A contribution to Mozambique's biodiversity offsetting scheme: Framework to assess the ecological condition of mangrove forests

Final Report

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Maputo, August 2021

Table of Contents

Figures

Tables

Acronyms

BA	Basal Area
BOMP	Biodiversity Offsets Management Plan
CBD	Convention of Biological Diversity
CI	Complexity Index
D	Density
DBH	Diameter at Breast Height
EIA	Environmental Impact Assessment
EIA	Environmental Impact Assessment
GPS	Global Position System
IFC	International Finance Cooperation
IUCN	Internation Union for Conservation of Nature
IVI	Importance Value Index
MIREME	Ministry of Mineral Resources and Energy
MQI	Mangrove Quality Index
MTA	Ministério da Terra e Ambiente
MTA	Ministry of Land and Environment
NDVI	Normalized Difference Vegetation Index
NG	Net Gain
NGO	Non Governamental Organization
NNL	No Net Loss
QI	Quality I
QII	Quality II
QIII	Quality III
RCI	Regeneration Class I
RCII	Regeneration Class II
RCIII	Regeneration Class III
REDD+	Reduced Emissions for Deforestation and forest Degradation, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries
USA	United States of America
USD	United States Dolar
WCS	Wildlife Conservation Society
WIO	Western Indian Ocean

1. Background

Over the last decade there has been a significant increase in the exploitation of natural resources in Mozambique, as well as the development of infrastructure, which have resulted in several negative environmental and associated social impacts. Consequently, there is an urgent need to find ways to reconcile the economic development with the biodiversity conservation in Mozambique, upon which over 80% of the population directly depend for their subsistence.

A promising approach that has been used internationally to reconcile economic development and biodiversity conservation is the implementation by project developers of the mitigation hierarchy[1]. This approach requires project developers to first avoid, then minimize impacts, and restore biodiversity and ecosystem services in impacted areas. If significant but acceptable residual impacts persist, the hierarchy demands designing and implementing biodiversity offsets, according to an appropriate Biodiversity Offsets Management Plan, in order to achieve No Net Loss (NNL) or a Net Gain (NG) of biodiversity (BBOP, 2012; IFC, 2012; IUCN, 2016). A key driver for the adoption of the mitigation hierarchy is the compliance with environmental standards and guidelines established by financial institutions (e.g. IFC, World Bank, bilateral donors, etc.) and some sectorial associations (e.g. Equator Banks[2]).

There is a growing consensus around the importance of achieving NNL/NG goal in Mozambique, particularly in the business sector as well as within key ministries such as the Ministry of Land and Environment (MTA) and the Ministry of Mineral Resources and Energy (MIREME). Biodiversity offsetting is a valuable tool to mitigate negative impacts from large-scale and/or high-risk development projects and to attract investors committed to international best practices for biodiversity and ecosystem services management. Various private sector companies, particularly multinationals operating in Mozambique, have expressed a clear commitment to such international best practice standards.

A national compliance framework would assist investors in fulfilling their obligations to comply with the performance standards of financial institutions, while requiring the same level of environmental performance from all project developers. In 2016, the World Bank funded the development of a Roadmap for a No Net Loss Aggregated System, including Biodiversity Offsets for Mozambique. This roadmap provides technical guidance for the development of policy and implementation options in the country.

As the last step of the mitigation hierarchy, biodiversity offsets aim to achieve NNL/NG of biodiversity by explicitly addressing residual impacts from a project, focusing on habitats and species (BBOP, 2012; IUCN, 2016; Maseyk et al., 2016). However one of the major challenges in offsets is the difficulty in measuring ecological impacts and gains delivered

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[1] Mitigation hierarchy, commonly applied tool in Environmental Impact Assessments (EIAs) that includes a hierarchy of steps to limit impacts on biodiversity: Prevention (or avoidance), Minimization, Rehabilitation/ Restoration and Biodiversity Offsets. Adapted from BBOP 2012.

