODE*	
Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	1	• Bioerosion • Food web stability • Habitat modification • Nutrient cycle
Regulation of sediment quality	Decomposition and fixing processes and their effect on soil quality	8	• Bioturbation
Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation	6	• Hydrological flux
Water conditions	Regulation of the chemical condition of salt waters by living processes	7	• Water quality

Cultural ES

Table 3-16 presents the identification and classification of the cultural ES supplied by MMI from MB´s mangrove forests and seagrasses meadows, where both physical and intellectual interactions with the environment stand out.

Table 3-16| Identification and classification (CICES and its IPBES equivalence) of cultural ES provided by MMI of MB´s mangrove forests and seagrass meadows. Adapted from Bandeira *et al.* (2014); Paula *et al.* (2014).

CICES			***IPBES***	***MMI´s ES***
DIVISION	*GROUP*	*CLASS*	*CODE*	
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	6 16	• Wildlife watching (MMI observation by snorkelling and scuba-diving, and during intertidal periods).
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	6 15	• Knowledge about the role of MMI in the environment and nature. • Skills or knowledge about MMI management (e.g.: stock management).
		Characteristics of living systems that enable education and training	6 15	

3.3.2. ES Quantification and future trends

Provisioning ES

Artisanal fishery

Figure 3-23 presents the artisanal fishery effort in Mozambique, in terms of the number of boats at the national and MB scale. In 2017 there were more than 23 000 boats solely dedicated to this type of fishing, being that more than 2 000 of them operated in MB. At the bay level, artisanal fishing was done daily, mostly 7 days a week, in shallow waters on sandbanks.

Figure 3-23| Overall scheme integrating the contribution of MB to artisanal fishing by putting into perspective the importance of its fleet on a national scale; general information about the temporal and spatial location of the fishing effort is also given. Source: António *et al.* (2017).

Figure 3-24 shows the percentage of the artisanal fishery from MB (Maputo Province) in a national perspective, comparing it with all the provinces of Mozambique, where MB represents about 5% of all the country's artisanal fishery production.

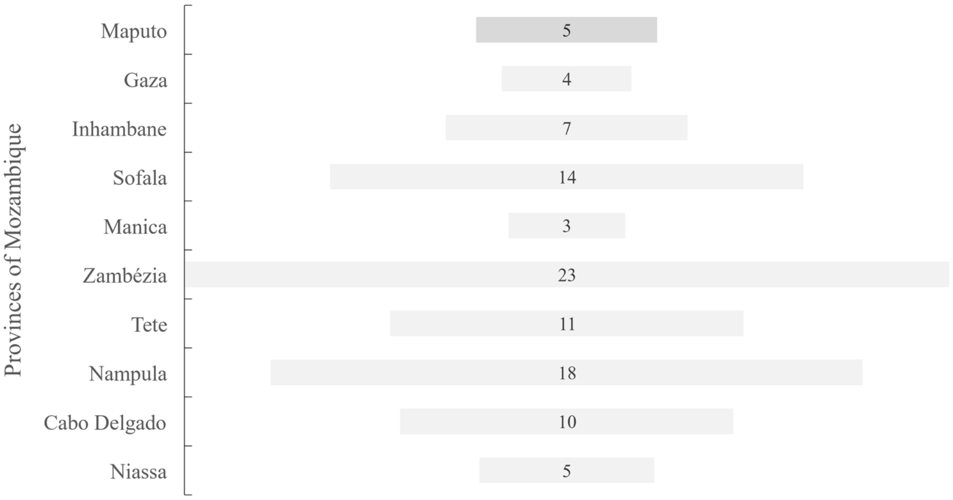


Figure 3-24| Percentage of artisanal mean fishing production per year between 2005 and 2017 of each Mozambique province, where Maputo is identified with a darker grey representing 5% of the total production of the country. Source: António *et al.* (2017).

Figure 3-25, details the production (in tons) of the artisanal fishery from MB in the national context. Overall, artisanal fishery production increased over time both nationally and at the Maputo level. However, whereas national production presented a practically steady increase from 2005 (57 748 tons) to 2017 (314 470 tons), in Maputo there was a decrease in the artisanal fishery production in 2011 (6 158 tons) followed by a two-fold increase until 2013 (13 867 tons); from 2014 to 2016, it decreased to 11 354 tons, increasing again to 16 088 tons in 2017.

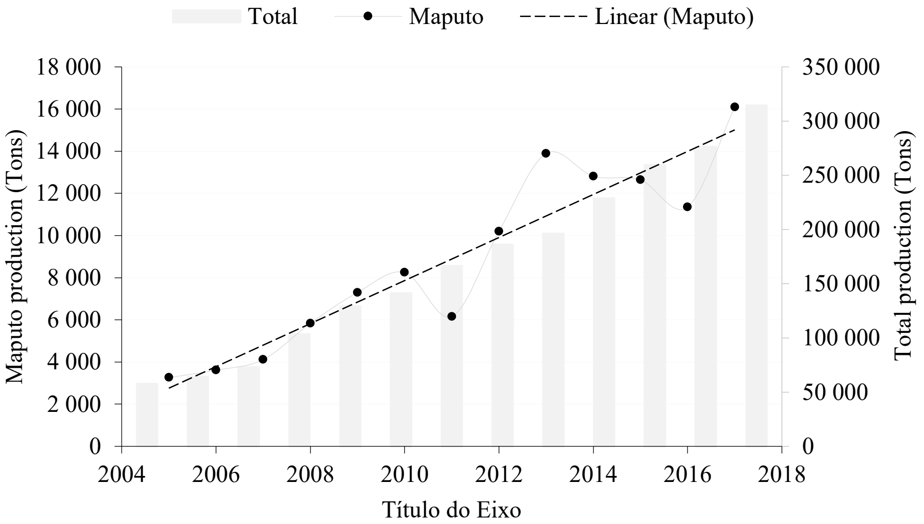
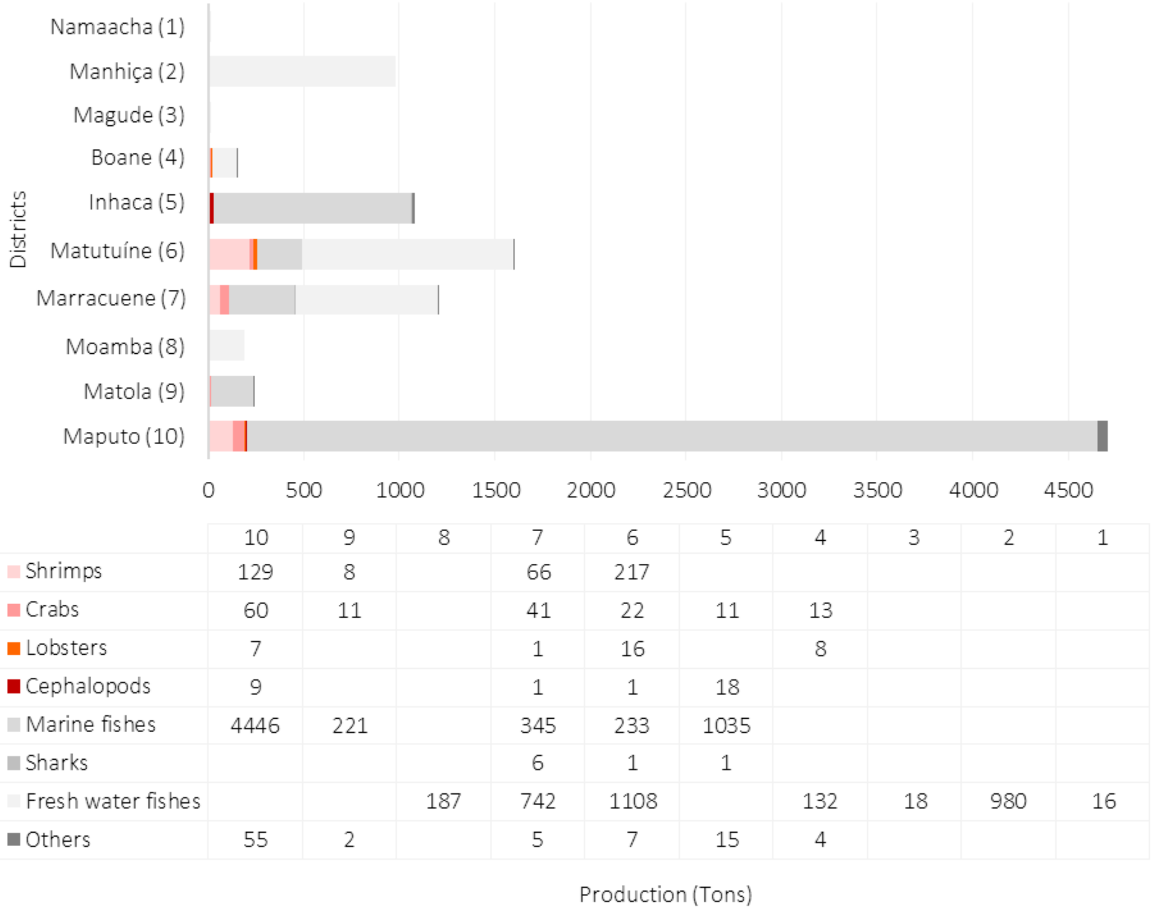


Figure 3-25| Scatterplot of the artisanal fishing production between 2005 and 2017 where Maputo Province's production (full line, where the dots correspond to known values) is compared alongside with total national production (grey columns) (Source: António et al. (2017); Ministério das Pescas (2012).

Figure 3-26 presents a closer look at the fishing effort of the different districts belonging to Maputo province, as well as to the groups of animals more captured. Marine fishes made up for the bulk of the captures, but MMI also had an important contribution to artisanal fishery (639 tons). The highest MMI catches referred to shrimps (420 tons), followed by crabs (158 tons), lobsters (32 tons) and cephalopods (29 tons); the three main districts responsible for these captures were Matutuíne, Maputo and Marracuene, in this order.



	10	9	8	7	6	5	4	3	2	1
Shrimps	129	8		66	217					
Crabs	60	11		41	22	11	13			
Lobsters	7			1	16		8			
Cephalopods	9			1	1	18				
Marine fishes	4446	221		345	233	1035				
Sharks				6	1	1				
Fresh water fishes			187	742	1108		132	18	980	16
Others	55	2		5	7	15	4			

Figure 3-26| General description of the artisanal fishing activity carried out at each district of the Maputo province in 2012, where other species besides MMI are included for comparison; MMI can be distinguished by warm colours. Source: Ministério das Pescas (2012).

Semi-industrial fishery

The semi-industrial fishery is a very important sector of MB that mostly relies on shrimp capture done by trawling. **Table 3-17** discloses that shrimp captures in the 1990s and 2000s mainly consisted of *Fenneropenaues indicus* and *Metapenaeus monoceros*, respectively white and brown shrimp, that contributed to approximately 80% of the catches; *Penaeus monodon* (giant tiger prawn), *Penaeus semisulcatus* (green tiger prawn) and *Metapenaeus stebbingi* (peregrine shrimp) made up the remaining 20%.