[2] 94 financial institutions in 37 countries have adopted the Equator Principles, including banks operating in Mozambique such as Standard Bank, Société General, Barclays and Nedbank.

through offset actions (BBOP, 2012; Bull and Brownlie, 2015; IUCN, 2016; Zambello et al., 2018).

Achieving NNL of biodiversity depends strongly on how biodiversity is defined and measured in a practical and transparent way so that their equivalence can be compared (Marshall et al., 2020). Commonly used offsetting metrics tend to focus on a measure of habitat condition which is calculated and weighted across several habitat features. This is combined with the area impacted and a ratio or multiplier value which may increase offset requirements to deliver equitable or greater biodiversity gains (Institute for European Environmental Policy, 2014; Marshall et al., 2020).

Globally, we are lacking simple generic methods that enable biodiversity losses and gains to be quantified in the context of biodiversity offsets that, in turn, can be used to transparently identify or audit development scenarios (Gibbons et al., 2016). This is because by definition, biodiversity is effectively infinitely diverse as it includes diversity within species, between species and of ecosystems (CBD 1992).

In this context, there is a need to develop a conceptual framework to assess the condition of key habitats and species in Mozambique in a pragmatic way which will inform an appropriated metric framework for determining losses and gains of biodiversity in the country. The biodiversity offsets program implemented by BIOFUND[3] and WCS through the COMBO Project[4] aims to support Mozambique in developing procedures for the implementation of the mitigation hierarchy. The program has been actively supporting the development of metrics for key habitats. The initially selected ecoosystems were miombo woodlands and mangrove forests, as these are widely distributed throughout the country (mangroves along the coastline), are habitat for many species and provide important services to local communities. However, due to human expansion and economic development, these ecosystems are being degraded and, in some cases, lost. The main threats to mangrove include unsustainable logging, urban expansion and coastal development. Mining and gas industry are currently a potential threat to mangroves (Macamo et al., 2016).

Mangrove forests were selected as a pilot ecosystem for testing this offsetting scheme for several reasons. They are globally critical ecosystems for biodiversity preservation and for the functioning of several coastal and marine ecosystems. Mozambique, on the other side, has the 13th larger area in the word, the 3rd in Africa and the first in the Western Indian Ocean Region, which indicates that the country has a major role in global picture (Spalding, 2010; Giri et al., 2011; Fatoyinbo and Simard, 2013).

Also the country holds several formations of regional and international importance, including the Zambezi delta, a RAMSAR site. At the national level, mangroves provide a number of ecological and socio-economic goods and services to coastal communities, including coastal protection, climate change mitigation through carbon sequestration, biodiversity, water purification, source of wood resurces, food security and supporting

[3]http://www.biofund.org.mz/
[4]http://combo-africa.org/

important economic activities, such as fisheries, aquaculture and salt production. Meanwhile they are threatened by several factors, coastal development and mining and gas industry being a major one.

In this regard, BIOFUND and WCS have requested the development of a conceptual model for mangrove forests, that is broad enough to allow assessment and reporting on mangroves ecological condition across the country, yet also including enough detail regarding the diverse interactions and factors in determining the health of the ecosystem to allow conservation programs and project developers to assess and report NNL and NG results.

This document provides a framework to determine the ecological condition of mangrove forests in Mozambique. This study had the following objectives:

1. To identify and analyse the metrics that are used to assess the ecological condition of mangrove forests;
2. To assess the applicability of such metrics for biodiversity offsets for mangrove forests;
3. To assess the options for improving such metrics (1 and 2) for quantifying biodiversity in the context of offsetting.

The report is organized in the following sessions:

1. **Background:** provides the context to the project.
2. **Brief description of mangrove forests:** provides a summary literature review of the ecological information on mangroves worldwide and in Mozambique.
3. **Methodological process:** provides an overview of international best practices, developing ecological condition indices for mangroves and describes the metric development for the case of Mozambique.
4. **Results and Discussion:** compiles and discusses the information regarding the ecological condition of mangroves and the metrics tested.
5. **Conclusion and Recommendations:** summarises project results and provides future recommendations.
6. **References:** provides a list of references used in this study.