Table 3-17| Composition of shrimp semi-industrial fishery captures in the 1990s and 2000s decades.

SPECIES	***CATCHES (%)***	***SOURCES***
Fenneropenaues indicus (white shrimp)	80	Chaúca *et al.* (2007)
Metapenaeus monoceros (brown shrimp)		
Penaeus monodon (giant tiger prawn)	20	Macia Jr (1990)
Penaeus semisulcatus (green tiger prawn)		
Metapenaeus stebbingi (peregrine shrimp)		

Though shrimp production has been facing a decline, the demand for it is increasing. Therefore, there has been an expansion of shrimps fishing areas. The main trawling areas were located in four distinct zones, which can be consulted in **Figure 3-27**: area A, near Maputo, is the largest of the four; B is where most *Fenneropenaues indicus* is captured; C, though not the largest area, enters the POPMR; and D is the smaller area and the one furthest to the shore.

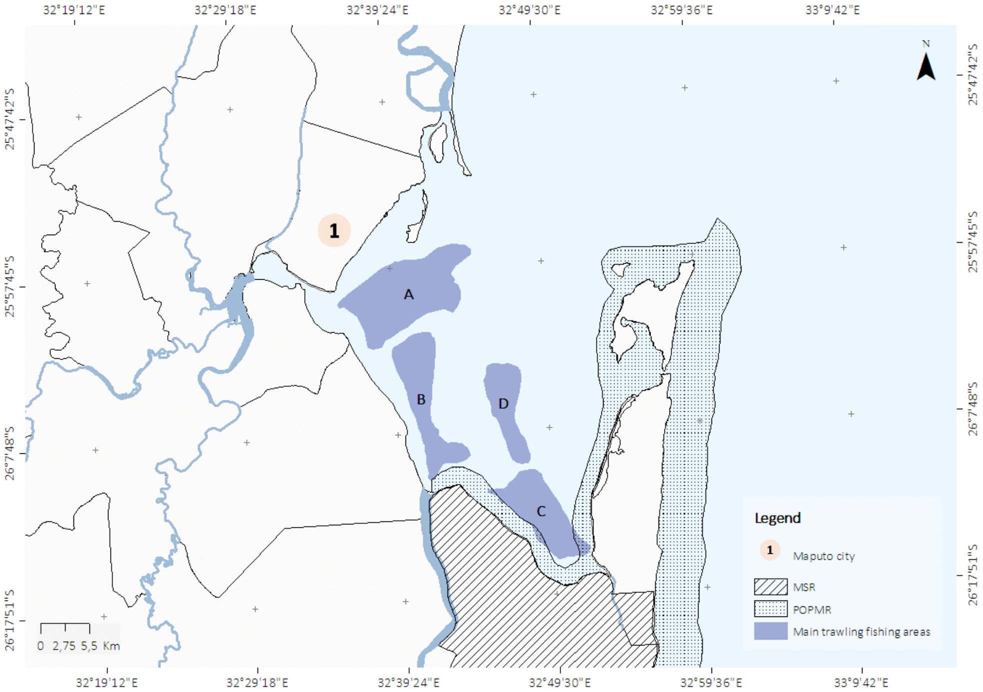


Figure 3-27| Four main shrimp trawling areas in MB. Adapted from Pregado & Masquine (2014).

Regulation and maintenance ES

An overview of **Table 3-18** reveals that the supply of all four ES classes analysed have been increasing over time, although with visible oscillations.

"Maintaining nursery populations and habitats" ES had the highest CF score of all four ES. At the bay level, as well as in seagrass meadows, its supply pic was during the last decade (2010-19), and for mangroves, it was during the 1960s. With the same CF over time at all levels were "decomposition and fixing processes and their effect on soil quality" and "hydrological cycle and water flow regulation" ES, and their pics had the same behaviour as first mentioned ES, although their value was slightly lower.

“Regulation and chemical condition of salt water by living processes” had the lowest CF score of all four, with its supply pic in the 2000s decade, although the 2010s represented a low decrease.

Table 3-18| Regulation and maintenance ES quantification at three levels: all bay, mangrove forests and seagrass meadows. The squares in darker grey correspond to the pic of each ES supply over time; the medium grey identifies relevant but smaller pics. Future trends are also detailed (T - represented by the up or downward arrows).

	MMI SERVICE				***ES CLASS***	***MMI SERVICE***	***ES CLASS***	***MMI SERVICE***	***ES CLASS***	***MMI SERVICE***	***ES CLASS***
Time (Years)	*Bioerosion*	*Food web stability*	*Habitat modification*	*Nutrient cycling*	*Maintaining nursery populations and habitats*	*Bioturbation*	*Decomposition and fixing processes and their effect on soil quality*	*Hydrological flux*	*Hydrological cycle and water flow regulation*	*Water quality*	*Regulation of the chemical condition of salt waters by living processes*
						ALL BAY					
1870-79	0	1	1	1	3	1	1	1	1	1	1
1880-89	0	1	1	1	3	1	1	1	1	1	1
1900-09	0	2	1	2	5	2	2	2	2	1	1
1910-19	0	10	8	10	28	9	9	9	9	8	8
1920-29	0	7	1	7	15	6	6	6	6	1	1
1930-39	0	9	3	9	21	8	8	8	8	3	3
1950-59	0	61	10	61	132	57	57	57	57	10	10
1960-69	0	147	98	147	392	129	129	129	129	98	98
1970-79	0	104	52	104	260	86	86	86	86	52	52
1980-89	4	57	13	57	131	56	56	56	56	13	13
1990-99	0	20	6	20	46	17	17	17	17	6	6
2000-09	0	70	44	70	184	69	69	69	69	44	44
2010-19	0	245	65	245	555	244	244	244	244	65	65
T	≅	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
						MANGROVE FORESTS					
1920-29	0	5	0	5	10	5	5	5	5	0	0
1930-39	0	3	2	3	8	3	3	3	3	2	2
1950-59	0	47	5	47	99	45	45	45	45	5	5
1960-69	0	110	74	110	294	101	101	101	101	74	74
1970-79	0	46	21	46	113	44	44	44	44	21	21
1980-89	3	48	13	48	112	47	47	47	47	13	13
1990-99	0	9	3	9	21	7	7	7	7	3	3
2000-09	0	5	3	5	13	5	5	5	5	3	3
2010-19	0	82	27	82	191	82	82	82	82	27	27
T	≅	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
						SEAGRASS MEADOWS					
1950-59	0	1	0	1	2	1	1	1	1	0	0
1970-79	0	1	0	1	2	1	1	1	1	0	0
1980-89	2	14	4	14	34	14	14	14	14	4	4
1990-99	0	1	0	1	2	1	1	1	1	0	0
2010-19	0	42	0	42	84	42	42	42	42	0	0
T	≅	▲	≅	▲	▲	▲	▲	▲	▲	≅	≅

Cultural ES

“Diversity of life from which to learn” was assessed through SR which is presented in **Figure 3-35** considering all of MB, and both the mangrove forests and seagrass meadows. In the three cases SR has been rising, although around the 1980s and 1990s there was a substantial decrease in SR followed by an exponential increase in the following years. Also worth noticing is the fact that SR reached higher values in mangrove forests when comparing to seagrass meadows, although that when in decline, both reached values around zero.

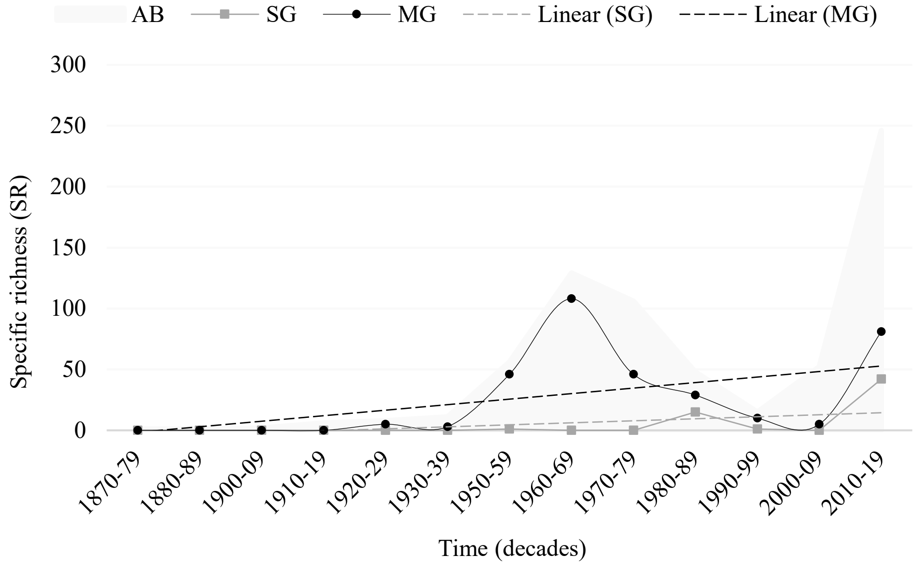


Figure 3-28| Specific richness (SR) in the Maputo Bay (MB) over time (in decades). The full black line (where each dot represents a known value) indicates SR in mangroves forests (MG), and the black dashed line its linear tendency; the full grey line (where each dot represents a known value) indicates SR in seagrass meadows (SG), and the grey dashed line its linear tendency; in the background, in light grey SR in all of the bay (MB) is also discriminated.

Recreational and sport fishing share the common feature of fishing for leisure. For this reason, both fishing types were considered only cultural interactions, though with a bit of skill, occasionally catches can add to the family's food security. **Figure 3-29** shows the growing number of licences for recreational and sport fishing over time, illustrating the cultural importance that this activity can represent.

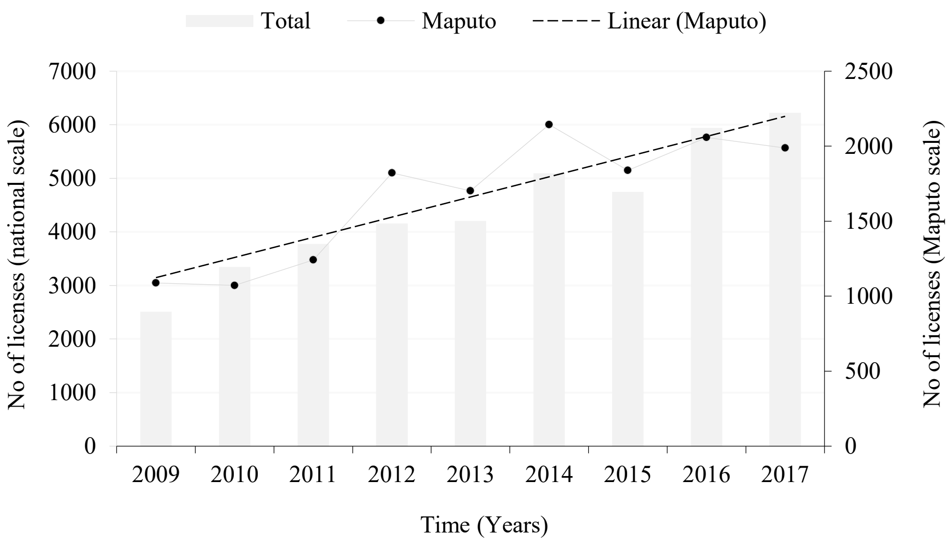


Figure 3-29| Number of licenses attributed to recreational and sport fishery over time, both on a national scale (grey columns and axle) and at MB scale (full line where each dot represents a known value; and the dashed line represents linear tendency).