2. Brief description of the mangrove forests

Mangroves are defined as a taxonomically diverse group of salt-tolerant, mainly arboreal (McLeod and Salm, 2006) intertidal communities of trees and shrubs distributed worldwide in tropical and sub-tropical coastal regions (Spalding et al., 1997; FAO, 2007; Giri et al., 2011). These plants developed specialized adaptations to live in the intertidal environment with variable salinity and tidally-driven inundation, strong winds and anaerobic mineral and organic soils (Kathiresan and Bingham, 2001; Hoghart, 2015). They developed unique structural, morphological and reproductive specializations, including aerial root systems (pneumatophores), salt-extracting leaves and viviparous water-dispersed propagules (Kathiresan and Bingham, 2001; Hoghart, 2015).

Mangroves are distributed within the tropics and subtropics, reaching their maximum development between 25°N and 25°S (Taylor et al., 2003, McLeod and Salm, 2006). Temperature is an important limiting factor but on regional and local scales variations in rainfall, tides, waves and river flow have a substantial effect on the distribution, diversity and biomass of mangrove forests (Alongi, 2002; Bosire et al., 2016). The largest extent of mangroves is found in Asia (42% of the global area) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%) (Giri et al., 2011; Page et al., 2011). Approximately 75% of mangroves are concentrated in 15 countries, Mozambique occupying the 13th position in the global ranking (Giri et al., 2011).

Mangrove ecosystems are recognized among the most productive and biologically important ecosystems in the world, as they provide valuable ecological, environmental and economic benefits for livelihoods of millions of people in coastal areas (Kathiresan and Bingham, 2001; FAO, 2007; Giri et al., 2011; Kauffman and Donato, 2012).

In terms of ecological benefits, mangroves support soil formation, photosynthesis, primary production, carbon storage, provision of habitat for fishery nursery, birds, and nutrients export (Cohen et al., 2013; UNEP, 2014). Mangroves also regulate ecological processes such as biological control, coastal protection, nutrient cycling, water quality regulation, erosion, wave attenuation, sediment accretion and maintenance of biodiversity (FAO, 2007; Cohen et al., 2013; UNEP, 2014).

Mangroves are also one of the most important carbon-rich forest types in the tropics and their importance in the global carbon sequestration is well recognized due to their high biomass density, productivity and carbon storage; mangrove forests can also be in the forefront within initiatives of marine and coastal resources sustainable use, also having appropriate payment for ecosystem services and REDD$^+$ initiatives (Donato et al., 2011; UNEP, 2014).

Despite their recognised importance, mangrove forests are among the most threatened ecosystems worldwide, with 35% of the original global area being degraded or destroyed since 1980. The current global rates of loss run between 1 - 2% per annum (Valiela et al., 2001). According to several studies, 11 of the 70 mangrove species (or 16%) are classified as threatened, and are on the IUCN Red List (Valiela et al.,2001; FAO, 2007; Donato et al., 2011; Cohen et al., 2013).

3. Mangroves in Mozambique

3.1. Country overview

With an estimated area of 3 050 km^2 of mangrove forests, Mozambique ranks 3rd in the African continent and 1st in the Western Indian Ocean, also holding extensive forests of regional and global importance (Giri et al., 2011; Fatoyinbo and Simard, 2013; Shapiro, 2018). Mangroves occur in distinct patterns along the 2 515 km long Mozambican coastline (INE, 2017).

The southern coast is dominated by coastal dunes and mangroves are scant, occurring in Maputo Bay, Limpopo Estuary, Inhambane Bay, Morrumbene and Vilanculos. The central area of the country is characterized by organic muddy soils and more than 20 rivers discharging into the Indian Ocean. This area is rich in mangrove forests with the most important formations at the Save River Delta, Zambezi Delta, Buzi River, Chinde, Marromeu and Bons Sinais Estuary (Barbosa et al., 2001). The northern coast goes from Angoche up to the Rovuma Estuary, and is dominated by corals. Mangroves occur in bays and other sheltered areas, as well as along the main estuaries. Some of the most important formations in this section include Pemba Bay, Quirimbas Archipelago and the Rovuma Estuary. All major coastal cities in the country (Maputo, Beira, Quelimane, Nacala and Pemba) are surrounded-by or have nearby mangroves (Macamo et al., 2018).