Future trends of MMI ES in MB's mangroves and seagrasses

Table 3-19 presents future trends (represented by the up or downward arrows) of provisioning, regulation and maintenance, and cultural ES provided by MMI of MB´s mangrove forests and seagrass meadows, based on the indicators applied here.

In terms of provisioning, all the ES identified were related to food security and the fact that MMI could be used for nutritional purposes. As a whole, the tendency of MMI production seems to be rising. However, when looking closer to shrimp production, the main target species of both fisheries (artisanal, but mainly semi-industrial), it is decreasing.

Within MMI regulation and maintenance ES, the future tendency of all of them seems to be increasing.

With regards to MMI cultural ES, the increasing SR increases the opportunity for scientific investigation or the creation of traditional ecological knowledge; at the same time, MMI may also represent an increasing target for recreation and sport fishing, a type of activity with an increasing number of licences.

Table 3-19| Future trends (T - represented by the up or downward arrows) of the MB´s MMI provision ES, regulation and maintenance ES and cultural ES. Based on the analysis of the indicators applied during this study.

ES SECTION	*CICES*	*IPBES*	*INDICATORS*	*T*
Provision	Wild animals used for nutritional purposes	12	Artisanal fishery (MMI) production	▲
			Semi-industrial fishery (shrimp) production	▼
Regulation and maintenance	Maintaining nursery populations and habitats (Including gene pool protection)	1	Score level of the calculated CF	▲
	Decomposition and fixing processes and their effect on soil quality	8	Score level of the calculated CF	▲
	Hydrological cycle and water flow regulation	6	Score level of the calculated CF	▲

Table 3-19| (cont.) Future trends (T - represented by the up or downward arrows) of the MB´s MMI provision ES, regulation and maintenance ES and cultural ES. Based on the analysis of the indicators applied during this study.

ES SECTION	*CICES*	*IPBES*	*INDICATORS*	*T*
Regulation and maintenance	Regulation of the chemical condition of salt waters by living processes	7	Score level of the calculated CF	▲
Cultural	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	6 15	Diversity of life from which to learn (SR)	▲
	Characteristics of living systems that enable education and training	6 15	Diversity of life from which to learn (SR)	▲
	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	6 16	No of licences for recreation and sport fishing	▲

3.4. ES CONCEPTUAL MODEL

Figure 3-30 illustrates an ES conceptual model applied to MMI from the MB, taking into consideration all the factors analysed during this study. This model links the drivers of change analysed (being the first five direct drivers, where habitat loss summarizes the consequences of LULC changes and deforestation, and the last one an indirect driver), condition features of both mangrove forests and seagrass meadows. the assessed MMI ES, and critical management goals in MB. Invasive species, climate change, habitat loss, overfishing, pollution and overpopulation affect biodiversity, edible MMI availability, the state of MMI fishing stocks, and may reduce or prevent the increase of MPAs. Furthermore, pollution, e.g., from agriculture and other sources such as industrial or urban wastewater discharges, affect the water quality of MB and generate solid waste (mainly plastic) which ultimately affect recreational opportunities. The MMI ES supply mainly depends on the maintenance of biodiversity, water quality, and the existence of MPAs that may function as fishing deterrents and high-quality nursery areas. Managing the MB for the sustainable supply of MMI ES must ensure food security, sustainable MMI fishing, good ecological status, biodiversity protection and increase recreational and educational opportunities, in particular for local populations.

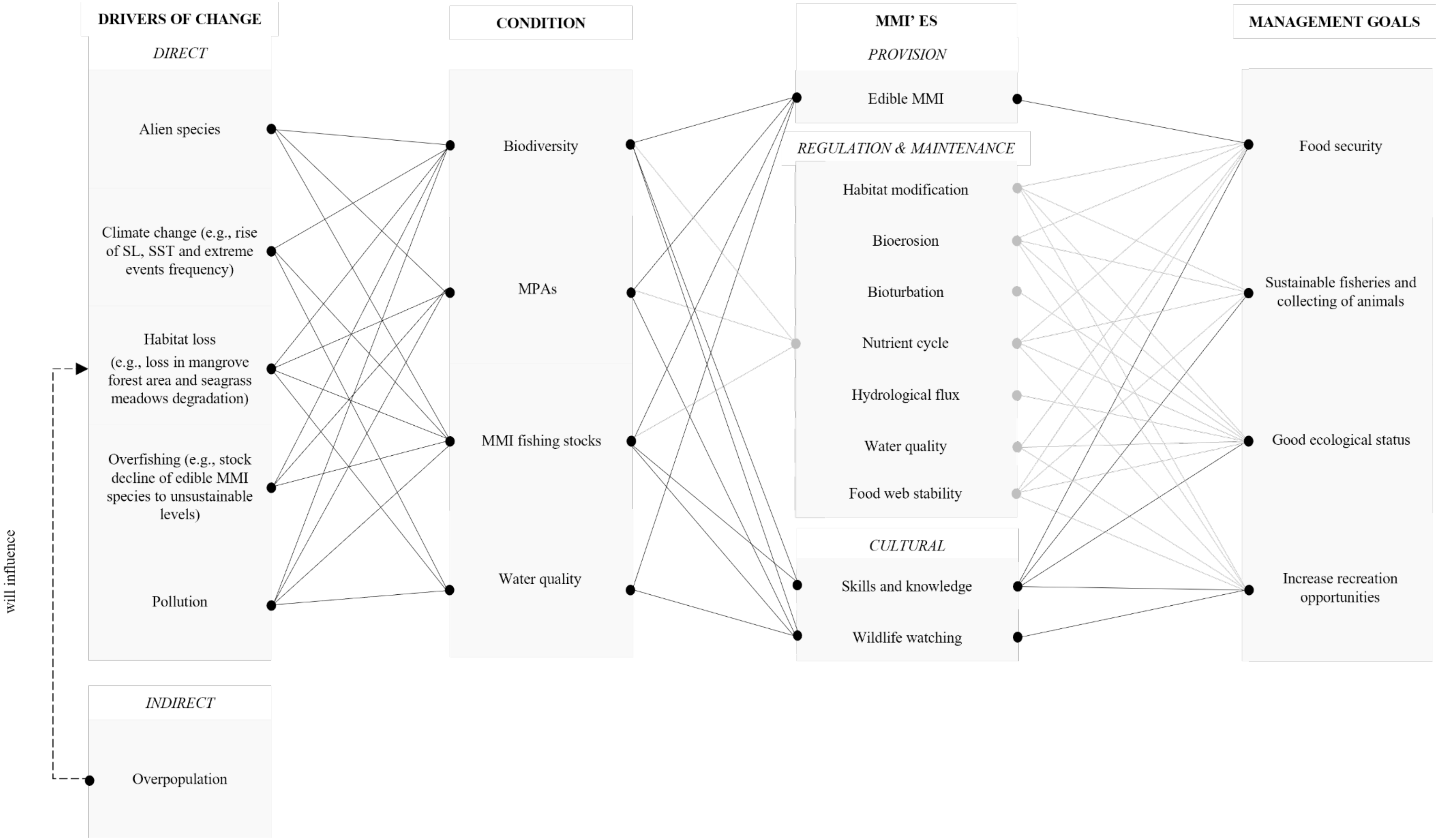


Figure 3-30| Conceptual model developed for addressing MMI ES sustainable use in Maputo Bay, linking direct and indirect drivers of change (first column), key ecosystem condition features (second column), specific MMI ES (third column), and the expected management goals (fourth column) to ensure a healthy supply of MMI ES. MPA – Marine Protected Areas; SL – Sela level; SST – Sea Surface Temperature.

4. DISCUSSION

4.1. CONDITION AND DRIVERS OF CHANGE IN MB´S MANGROVES AND SEAGRASSES

4.1.1. Mapping ecosystems

Mangrove forests border a big portion of the MB perimeter, widely covering estuaries, Inhaca island, mainly at Saco and Sangala bays, and the west coast of Machangulo Peninsula, being most of its extension within the MSR and POPMR – findings corroborated by Paula *et al.* (2014). Nevertheless, it is worth mentioning that the maps of 1996, 2007 and 2015 (**Figure 3-26** **A**, **B** and **C**, respectively, resulting from the dataset WCMC-001) revealed the lack of mangrove forest in the Espírito Santo estuary, whereas the assembled layer from 1997 to 2000 (product of the junction of the two datasets) showed the presence of mangroves, revealing a discrepancy between the dataset WCMC-001 and WCMC-010. These contrasting results are probably related to different dataset resolutions, thus WCMC-010 probably being more accurate. Nevertheless, WCMC-001 was still useful for the production of annual maps. Although presenting underestimated values, the evolution of the forest area could still be assessed, to eventually identify possible deforestation.

As regards to seagrass meadows, their distribution revealed to be more restricted, never reaching estuarine areas where many mangrove forest are found. Still, these two ecosystems were in close proximity around Inhaca island and at north of Maputo city. According to Bandeira *et al.* (2014), seagrasses occupy about 39 km^2 of the MB area, and those near Inhaca island cover 50% of the intertidal areas; the limited occurrence of seagrasses in mangrove areas is generally associated with coverage transitions.

The mapping results were vital outputs for understanding the bay's structure regarding these two ecosystems. However, some limitations were faced as there was no dataset with separate year information sufficiently precise to characterize a small area as is MB. In the future, updated and more fitted to regional scale imagery would be ideal to better assess the evolution of both ecosystems in the MB.

4.1.2. Ecosystem's condition

The MPAs area, specifically the ratio between the area of POPMR and the total marine area in the Maputo province, was low (0.661%) when compared to the standard value proposed by the Aichi target 11 (10%). This reflects the struggle of most developing countries to meet Aichi Target 11 (Failler *et al.* 2019). The question of Mozambique achieving Aichi Target 11 could also be raised at a national level, as the ratio is only 2.15% (UNEP, 2009), making this regional-scale analysis a reflection of the country's progress.

The poor coverage of protected marine areas in low and medium-income countries, as Mozambique, reflects the context in which conservation is implemented: institutions are too weak to meet their international commitments while economic development is the main public policy concern. In addition, the lack of funding and the political instability add to the difficulties of implementing measures to protect the environment (Failler *et al.*, 2019). A hypothetical solution for this situation would probably pass through the establishment of offshore MPAs (Failler *et al.*, 2019). However, this represents a huge challenge as it is incongruent with developing countries current economic strategies that are insufficiently geared towards environmental protection. To do so, these countries should receive substantial support from the industrialized countries for the maintenance and improvement of the health of their coastal ecosystems (Failler *et al.*, 2019), which ultimately will have worldwide benefits.