Figure 1. Mangrove forests in Mozambique. Source: WCS, 2021.

There are nine mangrove species in Mozambique, which are: *Avicennia marina* (Forssk.) Vierh., *Bruguiera gymnorrhiza* (L.) Savigny, *Ceriops tagal* (Pers.) C.B.Rob., *Lumnitzera racemosa* (Willd), *Heritiera littoralis (*Aiton), *Rhizophora mucronata* (Lam.), *Sonneratia* *alba* (Sm.), *Xylocarpus granatum (*K.D.Koenig) and *X. moluccensis* (Lam.) M.Roem., all common to the Western Indian Ocean Region (Bentjee and Bandeira 2007; Spalding *et al.* 2010). The number of true mangrove species increases from the south to the north. For instance, *S. alba* only occurs from Inhambane to the north and *X. moluccensis* has only been recorded at the Zambezi delta and Memba (Trettrin et al., 2016; Salomão Bandeira, personal observation). The mangroves also follow a specific zonation pattern: the terrestrial and seaward margins are usually dominated by *A. marina*. The seaward A. marina may be replaced by *S. alba* where it occurs. *Ceriops tagal*, *B. gymnorhiza* and *X. granatum* colonize the inner parts, while *R. mucronata* is commonest near muddy channels or other areas of limited salinity variation. In the transition between the terrestrial environment and the mangroves, *L. racemosa* and *H. littoralis* may occur, particularly when there is freshwater seepage (Macamo et al., 2016; Barbosa et al., 2001). Mangrove associated plant species include succulents (*Sesuvium portulacastrum*, *Salicornia spp.*, *Sarcocornia*), *Hibiscus tilliaceus*, and others.

Figure 2. Healthy *Rhizophora mucronata* stand with closed canopy. Lunga (Nampula province), September 2020. ©Celia Macamo.

Mangroves are also very rich in fauna species. Crabs constitute the most conspicuous group of fauna living in this habitat, but the diversity also includes other groups of crustacean (e.g.: shrimps), molluscs (bivalves and gastropods), insects, mammals, birds and reptiles (Paula et al., 2014). The mangrove fauna of Mozambique has not been described in detail, unless for a few sites such as Inhaca Island (Kalk, 1995; Paula et al., 2014). However it is widely acknowledged that the habitat provides home to or is visited by several species of special interest (endemic, rare, charismatic or endangered), with an emphasis on birds. Mangroves are also nursery for fish species, some of them threatened, such as sharks (e.g.: wedgefish Rhinidae family). Marine turtles have reportedly been seen at the Espírito Santo Estuary in Maputo Bay, while in the Save delta dolphins were spotted nearby the mangrove forest (Zacarias Nhantumbo, Célia Macamo, personal observation).

The mangroves of Mozambique provide an array of ecosystem services and important socio-economic goods to coastal communities (Macamo et al., 2016). Although the monetary value of such goods has yet not been fully assessed, some studies indicated that they make a significant contribution to the local economy (Machava-António et al., 2020). At the Zambezi delta it was found that mangrove related activities are the primary source of income for the coastal communities, and it was estimated that the resources are worth 1 026 582 480 USD/year in the Zambezi delta only (Hoguane et al., 2017).

Figure 3. Mangroves support fisheries, and provide income and food security to coastal communities in Mozambique. Praia Nova, Beira, February 2021. ©Celia Macamo.

Mangroves in Mozambique also support the fisheries sector (shrimp fishery being one of the most valuable mangrove-related fishery), an activity that provides a significant contribution to national economy. The artisanal fishing sector employs more than 400 000 people, while shrimp was the 9th most important product of export of Mozambique in 2017 (INE, 2018). The annual value of the mangrove-related industrial shrimp fisheries of the Sofala Bank (the most important fishing ground of the country) was estimated at USD million 50-60 in 2012 (FAO, 2017). Maputo Bay, the second most important fishing ground of the country, is also surrounded by mangroves (Paula et al., 2014).