Overall, regarding the assessment of the MB ecosystems condition, it is safe to say that the application of only an indicator is insufficient. However, there was no data that could be fitted into deep and detailed assays, such as physical, chemical and biological analyses, to achieve a holistic evaluation of both MB´s mangrove and seagrass condition through the application of different indicators. While attempting to understand the real condition of the MB and its ecosystems many aspects can be reasoned, yet what is truly key for tackling this type of approach is the existence of reliable data and standard points of reference. In essence, a well-established monitoring program is in need to acquire data and to establish an adequate classification system to compare the obtained results with a reference state. This information is key to objectively determine the quality of the ecosystems under study and to develop and apply appropriate indicators.

4.1.3. MMI of MB's mangroves and seagrasses

A general overview of the MMI in MB (**Figure 3-3**) showed that Mollusca and Arthropoda were the most prevalent phyla in the study area, although when looking closer to the ecosystems level that was not always the case.

It is important to acknowledge that mangrove forests had more and widely distributed MMI occurrences than seagrass meadows. This is congruent with a wider distribution of mangroves in the bay than seagrasses; hence there were more MMI PO overlapping with the former. Arguably, the resulting seagrass MMI dataset had limited metadata to be representative of reality, therefore it should be interpreted with some reservation.

As to the entire bay, the phyla Arthropoda and Mollusca were predominant in mangrove forests, whereas in seagrasses, only the phylum Mollusca met the same level, followed by Echinodermata. Such information is consistent with many crabs and shrimps having a close relationship with mangroves, and animals like sea urchins and clams with seagrasses (Fernando & Bandeira, 2014; Macia et al., 2014).

Lastly, a large concentration of places of occurrence for all phyla was found mainly at the Inhaca island, which suggests that this is an important area with high levels of biodiversity. This is probably related to Inhaca island being within the POPMR protected area. Nevertheless, this association is not certain since this correlation could be simply due to the fact that more studies have been carried out there. This was likely enhanced by the Marine Biology Station Eduardo Mondlane (Estação de Biologia Marinha da Inhaca - EMBI) stationed there and endorsing many research studies on the location.

4.1.4. Drivers of change

Alien species

Only the penaeid shrimp *Metapenaeus dobsoni* was identified in 2007 (Simbine *et al.*, 2018). This species has been the cause of some dissatisfaction among the fishing community, once alien individuals are of smaller body size than the native commercial ones, thereby potentially having negative impacts on fisheries and economic stability of the region (Simbine *et al.*, 2018).

The identification of only a single alien species is arguably less than expected since MB houses one of the most important and strategic ports of the region. Many ships enter the area raising the probability of introducing new species, for example through ballast water management. For this reason, an effective monitorization program of port operations is needed for the early detection of alien species and to prevent it.

Climate change

Sea level (SL) and sea surface temperature (SST) showed oscillations through time, but in overall there was an increase. Rouault *et al.* (2009) and Schumann *et al.* (1995) describe the phenomenon of rising SST surrounding southeast Africa, although the last further stated that parts of southern Mozambique, including MB, have cooled slightly due to stronger winds, which, along with the expected regional and interannual variability, may explain the observed oscillations. In the case of the rising SL, it is supported by Mahongo (2009) who found that it has been rising at a rate of 0.73 mm per year, also consistent with recent global SL rise trends (IPCC, 2007).

There is a growing concern for climate change effects on developing countries because they are the most vulnerable to the rising frequency and severity of extreme weather events and climate variability (Mirza, 2003). In Mozambique, there is an increasing variability in rainfall, either subjecting low-lying areas to extended floods or droughts; tropical cyclones are also more frequent due to El Niño Southern Oscillation (ENSO) (Christie & Hanlon, 2001). In the beginning of the 21st century, there was an intensification in the sedimentation phenomenon, which gave rise to seagrass meadows degradation, highlighting the connection between seagrasses dieback and climate change (Christie & Hanlon, 2001). Also, during that time, coastal erosion occurred in some points of the bay, which affected its geomorphology. A distressing example is the Xefina Grande island, where coastal erosion is often reported, and that in the year 2000 was divided into two as a direct effect of the floods (Bandeira & Gell, 2003); Portuguese island has also lost a large area over time, which affects the tidal recharge of the mangrove and causes its dieback (Hatton & Couto, 1992).

Climate change is a driver with potential for more complex analysis, and although only SL and SST were assessed, other phenomena, such as ocean acidity, could have been interesting to considered if data were available. SST was the only indicator with a good amount of data behind it. The SL records were relatively poor, and side effects such as coastal erosion in MB are still not comprehensively studied.

Monitoring SST, SL, rainfall, climatic variability and extreme events is needed in order to develop local models. Robust models based on solid data will allow to forecast and further understand the consequences of climate change at the MB local level, namely on its ES. This knowledge will contribute to informed options for climate adaptation and to implement mitigation measures to face detrimental impacts (Paula & Bandeira, 2014) and to promote a sustainable use of ES provided by the MB ecosystems**.**

LULC changes

LULC changes were key for understanding the growing urbanization and agricultural intensification, sometimes occurring in detriment to mangrove cover. This is a concerning situation, making soil reclamation a big threat to the study area, with an already and still-evolving overpopulated urban tissue. A disturbing example of urban and peri-urban extension is Costa do Sol, where reclamation for housing is very aggressive; in Matola city this problem was also aggravated by land conversion to saltpans and shrimp aquaculture farms, although the last ones are now abandoned (Brouwer & Falcão, 2004).

LULC changes are in substance a direct cause of the urban expansion and agriculture intensification due to overpopulation, and possibly very complex to avoid. Negative LULC changes may perhaps be contained through better administrative and spatial management, where the integrity of coastal ecosystems must be prioritized. Finally, as the assessment of this driver was mainly carried out through mapping tools, it would beneficiate from imagery with better resolution and a greater timespan.

Overexploitation: deforestation

Mangrove's deforestation, besides being directly connected to urban development, can also be related to the exploitation of wood. According to Brouwer & Falcão (2004), deforestation in MB is strongly linked to the use of fuelwood, which along with charcoal are prime sources of domestic fuel for peri-urban populations. Furthermore, wood is widely collected both for domestic consumption and commercial purposes, being a useful material not only for boat and house construction, but also for the production of various household utensils. Macamo *et al.* (2015) reported the Incomati estuary as probably one of the most impacted mangrove forests of the bay, resulting from the pollution and freshwater abstraction, as well as deforestation. Peri-urban mangroves are particularly vulnerable to degradation, as the population density is high and local communities still have a high level of dependency on coastal natural resources (Macamo *et al.*, 2015).

There were admittedly clear knowledge gaps on deforestation as the data didn't include the mangrove forests of the Espírito Santos estuary, and according to Paula & Bandeira (2014), the forests in the south and south-east of the bay are poorly known in comparison to those at north and north-west. Future steps need to encompass a more thorough assessment of mangrove forests in south Maputo Bay and Machangulo peninsula, as well as more detailed shape or raster files of the study area with mangrove ecosystems well discriminated. Operations to strengthen conservation and strategic reforestation of mangroves at the bay, while the regeneration capacity of degraded mangroves is assessed, would also be very beneficial.

Overexploitation: fisheries

Another detected form of overexploitation found at MB was overfishing. On a national scale, fisheries are an important source of income, as well as the main sources of protein for the population (Macia, 2004), and the same can be stated for MB, as it is the second-largest fishing zone in the country. Even though consistent numbers of annual MSY were not found, in accordance with previous studies (e.g. Chaúca *et al.*, 2007; de Freitas & Araujo, 1974; Dengo & Govender, 1998; Macia Jr, 1990; Sousa & Gjøsaeter, 1987; Ulltang, 1980) fishing stocks, in general, are overexploited and fisheries need contention.

Artisanal fishing licenses showed a rising number, implying an increase in fisheries exploitation over the years.

Vital information regarding bycatch linked to shrimp fisheries (both artisanal and semi-industrial) was obtained, indicating that semi-industrial fisheries represent a major concern. The associated mechanized fishing arts (bottom trawls and more recently bottom gill nets, IIP, 2009) have low selectivity (Graça-Lopes, 1996), enhancing the capture of bycatch and having a huge impact on the seabed (Freese *et al.*, 1999) degrading ecosystems such as seagrass meadows.

In closer scrutiny, the problem of bycatch is related to the fact that captures with a high diversity of organisms are often discarded as they don't mainly represent the target species (shrimp) (Severino-Rodrigues *et al.*, 2002). In semi-industrial fisheries , by-catch generally ends up being thrown back at sea because the biomass has no commercial value, or the individuals are not of marketable size (Graça-Lopes, 1996). Besides endangering the populations and biodiversity of the bay, there is also the generation of waste that otherwise represented an important protein source with the potential to contribute to food security (Silva & Masquine, 2014). Hence, one may argue that artisanal fishermen make better use of the species caught for their consumption, discarding a very small part of the bycatch. Nonetheless, the amount of bycatch discarded in total by both fisheries is significant and it culminates in a bigger pressure for the bay.

On a final note, it is important to mention that China has been investing in Mozambique, boosting a variety of economic sectors, many times in return of natural resources. For this reason, fishing licenses have been used as a trade-off, leading to the continuous arrival of Chinese fleets to the country (some for deep-sea fishing of shrimp). Local fishermen have already voiced their worry about the ecosystems wellbeing and the preservation of their livelihoods, as they face uncertainty towards the claimed excessive exploration brought by the Chinese fleets (Mosse, 2018; Baker, 2019).

Due to the economical and food security weight that MMI represent at MB, overfishing and the unknown state of some stocks is very concerning. For this reason, the monitoring of MMI stocks, aiming to obtain long data series and reliable bio-ecological data related to industrial, semi-industrial and artisanal fisheries is of particular importance. Only sound reliable data will guarantee an adequate management of the stocks which will have to be reinforced through up-to-date legislation (Paula & Bandeira, 2014). At the same time, the excessive bycatch must be monitored together with the investigation for potentially new technologies to reduce it to acceptable standards (Paula & Bandeira, 2014). Finally, although less armful, it would be beneficial to better comprehend the evolution of the recreational and sport fishing industry, hence promoting their sustainable management.