Mangrove's role in coastal protection has been emphasized in several studies in Mozambique. At the Save delta it was demonstrated that mangroves protected the coastal village of Nova Mambone during cyclone Eline (Massuanganhe et al., 2015; Macamo et al., 2016). The importance of mangroves for climate change adaptation was also investigated, and it was demonstrated that they will have a crucial role in the most climate vulnerable areas in the coast (Cabral et al., 2017). During cyclone Idai (one of the worst to ever hit the country), mangroves were also acknowledged by communities at Beira town and Nhangau village in Sofala province as effective protectors of the coastline and infrastructures (Rufu Vengai, personal communication).

Mangroves also sequester and store carbon more than any other terrestrial ecosystem (Donato et al., 2011). In Mozambique there have been few studies assessing the amount of carbon stored in mangrove forests, but those conducted at Sofala Bay, Zambezi delta and Maputo Bay indicate that the storage capacity of these forests is within global averages, even if the forest has been significantly impacted by anthropogenic activities (Sitoe et al., 2014; Stringer et al., 2015; Magalhães, 2018).

Figure 4. Mangrove community reforestation site in Pebane, Zambézia. ©Denise Nicolau.

3.2. Threats to mangrove forests in Mozambique

Mangroves endure enormous pressure from human and climate impacts.

In Mozambique, threats are due to the clearance of mangrove forests for wood extraction (building material and for charcoal production), even though the commercial exploitation of mangrove wood resources is prohibited in the country (Macamo and Sitoe, 2017). This type of human disturbance has also been documented in protected areas such as the Pomene Reserve and the Quirimbas National Park (MITADER, 2016; Nicolau et al., 2017), where law enforcement is still deficient due to poor management capacity. Peri-urban mangroves are also threatened by the expansion of urban areas. In Maputo that has been seen at Costa do Sol, Bairro dos Pescadores, Mapulene and other neighbourhoods near the Espírito Santo Estuary, were large extensions of mangroves have been cleared to build houses (Paula et al., 2014). At Quelimane and Pemba towns clearing mangroves to build houses and implant salt pans is also common.

Mangroves are also impacted by extreme climate events, such as cyclones and heavy rains. In 2000, cyclone Eline hit the southern and central coast of Mozambique and caused severe impacts on people, coastal infrastructure and natural environment in the area between northern Inhambane and Beira. The cyclone and associated floods degraded about 400 ha of mangrove forests at Limpopo estuary and impacted 47.8% of the mangrove area at Save river (Bandeira and Balidy, 2016; Macamo et al., 2016). In 2019, for the first time ever recorded, two cyclones made landfall in the Mozambican coast during the same season. Cyclones Idai and Kenneth hit central and northern Mozambique, causing massive destruction, more than 645 losses in human lives and damage to human and natural infrastructure. The losses in mangrove forests were assessed at more than 2500 ha in the districts of Búzi, Dondo and Beira, while at Cabo Delgado (Ibo) some mangrove areas were completely cleared (UNDP, 2019; IUCN, 2020).

As the extractive sector rapidly grows, particularly in the last decade, it requires new support infrastructure, such as roads and ports, whose strategic location often coincides with biodiversity hotspots and mangrove occurrence sites (Bosire et al., 2016). Some examples in Mozambique include the building of a new port and the expansion of an old port that have cleared about 24% of the mangrove forest in Namelala Bay (Nacala, northern Mozambique). At the Rovuma estuary, residual impacts of gas exploitation could affect the nearby mangrove forest. It is also expected that the expansion of Beira Port in the coming years will claim a significant extension of the mangroves at the Buzi estuary[5]. In the Primeiras and Segundas Environmental Protected Area (PSEPA), off the coast of Nampula and Zambezia provinces, large mining projects of heavy sands exploitation have been impacting coastal and marine ecosystems, including mangrove forests, exposing local communities to high vulnerability to extreme climate events such as flooding, cyclones, heavy rainfall and droughts[6].

[5] https://www.slideshare.net/TristanWiggill/port-of-beira?next_slideshow=1
[6] http://www.biofund.org.mz/en/projects/apoio-as-ilhas-primeiras-e-segundas/

Mangrove forests perform valued regional and site-specific functions (Walters et al., 2008). Reduced mangrove area and health will reduce the accessibility to the ecosystem services described in the previous chapter and it will increase the threat to human safety and shoreline development from coastal hazards such erosion, flooding, storm waves and surges (Kathiresan and Rajendran, 2005; Dahdouh-Guebas et al., 2005; Williams et al., 2007).

Figure 5. Intensive and unsustainable mangrove logging in Mongicual, Nampula province. September 2020. ©Celia Macamo.

There is an urgency to reconcile economic development and biodiversity conservation in Mozambique in order to secure long-term ecosystem services provided by mangrove forests for current and future generations. Its critical to assess development projects' potential impacts and adequately implement the mitigation hierarchy. Therefore, future coastal development projects should be carried out in such a way that they protect the remaining mangrove communities and minimize the destructive impacts caused by human activity (Khan and Kumar, 2009).

4. Metrics within the biodiversity offset scheme

The mitigation hierarchy appears as a promising approach to bring together economic development and biodiversity conservation, and it is aimed at large-scale development projects[7] that cause impacts to biodiversity, including fauna and flora species. The mechanism aims to reach No Net Loss (NNL) or Net Gain (NG) through the application of a mitigation hierarchy that starts with avoidance, minimization, restoration, and as a last resource, biodiversity offsetting (BBOP, 2012; IFC, 2012; IUCN, 2016). Offsets are required to fully address the significant residual impacts of a project on biodiversity and such impacts must be calculated and then offset by activities to improve and protect the same type of biodiversity as that which would be lost or degraded under the project (Maseyk et al., 2016; Booth et al., 2019).

Biodiversity in its entirety is effectively impossible to be measured so a 'metric' or 'index' is used to represent, and provide a measure of overall biodiversity. Metrics are combinations of measurements, that together provide an assessment of the biodiversity value of a particular area. The metric allows the biodiversity impact of a development project to be quantified, so that the offset requirement, and the value of the compensatory action, can be clearly defined. Metrics are transferable between sites and, in some cases, habitats, allowing an impact on one habitat type to be offset with conservation action elsewhere, or involving a different habitat type and/or quality of habitat (DEFRA, 2012).

There are a number of different types of metrics used in offsetting schemes around the world. Some use single attributes but most use multiple attributes. In many cases, metrics also make use of a quantity measurement, for example land area adjusted in some way for quality (Eftec, 2010). There are no "off the shelf packages" suitable for all situations. The mechanism used depends on the characteristics of the biodiversity interests and the scheme's objectives. Examples of single-attribute metrics (or surrogates) include measures of vegetation density, cover, or biomass; density of seedlings; index of vegetation structural diversity, and others. Multiple attribute metrics make use of a number of different measures to come up with a single figure or index, and by nature are more complex.

A good biodiversity metric can help monitoring restoration success, for example, by assessing whether efforts to protect a species or ecosystems are successful. A metric also underpins the calculation of losses due to a development project and the gains (or compensation requirements) that will be needed to achieve goals such as NNL or NG and thus with determining the success of mitigation measures, including offsets.

One of the most used metric system is habitat hectares. This approach was originally developed for use in Victoria in Australia and is described in Parkes et al. (2003). Most metrics used for this purpose include information about *extent* – a measure of habitat area (e.g. the extent of an affected ecosystem or habitat) –*condition* – a measure of habitat condition (e.g. the health or quality of the affected habitat, including its typically associated fauna) – and *priority* – conservation concern or relative importance of the affected type of habitat or species.

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[7] Category A/A+ Projects according to Mozambican Environmental Impact Assessment Regulation 54/2015.

Figure 6. Massive mangrove mortality due to infrastructure development in Nacala, northern Mozambique. ©Celia Macamo.

Conceptually, metrics should be able to assess the capacity of an area of vegetation to provide the structure and functions necessary for the persistence of fauna and flora species that would be expected to occur at that location if it were still in what could be considered a natural state.