Pollution

In terms of land-based pollution, agriculture raises concern for the poorly managed use of pesticides, which reflects a lack of awareness of the health and environmental risks of their indiscriminate use (Scarlet & Bandeira, 2014). This type of chemicals may enter the aquatic food chains and accumulate in animal tissues, particularly in fatty tissues (Fernandes, 1996), thus having the potential to represent a sanitary and food security problem. Regarding industry, although it is an activity heavily concentrated in Maputo and Matola cities, its impact on the bay's water has remained relatively low. Yet, the total number of industrial units has increased, and worryingly, many of them discharge partially or totally untreated effluents into Matola and Infulene rivers. Furthermore, there is a lack of information about the perceived impacts of such actions on the environment (Scarlet & Bandeira, 2014). Adding to the mix, there is also domestic sewage discharged into Espírito Santo estuary (Achimo, 2004), that alike agricultural waste, plays an important role in eutrophication, which seems to have had its biggest impact around Costa do Sol. Also, the proliferation of invasive species of aquatic plants have been identified in Incomati and Umbeluzi rivers, due to nutrients enrichment (Scarlet & Bandeira, 2014). Moreover, periodically enhancing the discharge of all urban sewage is stormwater, an episodic and diffuse source of pollution aggravated by climate change (Scarlet & Bandeira, 2014).

Other more specific types of pollution encompassing warm coastal waters near large cities are marine litter (mainly plastic), as well as microbial pollution. The first, according to Scarlet & Bandeira (2014), has strong impact surprisingly not only at Maputo's shore but also at Machangulo peninsula and Inhaca island, two locations protected by the MSR. The second, is closely related to food security and will be further discussed.

As for port-related pollution, although only occurring at one point of the bay, it can be embodied by many sources, between them antifouling paints that stood out for causing "imposex" (reversal of sex organ development) and "intersex" (indeterminate biological sex) in gastropods. This was confirmed to happen in Espírito Santo estuary, although tributyltin (TBT), the compound believed to cause the mentioned alterations, is now completely prohibited by the International Maritime Organization Convention (IMO) (Scarlet & Bandeira, 2014). Also of worry are the oil spills from bunkering, de-ballast and tank clearing, which are the main sources of petroleum hydrocarbon pollution in Mozambique (Scarlet & Bandeira, 2014). In MB, the worst crude oil spill incident occurred in 1992, when an oil tanker released over 72,000 T, an event that affected local communities due to imposed restrains regarding an important food source colliding with a few thousand families of fishermen that were deprived of their livelihood (Clark, 2001).

Information regarding pollution in MB was enough for understanding the complexity of the study area in terms of imposed pressures. Nevertheless, no quantitative data was found to quantify pollution, an important knowledge gap that must be addressed.

As the sources of pollution come from two fronts, measures regarding both land and port-based pollution must be considered to tackle the problem. In terms of land-based pollution it is crucial to: contain and monitor the use of pesticides; develop environmental management actions and adequate wastewater treatment plants for Maputo and Matola cities; monitor pathogenic organisms on bathing areas while assessing the true impacts of the collection of bivalves; and assess the trans-boundary rivers (Incomati, Umbeluzi, Maputo and Tembe), reinforcing the regional and international instruments that deal with management, treatment and elimination of hazardous waste (Paula & Bandeira, 2014). In terms of port-based pollution, the minimization of impacts encompasses the improvement of the monitorization of Maputo's port operations along with the development of strategic plans for oil spills and tank cleaning (Paula & Bandeira, 2014).

Overpopulation

The problem of overpopulation is a complex issue that far extends beyond the dimension of this work. The still-evolving population in the MB area, with an increasing population density is a catalyst for all the above-mentioned direct drivers of change. Although it operates more diffusely, its negative potential towards ecosystem degradation and consequent decrease in the supply of ES needs to be addressed. An important approach lies on the education of local citizens and work with local communities and stakeholders towards achieving environmental awareness and responsibility to mitigate the impact of population growth on MB´s mangroves and seagrasses.

4.2. ASSESSMENT OF MB´S MANGROVES AND SEAGRASSES ES

According to the results, both the mangrove forest and seagrass meadows of Maputo have a variety of ecosystem services,

In terms of provisioning ES, in mangrove forests wood had several uses, yet seagrass meadows seem to be more intrinsically connected to traditional practices providing versatile materials for local communities which resourcefully use them for many ends.

It is though in the regulation and maintenance section that the ES related to these ecosystems stood out, as they have the potential to mitigate the effects of many of the identified drivers of change. Mangroves and seagrasses help improving soil and water quality, plus performing mediation of waste or toxic substances, very important in a water body like MB, which faces river discharges contaminated by urban sewage, a direct consequence of high density of urban development and industrialization. Also, erosion prevention, flood control and coastal protection benefit from these natural formations, which battle against the consequences of extreme events like heavy rains and tropical cyclones; at the same time, not only they mitigate the consequences of climate change, but directly fight the root problem by performing carbon sequestration, hence contributing to its prevention at a local and global level. Lastly, both ecosystems revealed to be important nursing areas, inclusively for MMI species: mangrove forests are vital for the protection of edible species such as the crab *Scylla serrata* and prawns, mainly *Fenneropenaeus indicus* (white shrimp); seagrasses are closely connected to the harvesting of edible sea urchin and clams.

In terms of cultural ES, mangroves and seagrasses have the potential for physical, intellectual and spiritual interactions. In the case of mangroves, intellectual interaction with "characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge" stand out due to the importance of these ecosystems to provide so many goods and services for human coastal populations, turning them into a central model system in research activities in MB area. This is corroborated by the fact that the total number of published papers, related not only to mangroves but also seagrasses, has been rising. As regards to seagrasses, the association to active and immersive activities excelled as they represented a great place for diving and snorkelling where flag species like dugongs and sea turtles are more likely to be seen, an angle with great potential for ecotourism.

In this ES section, it was also possible to assess the average stays (in days) at the Maputo province both by national and international visitors, where the last ones are rising in spite of various oscillations. As for the total number of guests in Maputo through time showed an overall decrease. Arguably, these results could translate into a decrease in interest in visiting the area of MB, although the justifications behind such premise could relate to many factors, including the degradation of the ecosystems and therefore a decrease in the supply of ES of interest to the visitors. A deeper analysis to why this happens still must be done.

This work acknowledged the importance of mangrove forests and seagrass meadows at MB and the ES supply potential that they represented. Although the assessment of their condition and the quantification of their ES supply faced limitations, it is clear that to maintain them healthy and sustainably, two lines of action must be taken. The most direct one covers the prevention and mitigation of the consequences of the existing drivers of change, which were addressed above; and the other one relies on the active restoration of the affected ecosystems, which already began but needs to be continued and will be here further discussed.

As regards to mangrove forests, new projects regarding replantation have started to arise, as is the case in Matutuíne, in the region of Tsolombane which was hit by lightning in 2000 that caused a fire in the mangrove forest leading to extensive devastation (Bandeira *et al.*, 2016).

At the beginning of the century, Calumpong & Fonseca (2001) had already highlighted the need for seagrass beds restoration and the need to find out whether their causes of destruction in the region have ceased or were at least contained. On that note, the fact that the impact of sand and seagrass excavation for clam collection was still not well understood was also highlighted, along with the need for further studies prior to replantation. The impacts of heavy rains and floods that have not been thoroughly examined and need monitoring on a regular basis.

According to UN (2020), the Eduardo Mondlane University, supported by the Mozambican government, has been identifying and restoring seagrass habitats in MB. As part of the project, local communities will learn non-destructive fishing practices and to develop a local seagrass management plan. Additionally, and already in connection to the subject of MMI, more healthy seagrasses, will provide grounds for increasing MMI diversity and quantity, which could boost local fishing and improve food security. Apart from that, the project could even have a greater impact as the lessons learned it can be used in other countries in the Western Indian Ocean, also combating seagrass degradation.

Mozambique is starting to work towards the 2030 Agenda for Sustainable Development, more precisely to the SDG 14, “Conserve and sustainably use the oceans, seas and marine resources for sustainable development” through the Target 14.2, “By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans”.

4.3. ASSESSMENT OF MMI’S ES IN MB’S MANGROVES AND SEAGRASSES

In terms of provision, MMI edible potential was identified and studied through the lens of production indicators regarding artisanal and semi-industrial fisheries. Artisanal fisheries, where MB represented 5% at a national level, annually captured around 639 tons of MMI, more than half (420 tons) corresponding to shrimp species. These species are also the main target of semi-industrial fisheries, revealing that they are a very important source of protein and income for the bay, namely *Fenneropenaues indicus* (white shrimp) and *Metapenaeus monoceros* (brown shrimp). Contrasting with the artisanal fisheries, semi-industrial production of shrimp has been identified as in decline, thereby two hypothesis arise: (1) the MSY has been lowered and therefore shrimp capture has become more restricted to protect shrimp species stocks; and/ or (2) the stocks of shrimp species have not been rightfully protected and their population is declining which is being reflected in the lower captures. Considering the little MSY information available and that shrimps are a common target species for both fisheries in analysis, it is likely that there is an overexploitation of this resource – supported by an increase in demand for this delicacy, indicated by an expansion in the fishing area which alarmingly is being practised inside POPMR near Machangulo peninsula.

As for all regulating and maintenance ES, supply is rising, indicating that even though MMI face many pressures, their effects are still not visible at this scale. Overall, it is safe to say that MMI play an important role in the regulation and maintenance of the surrounding environment, contributing both to water and soil quality, enhancing seagrass meadows and mangrove forests ecological status.

MMI SR delivers a good opportunity for scientific investigation or the creation of traditional ecological knowledge, and at the same time may represent an increasing target for recreation and sport fishing, a type of activity with an increasing number of licences, which may reflect an increase in demand of this ES.

The study of MMI ES was limited by the availability of information and scattered data resulting in knowledge gaps related to species representation and abundance. For example, the high number of MMI registers in the DB in the 1960s or the 2010s probably corresponded to more intensive fieldwork in MB during those periods. Further steps need to be taken to correctly assess MMI at MB, including the implementation of a well-thought methodology for monitoring MMI biodiversity. This information can be integrated into the MB DB to provide new knowledge. Nevertheless, this study, even with the ineluctable limitations, made the best of the current available data, leading to baseline information that can be further used in research and MB ecological management.

4.4. ES CONCEPTUAL MODEL

The development of an exploratory ESCM represents a simplified mean of holistically describing the nodes between the introduction of alien species, the effects of climate change, habitat loss due to LULC changes and deforestation, overfishing and the many identified sources of pollution, and how they all negatively influence biodiversity, MMI fishing stocks, water quality and possibly the MPAs effectiveness, which affect MMI ES supply, and ultimately the established management goals. The understanding of such nodes is therefore vital to delineate more effective mitigation practices. Monitoring of the MB' condition is of paramount importance, and it can be achieved by the selection and application of a good set of core indicators. An exploratory ESCM has the potential to help transitioning ES considerations from an interesting concept to an actionable approach to natural resource management.

Focusing on MMI's ES, the obtained results highlighted the need to further understand and safeguard food security, as the fishing effort seem to be rising and the shrimp species stocks overexploited: The other ES supply, although apparently more stable, would benefit from further research and monitoring, since more data could reveal a more accurate reality concerning their state, attending to the fact that the ESCM made clear that the supply of both regulation and maintenance and cultural ES can be affected by all drivers of change through the decrease of biodiversity, the depletion of MMI fishing stocks, degradation of water quality and the effectiveness of MPAs.

The ESCM represents a practical tool to help design a plan of how to achieve the established management goals of food security, sustainable fisheries and collecting of animals, good ecological status and the increase in recreational opportunities; it is also a good starting point of exploration for future projects which hopefully can be applied in similar areas to MB, however, to reach more complex models, further actions must be taken where the input of locals and other stakeholders is arranged.

4.5. MMI AND FOOD SECURITY

According to Raimundo (2016), Maputo local communities interpret food security as depending on access to fisheries, rice and maize, a perspective that implies both agricultural and fishing assets. These communities use fish as an important source of protein which is in fact a big parcel of the fishing production. However, MMI still have an important role in the food security of MB local communities.

The shrimp industry, which has tremendous importance in food security and economical income of the region, is facing a decrease in production which paired with the stocks most probably depleting, represents an alarming situation, which will be aggravated by the increase in the demand by a still-growing population. Besides shrimp fisheries, there are other examples of MMI species exploited, mainly bivalves, sea urchins, gastropods and crabs. Specifically, in the intertidal area, these MMI resources encompass important sources of livelihood and food security for many households, establishing a strong dependency of coastal communities on these resources (de la Torre-Castro & Rönnbäck, 2004). For example, the mud crab *Scylla serrata*, locally known as "Hala", is exploited as a traditional artisanal activity that requires a relatively small fishing investment and has a high demand as a delicacy both for tourists and local consumers (Piatek, 1981); the sea urchin *Tripneustes gratilla* is an important consumption item playing a social and ecological role in Inhaca island, where fishing is the main source of livelihood, carried out by around 70% of the population. This activity may serve as a controlling factor to prevent a dramatic increase in sea urchin density, which may lead to seagrass reduction (Fernando & Bandeira, 2014). Additionally, MMI harvested from seagrass beds have been a focal point of study in Bairro dos Pescadores near Maputo city (urban setting) and Inhaca island (rural setting), being worth to highlight that in the urban setting, mostly bivalves and gastropods are collected for markets and restaurants (Fernando & Bandeira, 2014). In the rural setting, mostly bivalves and sea urchins are collected for domestic consumption, and here the importance of seagrass meadows for food security seem to be more valued by local populations, indicating a high degree of local ecological knowledge (Fernando & Bandeira, 2014).

Rönnbäck *et al.* (2002), Macia *et al.* (2014), and de Abreu *et al.* (2017) provide vital information about important edible MMI of MB, and the relevance of mangroves and seagrass meadows in their preservation. For instance, the commercial *Penaeus* and *Metapenaeus* shrimps spawn at sea and the post larval individuals settle in inshore and estuarine waters which are used as nurseries, and after a few months, the sub-adults start their emigration offshore to complete their life cycle (Rönnbäck *et al.*, 2002). At Saco and Sangala bays (Inhaca island), juveniles were found to shift between mangrove forests and seagrass meadows according to tidal cycles, seeking protection against predators in mangrove forest until the water level is too low, and then feeding in seagrass meadows, where there still is water (de Abreu *et al.*, 2017). The crab *Scylla serrata*, recruits to mangrove forests where it resides during the juvenile phase, making burrows in the muddier parts of the forest, which function as a nursery; when mature the crabs move offshore where reproduction takes place (Macia *et al.*, 2014).

To achieve and maintain food security linked to MMI, the pressures applied to MB must be regarded, since they are behind the deterioration of its ecosystems, e.g., mangrove forests and seagrass meadows, meaning that healthy MMI populations are also compromised. The introduction of alien species, climate change, habitat loss (due to LULC changes and deforestation), overexploitation of MMI fishing stocks, and pollution must be handled in order to prevent or mitigate their consequences.

Furthermore, by degrading MMI environment these drivers of change, may directly affect the health of consumers. Examples of this are the gastro-intestinal illnesses events linked to clam harvesting near the shore close to the city and of the Incomati river mouth in which sometimes the bacteria *Vibrio parahaemolyticus* and *V. mimicus* are present (Fernandes *et al.*, 1993). Also, clams carrying *Salmonela* spp. and even *Hepatitis A* were already detected (Nenonen *et al.*, 2006), indicating that bivalves can be a significant vector of both enteric bacteria and viruses. For this reason, a high alert for pathogenic agents, especially in bathing areas, is necessary to tackle outbreaks resulting from collected seafood which can compromise food security and represent sanitary problems.

All things considered, to assure healthy ecosystems and a sustainable ES supply to guarantee the food security of local populations that rely on MMI as an important source of protein. requires a management plan taking into account different drivers of change, the monitoring of the MB ecological status and the trends of MMI ES, by studying MMI populations as well as their inter and intraspecific interactions. This is important to minimize and prevent further damage of the MB and its ecological components and provide reliable and continuous data to understand and guarantee food security in MB.

4.6. FUTURE TRENDS AND THE WAY FORWARD

All drivers of change assessed are progressing in a concerning way, which undeniably implicates the degradation of the MB's ecosystems and MMI. It was possible to grasp trends of climate change, overexploitation and LULC changes, concluding that: the mean SL and SST are rising; the artisanal fishing production is rising; and deforestation and LULC changes are both contributing to the loss of habitat. Additionally, the indirect driver of overpopulation represents a boosting factor to direct drivers, from the ones assessed, to the ones not yet well understood, as it is the introduction of alien species and pollution, which although not quantified, also appear to have undesirable consequences on the MB's ecosystem condition.

The pressures applied to mangrove forests and seagrass meadows can lead to their disappearance or degradation, which ultimately will affect their ES supply. In terms of regulation and maintenance, that would mean the loss of important nursing areas, threat to regulation of baseline flows and extreme events, loss of good atmospheric composition (worsening climate change) and both water and soil quality – all culminating in the aggravation of the management goal of good ecological status, in due course affecting MMI populations and their ES, hence also putting on the line food security, sustainable fisheries and collection of animals, and even recreational opportunities.

Focusing on MMI provisioning ES, although artisanal fishery production trend is positive, the semi-industrial fishery of shrimp is not, representing a possible threat regarding food security. There is an evident lack of information regarding MMI stocks, and the available data is far too old and only referring to shrimp populations, not delivering a representing present-day situation. The use of MMI stocks to an unsustainable level is prone to be taking course, and monitorization of this practice needs to be urgently improved. As for the regulation and maintenance ES supply, they were all rising, although drivers of change may have not yet affected MMI regulating and maintenance ES. The most probable scenario is that the available data is insufficient to accurately quantify these ES. The same can be applied to cultural ES.

Ensuring food security, sustainable fisheries and collecting of animals, good ecological status, and increasing recreational opportunities needs a holistic approach encompassing monitoring plans to gather reliable and continuous data grasping drivers of change, ecosystems condition and MMI ES. These together with the establishment of more MPAs, along with their effective protection, could help guarantee the health of the bay and, in the long run, safeguard local communities.

5. REFERENCES

Achimo, M. (2004). *Evaluation of heavy metal pollution in the surface sediments in Maputo Bay, Mozambique*. Stockolm University, Sweden.

Aksornkoae, S., & Kato, S. (2011). Mangroves for the people and environmental conservation in Asia. *Bulletin of the Society of Sea Water Science, Japan*, *65*(1), 3–9.

Alfaro, A. C. (2006). Benthic macro-invertebrate community composition within a mangrove/seagrass estuary in northern New Zealand. *Estuarine, Coastal and Shelf Science*, *66*(1–2), 97–110.

Anderson, J. (2009). *Southern oceans education and development (SOED) project*. https://silo.tips/download/southern-oceans-education-development-soed-project-relatorio-de-estudo-and-evelo#

António, E. de A., Rombe, C. M., Afonso, N., Masquine, Z., & Pires, P. (2017). Boletim estatístico da pesca e aquacultura 2006-2017. In *Ministério do mar, águas interiores e pescas*. http://www.mimaip.gov.mz/wp-content/uploads/2019/06/AF_Boletim-Estatistico-Miolo-2006-2017-Final-em-usoFev2019.pdf

Baker, L. (2019). *Bridging Perceptions: China in Mozambique*. Macro Polo. https://macropolo.org/analysis/china-mozambique-elite-perceptions/

Bandeira, S. (2002). Diversity and distribution of seagrasses around Inhaca island, southern Mozambique. *South African Journal of Botany*, *68*(2), 191–198.

Bandeira, S., & Gell, F. (2003). The seagrasses of Mozambique and southeastern Africa. In UNEP-WCMC (Ed.), *World atlas of seagrasses,* (8), 93–100. University of California Press: Berkeley, CA.

Bandeira, S., Gullström, M., Balidy, H., Samussone, D., & Cossa, D. (2014). Seagrass meadows in Maputo bay. In S. Bandeira & J. Paula (Eds.), *The Maputo bay ecosystem* (8), 147–170. WIOMSA.

Bandeira, S., Macamo, C., Mahazule, R., & Mabilana, H. (2016). *Estudo de lições aprendidas e boas práticas de reabilitação do mangal*. Estudo de Lições Aprendidas e Boas%0APráticas de Reabilitação do Mangal%0D

Banderia, S., & Paula, J. (2014). *The Maputo bay ecosystem* (WIMOSA (Ed.)).

Barbier, E. B. (2007). Valuing ecosystem services as productive inputs. *Economic Policy*, *22*(49), 178–229.

Barbosa, F., Cuambe, C., & Bandeira, S. (2001). Status and distribution of mangroves in Mozambique. *South African Journal of Botany*, *67*(3), 393–398.

Bingham, G., Bishop, R., Brody, M., Bromley, D., Clark, E. T., Cooper, W., Costanza, R., Hale, T., Hayden, G., & Kellert, S. (1995). Issues in ecosystem valuation: improving information for decision making. *Ecological Economics*, *14*(2), 73–90.

Börger, T., Beaumont, N., Pendleton, L., Boyle, K., Cooper, P., Fletcher, S., Haab, T., Hanemann, M., Hooper, T., Hussain, S., Portela, R., Stithou, M., Stockhill, J., Taylor, T., & Austen, M. (2014). Incorporating ecosystem services in marine planning: The role of valuation. *Marine Policy*, *46*, 161–170.

Borgman, C., Wallis, J., & Enyedy, N. (2007). Little science confronts the data deluge: habitat ecology, embedded sensor networks, and digital libraries. *International Journal on Digital Libraries*, *7*(1), 17–30.

Borgman, C., Wallis, J., & Enyedy, N. (2006). Building digital libraries for scientific data: an exploratory study of data practices in habitat ecology. *International Conference on Theory and Practice of Digital Libraries*, 170–183.

Brouwer, R., & Falcão, M. P. (2004). Wood fuel consumption in Maputo, Mozambique. *Biomass and Bioenergy*, *27*(3), 233–245.

Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand and budgets. *Ecological Indicators*, *21*, 17–29.

Burkhard, B., & Maes, J. (2017). *Mapping ecosystem services* (B. Burkhard & J. Maes (Eds.)). Pensoft publishers.