In this regard, Mozambique is working towards the development of a metric to assess mangrove condition that is robust enough and practical to be used throughout the country.

5. Methodological process

In order to design a metric to assess ecological condition of mangrove forests our approach comprised the following steps:

1. Compilation of global metrics used to determine habitat condition in biodiversity offsetting schemes;
2. Compilation and analysis of international mangrove assessment tools, with emphasis on the Western Indian Ocean Region and Mozambique. This stage was

crucial to understand the common practices on mangrove assessments, what kind of data are readily available and infer about human capacity and other resources availability. All type of mangrove assessment was included;

3. Compilation and analysis of international methods to assess the overall ecological condition of mangrove forests. This stage focused on understanding whether there are metrics for offsetting schemes in mangrove forests; and what methods are employed to assess the ecological condition of mangroves holistically;
4. Analysis of the methods identified in 3. This stage aimed at assessing the applicability of such methods in the Mozambican context;
5. Technical meeting with key national stakeholders. All findings were presented and discussed; recommendations to be considered the following stages were given by meeting participants;
6. Consultation with international experts, with similar objectives as in 5;
7. Conception of a new mangrove condition assessment tool, based on current mangrove assessment practices and commonly collected data in Mozambique;
8. Testing the metric with readily available data;
9. Validation at a national workshop with key stakeholders.

6. Compilation of worldwide metrics assessing habitat quality in biodiversity offsets schemes

The choice of a metric is complex and requires the integration of a number of biodiversity components. There has been considerable evolution in metrics over the history of offsets design. In early offset projects, area alone was the currency used: the area impacted was offset by at least an equal area elsewhere (King and Price, 2004). However, as the importance of considering ecosystem function grew, area alone was no longer considered adequate (Parkes et al., 2003; Quetier and Lavorel, 2011).

Several methods have been developed to supplement area measurements in order to account for multiple biodiversity dimensions such as the condition, quality, ecological function and integrity of ecosystems (Gonçalves et al., 2015).

Much of recent scientific literature attempts to deal with the multiple theoretical challenges of determining quality, often recommending ever more complex measurements and aspects for consideration (Bezombes et al. 2018 for example recommend the use of 107 distinct indicators). It is clear that there is a substantial divergence in biodiversity outcomes when using different metrics for calculating the gains required to offset the same development (Strange et al., 2002; Bull et al., 2014), and that no assessment method combines all the various challenges perfectly (Bezombes et al., 2017; Zambello et al., 2018).

Up to now, biodiversity offsets have operated locally or regionally, often on a case-by-case basis. Therefore, each offset scheme has developed its own methodology, considering its context and compensation goals. This situation makes difficult to measure and compare performance of different projects leading to low levels of implementation despite ambitious policy goals for offsets implementation (Gonçalves et al., 2015).

Technical issues such as metrics and exchange rules for offsets are only one of the challenges to be addressed in order to achieve NNL/NG in practice (Bull et al., 2013). It is important to provide methods for designing and quantifying appropriate offsets that are both pragmatic and defensible enough that they can actually be implemented based on available national capacity and environmental impact assessment (EIA) timelines.

Different methods focus on different target components of biodiversity and ecosystems depending on the specific target of the applicable NNL/NG policy (Quetier and Lavorel, 2011). Ribeiro et al. (2019) have revised a number of international systems for the miombo forest as described in the Table 1.

Table 1: List of international metrics assessed by Ribeiro et al, 2019 under the Miombo woodlands condition assessment for Mozambique