Burkhard, B., Santos-Martin, F., Nedkov, S., & Maes, J. (2018). An operational framework for integrated mapping and assessment of ecosystems and their services (MAES). *One Ecosystem*, *3*.

Calumpong, H. P., & Fonseca, M. S. (2001). Seagrass transplantation and other seagrass restoration methods. *Global Seagrass Res. Methods*, *33*, 425–443.

Casado-Arzuaga, I., Madariaga, I., & Onaindia, M. (2013). Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of Environmental Management*, *129*, 33–43.

Cavanagh, R. D., Broszeit, S., Pilling, G. M., Grant, S. M., Murphy, E. J., & Austen, M. C. (2016). Valuing biodiversity and ecosystem services: a useful way to manage and conserve marine resources? *Proceedings of the Royal Society: Biological Sciences*, *283*(1844).

Chaikumbung, M., Doucouliagos, H., & Scarborough, H. (2016). The economic value of wetlands in developing countries: a meta-regression analysis. *Ecological Economics*, *124*, 164–174.

Chaúca, I., Inácio, A., Sousa, L., & Caramelo, A. (2007). Análise dos principais recursos de camarão na baía de Maputo. *Unpublished Report, Instituto Nacional de Investigação Pesqueira, Maputo*.

Christie, F., & Hanlon, J. (2001). *Mozambique & the great flood of 2000*. Indiana University press.

Clark, R. B. (2001). *Marine pollution* (O. U. Press (Ed.); 5th ed.).

Conselho municipal de Maputo (CMM). (2008). *Perfil estatístico do município de Maputo 2004-2007*. https://docplayer.com.br/23922462-Perfil-estatistico-do-municipio-de-maputo.html

Convention on biological diversity (CBD). (2013). Quick guide to the Aichi Biodiversity Targets. *Protected Areas Increased and Improved*, 23–24.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253–260.

Cruz-Garcia, G. S., Sachet, E., Blundo-Canto, G., Vanegas, M., & Quintero, M. (2017). To what extent have the links between ecosystem services and human well-being been researched in Africa, Asia, and Latin America? *Ecosystem Services*, *25*, 201–212.

da Silva, A., & Rafael, J. (2014). Geographical and socio-economic setting of Maputo bay. In S. Bandeira & J. Paula (Eds.), *The Maputo bay ecosystem* (WIOMSA, Issue 2, p. 427).

Daily, G. C. (1997). Countryside biogeography and the provision of ecosystem services. *Nature and Human Society: The Quest for a Sustainable World*, 104–113.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., Ricketts, T. H., Salzman, J., & Shallenberger, R. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, *7*(1), 21–28.

de Abreu, D. C., Paula, J., & Macia, A. (2017). Tropical seascapes as feeding grounds for juvenile penaeid shrimps in southern Mozambique revealed using stable isotopes. *Estuarine, Coastal and Shelf Science*, *198*, 21–28.

de Boer, W. F., Blijdenstein, A. F., & Longamane, F. (2002). Prey choice and habitat use of people exploiting intertidal resources. *Environmental Conservation*, *29*(2), 238–252.

de Freitas, A. I., & Araujo, J. M. (1974). Status of the penaeid shrimp stocks of Mozambique. *Coll. Sci. Papers*, *1*, 271–277.

de Groot, R. S. (1992). Functions of nature: evaluation of nature in environmental planning, management and decision. *Polar Record*, *29*(169), 162.

de Groot, Rudolf S, Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, *7*(3), 260–272.

de la Torre-Castro, M., & Rönnbäck, P. (2004). Links between humans and seagrasses—an example from tropical East Africa. *Ocean & Coastal Management*, *47*(7–8), 361–387.

Dengo, A., & Govender, A. (1998). The shrimp resource of Maputo Bay: semi-industrial and artisanal fisheries. *Instituto Nacional de Investigação Pesqueira, Maputo*, 21.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J. R., Arico, S., & Báldi, A. (2015). The IPBES conceptual framework - connecting nature and people. *Current Opinion in Environmental Sustainability*, *14*, 1–16.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., & Brauman, K. A. (2018). Assessing nature's contributions to people. *Science*, *359*(6373), 270–272.

Elsevier. (2021). *Scopus*. https://www.scopus.com/

Environmental systems research institute (ESRI). (2020). *ArcGIS*. https://www.esri.com/en-us/arcgis/about-arcgis/overview

European space agency (ESA). (2017). *300 m annual global land cover time series from 1992 to 2015*. ESA. http://www.esa-landcover-cci.org/?q=node/175

European Union (UE). (2018). *Mapping and assessment of ecosystems and their services (MAES): an analytical framework for mapping and assessment of ecosystem condition in EU (5th edition)*.

Failler, P., Touron-Gardic, G., & Traore, M. S. (2019). Is Aichi target 11 progress correctly measured for developing countries? *Trends in Ecology and Evolution*, *34*(10), 875–879.

Fernandes, A. (1996). Poluição: factos e figuras. In D. Dias, P. Scarlet, J. Hatton, & A. Macia (Eds.), *Proceedings from the Workshop on the role of research in coastal management.* Departamento de ciências biológicas, Universidade Eduardo Mondlane.

Fernandes, A., Murta, M., Manuel, A., Amado, I., & Abixai, Z. (1993). Pollution in Maputo bay. *Revista Médica de Moçambique*, *4*, 17–22.

Fernando, S., & Bandeira, S. (2014). The sea urchin Tripneustes gratilla: insight to an important food resource at Inhaca island. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem* (15), 335–340. WIOMSA.

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, *68*(3), 643–653.

Flanders marine institute (VLIZ). (2019). *Maritime boundaries geodatabase: maritime boundaries and exclusive economic zones (200NM)*. http://www.marineregions.org/

Food and agriculture organization of the United Nations (FAO), International Fund For Agricultural Development (IFAD), United Nations Children's Fund (UNICEF), World Food Programme (WFP), & World Health Organization (WHO). (2019). *The state of Food Security and Nutrition in the world 2019: safeguarding against economic slowdowns and downturns*.

Food and agriculture organization of the United Nations, F. (2020). *Hunger and food insecurity*. http://www.fao.org/hunger/en/

Freese, L., Auster, P. J., Heifetz, J., & Wing, B. L. (1999). Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. *Marine Ecology Progress Series*, *182*, 119–126.

Gillespie, K. M., & Vincent, A. C. J. (2019). Tropical invertebrate response to marine reserves varies with protection duration, habitat type, and exploitation history. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(3), 511–520.

Goñi, R., Badalamenti, F., & Tupper, M. H. (2011). Fisheries-effects of marine protected areas on local fisheries: evidence from empirical studies. *Marine Protected Areas: A Multidisciplinary Approach*, *72*, 73.

Graça-Lopes, R. da. (1996). *A pesca do camarão sete-barbas Xiphopenaeus Kroyeri, Heller (1862) e sua fauna acompanhante no litoral do Estado de São Paulo*. Tese (Doutorado em ciências biológicas) - Universidade Estadual Paulista Júlio.

Green, E. P., Short, F. T., & Frederick, T. (2003). *World atlas of seagrasses*. Univ of California Press.

Haines-Young, R., & Potschin, M. (2013). *Common international classification of ecosystem services (CICES): version 4*.

Hatton, J. C., & Couto, A. L. (1992). The effect of coastline changes on mangrove community structure, Portuguese island, Mozambique. *Hydrobiologia*, *247*(1), 49–57.

Hatziiordanou, L., Fitoka, E., Hadjicharalampous, E., Votsi, N. E., Palaskas, D., & Malak, D. A. (2019). Indicators for mapping and assessment of ecosystem condition and of the ecosystem service habitat maintenance in support of the EU Biodiversity Strategy to 2020. *One Ecosystem*, *4*.

Hueting, R. (1970). Moet de natuur worden gekwantificeerd? (should nature be quantified). *Economica Statistische Berichten*, *55*(2730), 80–84.

International Panel on Climate Change (IPCC). (2007). Climate change 2007: the physical science basis. Contributions of working group I to the fourth assessment report of the intergovernmental panel of climate change. *Cambridge University Press*, *6*(7), 333.

Instituto Nacional de Estatística (INE). (1997). *Censos 1997*. INE. http://www.ine.gov.mz/operacoes-estatisticas/censos

Instituto Nacional de Estatística (INE). (2007). *Censos 2007*. INE. http://www.ine.gov.mz/operacoes-estatisticas/censos

Instituto Nacional de Estatística (INE). (2017). *Censos 2017*. INE. http://www.ine.gov.mz/operacoes-estatisticas/censos

Instituto Nacional de Estatística (INE). (2020). *Estatística do turismo 2012-2019*. INE. http://www.ine.gov.mz/estatisticas/estatisticas-sectoriais/turismo

Instituto Nacional de Investigação Pesqueira (IIP). (2009). *Relatório anual de 2008*. http://www.iip.gov.mz/index.php/publicacoes/relatorio-anual

Kalk, M. (1995). A natural history of Inhaca island, Mozambique. *Witwatersrand University Press*.

King, R. T. (1966). Wildlife and man. In *NY conservationist*, *20*(6), 8–11.

Knights, A. M., Koss, R. S., & Robinson, L. A. (2013). Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. *Ecological Applications*, *23*(4), 755–765.

Ladouceur, E., & Shackelford, N. (2021). The power of data synthesis to shape the future of the restoration community and capacity. *Restoration Ecology*, *29*, e13251.

Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., Mckee, K., Bosire, J. O., Cannicci, S., Diele, K., Fromard, F., Koedam, N., Marchand, C., Mendelssohn, I., Mukherjee, N., & Record, S. (2014). Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography*, *23*(7), 726–743.

Macamo, C., Balidy, H., Bandeira, S., & Kairo, J. (2015). Mangrove transformation in the Incomati Estuary, Maputo bay, Mozambique. *Western Indian Ocean Journal of Marine Science*, *14*(1 & 2), 11–22.

Mace, G. M., Norris, K., & Fitter, A. H. (2012). Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution*, *27*(1), 19–26.

Machava, V., Macia, A., & de Abreu, D. (2014). By-catch in the artisanal and semi-industrial shrimp trawl fisheries in Maputo bay. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem*

(13), 291–295. WIOMSA.

Macia, A. (2004). Juvenile penaeid shrimp density, spatial distribution and size composition in four adjacent habitats within a mangrove-fringed bay on Inhaca island, Mozambique. *Western Indian Ocean Journal of Marine Science*, *3*(2), 163–178.

Macia, A., Afonso, P. S., Paula, J., & e Silva, R. P. (2014). The mud crab Scylla serrata (Forskål) in Maputo Bay, Mozambique. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem* (Issue 7). WIOMSA.

Macia Jr, A. A. (1990). *Estudo de duas espécies de camarão (Fenneropenaeus indicus e Metapenaeus monoceros) capturadas nas pescarias artesanal e semi-industrial da baía de Maputo*. Tese de licenciatura. Universidade Eduardo Mondlane, Maputo.

Mahongo, S. B. (2009). The changing global climate and its implication on sea level trends in Tanzania and the western indian ocean region. *Western Indian Ocean Journal of Marine Science*, *8*(2).

Millennium ecosystem assessment, M. E. A. (2005). *Ecosystems and human well-being* (Vol. 5). Island press Washington, DC.

Ministério das Pescas. (2012). *Boletim estatistico 2005-2012*. http://www.mimaip.gov.mz/wp-content/uploads/2018/09/Boletim_Estatistico_2005-2012.pdf

Mirza, M. M. Q. (2003). Climate change and extreme weather events: can developing countries adapt? *Climate Policy*, *3*(3), 233–248.

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics*, *29*(2), 215–233.

Mosse, M. (2018). *Assalto chinês aos mares de Moçambique*. Carta de Moçambique. https://cartamz.com/index.php/economia-e-negocios/item/300-assalto-chines-aos-mares-de-mocambique

Mtwana Nordlund, L., Koch, E. W., Barbier, E. B., & Creed, J. C. (2016). Seagrass ecosystem services and their variability across genera and geographical regions. *Plos One*, *11*(10), 1–23.

Mumby, P. J., Edwards, A., & Clark, C. D. (2000). Cost-effectiveness of remote sensing for coastal management. In *Remote sensing handbook for tropical coastal management,* 271–285.

Nasa Earth Observations (NEO). (2020). *Sea surface temperature (1 month - AQUA/MODIS)*. NEO. https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MYD28M&year=2020

Naylor, R., & Drew, M. (1998). Valuing mangrove resources in Kosrae, Micronesia. *Environment and Development Economics*, 471–490.

Nenonen, N. P., Hernroth, B., Chauque, A. A., Hannoun, C., & Bergström, T. (2006). Detection of hepatitis A virus genotype IB variants in clams from Maputo bay, Mozambique. *Journal of Medical Virology*, *78*(7), 896–905.

Newton, A., Brito, A. C., Icely, J. D., Derolez, V., Clara, I., Angus, S., Schernewski, G., Inácio, M., Lillebø, A. I., & Sousa, A. I. (2018). Assessing, quantifying and valuing the ecosystem services of coastal lagoons. *Journal for Nature Conservation*, *44*, 50–65.

Niza, H., Bento, M., Lopes, L., Cartaxana, A., & Correia, A. (2021). A picture is worth a thousand words: using digital tools to visualize marine invertebrate diversity data along the coasts of Mozambique and São Tomé & Príncipe. *Biodiversity Data Journal*, *9*.

Niza, H. M. E. (2019). *African marine invertebrate data analysis and imaging: a dataset and digital platform for research, education and outreach*.

Odum, E. P., & Odum, H. T. (1972). Natural areas as necessary components of man's total environment. *Trans North Am Wildl Nat Res Conf*, *37*, 189.

Olander, L., Mason, S., Warnell, K., & Tallis, H. (2018). Building ecosystem services conceptual models. In *National ecosystem services partnership conceptual model series*.

Olander, L., Polasky, S., Kagan, J. S., Johnston, R. J., Wainger, L., Saah, D., Maguire, L., Boyd, J., & Yoskowitz, D. (2017). So you want your research to be relevant? Building the bridge between ecosystem services research and practice. *Ecosystem Services*, *26*, 170–182.

Paula, J., & Bandeira, S. (2014). Maputo bay: the way forward. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem*, 419–427. WIOMSA.

Paula, J., Macamo, C., & Bandeira, S. (2014). Mangroves of Maputo bay. In S. Bandeira & J. Paula (Eds.), *The Maputo bay ecosystem*, 109–146. WIOMSA.

Pearce, D. W. (1993). *Economic values and the natural world*. Earthscan.

Permanent Service for Mean Sea Level (PSMSL). (2005). *Maputo' sea level*. PSMSL. https://www.psmsl.org/data/obtaining/stations/986.php

Piatek, M. A. (1981). *Mangrove crab, Scylla serrata, and its utilization with particular reference to Mozambique. A report prepared for the research and development of inland fisheries project*.

Poppy, G. M., Chiotha, S., Eigenbrod, F., Harvey, C. A., Honzák, M., Hudson, M. D., Jarvis, A., Madise, N. J., Schreckenberg, K., Shackleton, C. M., Villa, F., & Dawson, T. P. (2014). Food security in a perfect storm: using the ecosystem services framework to increase understanding. *Philosophical Transactions of the Royal Society: Biological Sciences*, *369*(1639), 20120288.

Pregado, A., & Masquine, Z. (2014). Distribution and abundance of the shrimp Fenneropenaeus indicus in Maputo bay. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem*, 289–290. WIOMSA.

Queiroz, L. de S., Rossi, S., Calvet-Mir, L., Ruiz-Mallén, I., García-Betorz, S., Salvà-Prat, J., & Meireles, A. J. de A. (2017). Neglected ecosystem services: highlighting the socio-cultural perception of mangroves in decision-making processes. *Ecosystem Services*, *26*, 137–145.

Raimundo, I. M. (2016). Food insecurity in the context of climate change in Maputo city, Mozambique: challenges and coping strategies. In *Climate change and food security*, 188–196. Routledge.

Rönnbäck, P., Macia, A., Almqvist, G., Schultz, L., & Troell, M. (2002). Do penaeid shrimps have a preference for mangrove habitats? Distribution pattern analysis on Inhaca Island, Mozambique. *Estuarine, Coastal and Shelf Science*, *55*(3), 427–436.

Rouault, M., Penven, P., & Pohl, B. (2009). Warming in the agulhas current system since the 1980's.

Geophysical Research Letters, *36*(12).

Scarlet, M. P., & Bandeira, S. (2014). Pollution in Maputo Bay. In S. Bandeira & J. Paula (Eds.), *The Maputo Bay Ecosystem*, 347–382. WIOMSA.

Scholte, S. S. K., Van Teeffelen, A. J. A., & Verburg, P. H. (2015). Integrating socio-cultural perspectives into ecosystem service valuation: a review of concepts and methods. *Ecological Economics*, *114*, 67–78.

Schumann, E. H., Cohen, A. L., & Jury, M. R. (1995). Coastal sea surface temperature variability along the south coast of South Africa and the relationship to regional and global climate. *Journal of Marine Research*, *53*(2), 231–248.

Severino-Rodrigues, Guerra, E., F., D. S., & Graça–Lopes, R. (2002). Carcinofauna acompanhante da pesca dirigida ao camarão-sete-barbas (Xiphopenaeus kroyeri) desembarcada na praia do Perequê, Estado de São Paulo, Brasil. *Boletim Do Instituto de Pesca*, *28*(1), 33–48.

Silva, R. de P. e, & Masquine, Z. (2014). Shallow-water shrimp fisheries in Maputo bay. In Salomão Bandeira; José Paula (Ed.), *The Maputo bay ecosystem*, 277–296. WIOMSA.

Simbine, L., Marques, C. G., Freitas, P. D., Samucidine, K. E., Gusmão, J., Tavares, C., & Junior, P. G. (2018). Metapenaeus dobsoni (Miers, 1878), an alien Penaeidae in Mozambican coastal waters: confirmation by mtDNA and morphology analyses. *Western Indian Ocean Journal of Marine Science*, *17*(1), 1–12.

Sousa, M. I. de. (1989). Boletim de divulgação: estado atual das principais pescarias da baía de Maputo. *IRevista de Investigação Pesqueira*, *1*, 1–69. https://aquadocs.org/handle/1834/31473

Sousa, M. I., & Gjøsaeter, J. (1987). Reproduction, age and growth of the round scad Decapterus macrosoma Blecker 1851, Carangidae from Mozambique. *Revista de Investigação Pesqueira*, *16*, 1–17.

Summers, J. K., Smith, L. M., Case, J. L., & Linthurst, R. A. (2012). A review of the elements of human well-being with an emphasis on the contribution of ecosystem services. *Ambio*, *41*(4), 327–340.

Swetnam, R. D., Fisher, B., Mbilinyi, B. P., Munishi, P. K. . T., Willcock, S., Ricketts, T., Mwakalila, S., Balmford, A., Burgess, N. D., & Marshall, A. R. (2011). Mapping socio-economic scenarios of land cover change: a GIS method to enable ecosystem service modelling. *Journal of Environmental Management*, *92*(3), 563–574.

The economics of ecosystems and biodiversity (TEEB). (2010).

Ulltang, O. (1980). Stock assessment study of the resources of shrimp and lobster off Mozambique. *Revista de Investigação Pesqueira*, *1*, 1–69.

United Nations (UN). (2020). *Em Moçambique, recuperação de ervas marinhas pode beneficiar comunidades locais*. ONU News. https://news.un.org/pt/story/2020/02/1705661

United Nations Department of Economic and Social Affairs (DESA). (2015). *The 17 goals*. https://sdgs.un.org/goals

UNEP/Nairobi convention secretariat. (2009). *Transboundary diagnostic analysis of land-based* *sources and activities affecting the western indian ocean coastal and marine environment*. *November*, 1–291.

Unnevehr, L. (2003). *Food safety in food security and food trade* (Vol. 10). International food policy research institute Washington, DC.

Westman, W. E. (1977). How much are nature's services worth? *Science*, *197*(4307), 960–964.

Worthington, T. A., zu Ermgassen, P. S. E., Friess, D. A., Krauss, K. W., Lovelock, C. E., Thorley, J., Tingey, R., Woodroffe, C. D., Bunting, P., Cormier, N., Lagomasino, D., Lucas, R., Murray, N. J., Sutherland, W. J., & Spalding, M. (2020). A global biophysical typology of mangroves and its relevance for ecosystem structure and deforestation. *Science Reporter*, *10*. https://data.unep-wcmc.org/datasets/48

6. ANNEXES

Table 6-1| Maputo population number as well as the equation of the growing rate of the population for each district of Maputo province. Population density is also detailed. Adapted from INE (1997, 2007, 2017).

DISTRICT	EQUATION	POPULATION			POP. DENSITY			AREA (KM^2)
		1996	2007	2015	1996	2007	2015	
Boane	y = 28962e0.6558x	52259	104128	170144	64	128	209	813
Magude	y = 35511e0.1989x	42472	54195	60756	6	8	9	7036
Manhiça	y = 102076e0.2348x	126095	160096	192419	53	67	81	2386
Marracuene	y = 16976e0.8552x	36652	86177	170859	52	123	243	703
Matola	y = 204075e0.6683x	372396	682691	1240038	1003	1839	3340	371
Matutuíne	y = 30669e0.1215x	34213	37939	42576	6	7	8	5392
Moamba	y = 30730e0.3295x	41338	57568	74805	9	12	16	4629
Namaacha	y = 25925e0.2212x	31636	42694	47108	15	20	22	2175
Maputo C.	y = 923968e0.065x	979632	1094628	1101224	2797	3125	3144	350
Total	-	1716694	2320116	3099931	73	97	130	23857