Number	Metric System	Reference
1	Wetland banking in the United States	FWS, 2003
2	Habitat and Resource Equivalency Analysis in the United States	Strange et al.,2002; Dunford et al., 2004
3	Habitat Hectare approach used in Victoria, Australia (Vegetation quality Assessment Manual)	Parkes et al., 2003
4	Brazilian Native Forest Protection System	Sparovek et al., 2012; Soares-Filho et al., 2014
5	Natura 2000 network of protected areas under the European Habitats directive	
6	Metric for Biodiversity Offsetting Pilots in England	DEFRA, 2012
7	Canadian fish habitat	Minns et al., 2001; DFO, 2002
8	South Africa's Western Cape offset guidelines	DEADP, 2007
9	Conservation Significance Index	Sawmy et al., 2014
10	Germany's Biotope Valuation	German Impact Mitigation Regulation- *Eingriffsregelung*
11	South Australia's Significant Environmental Benefit	Department of Water, Land and Biodiversity Conservation, State of South Australia, Australia
12	Switzerland's Module Assessment Method	Federal Office for the Environment – FOEN; Switzerland
13	Biodiversity Offsets Accounting Model for New Zealand: User Manual	Maseyk et al.,(2015)
14	Forest Integrity Assessment Tool	Proforest, HCV Resource Network and WWF
15	Madagascar Ambatovy mine metric (a redacted version of the Victoria habitat hectare approach)	BBOP Ambatovy case studies: Berner et al., 2009 and von Hase et al., 2014

According to our analysis, of the above methodologies generally use habitat quality to qualify a specific habitat condition or species-habitat condition for the purpose of achievement of No Net Loss and Net Gain, however, they don't provide a comprehensive analysis of habitat condition considering all complexities of an habitat and its ecosystem services.

As referred by Gonçalves et al. (2015), two of the most pressing conceptual issues associated with implementation of biodiversity offsets are the choice of metric and location. In general, most of the metrics use indicators to calculate an overall multiplication factor, which is then applied to the impacted area to determine the area of the offset. Since habitat condition is usually only one of these factors, the condition index is usually only a three to six-point scale.

Other methodologies usually then multiply area by the condition assessment in both the impact and offset sites to determine equivalence. Since habitat condition is the principle characteristic measured in these systems, it is generally a detailed process, leading to a precise condition score, often expressed in percentages.

Other methods assess specific species and tend to calculate the offset area based on the size needed to sustain a given population of specific species. Habitat quality is principally focused on the services it provides (e.g. food, shelter, breeding requirements) to these key species, and so it is these specific aspects that are quantified.

On the other hand, there is no single metric used to assess mangrove condition worldwide. In this regard, for the current assignment we have combined offset metrics with the existing health condition assessment tools for mangroves and adapt and test it for the Mozambican context.

7. Common practices on mangrove condition assessments: experiences from Western Indian Ocean (WIO) Region

Several approaches have been taken to assess condition of mangrove forests in WIO region, however relatively few published studies qualify the ecological conditions of the forest holistically, i.e., by combining several forest components such as biotic (fauna, flora), chemical and physical parameters and human transformation.

Most studies evaluate specific components of the ecological condition of the forest, usually forest structure, mapping and change detection, pollution, biomass and carbon assessments and primary productivity. A few others also look at the variation of physic-chemical parameters (Lawson, 2011; Satheshkumar and Khan, 2009; Krumme et al., 2012), impact of natural stressors (such as cyclones, tsunami, hail, diseases, etc.) and changes in weather patterns (Alongi, 2008; Macamo et al., 2016; Duke et al., 2017).

Remote sensing combined with Normalized Difference Vegetation Index (NDVI) have been considered powerful tools for analysing mangrove forests. Remote sensing is suitable for monitoring the spatial and temporal evolution of mangrove ecosystems because it is cost-effective, time-efficient, accessible to remote regions and non-invasive (Kuenzer et al., 2011). NDVI provides information on temporal variability of vegetation activity (Alatorre et al., 2016) and a direct significant relationship between NDVI and the forest condition (degraded vs healthy) has been found in some of those studies (Ibrahim et al., 2019a).

Remote sensing tools can be used to assess forest extent, species distribution, forest productivity over time, and other types of information (Ferreira et al, 2009; Alatorre et al, 2011a; Fatoyinbo and Simard, 2013; Macamo et al., 2016; Shapiro, 2018). The results accuracy can be further improved with intensive ground truthing (Alatorre et al., 2016; Macamo et al., 2016; Ibrahim et al., 2019). Despite being a useful management tool, mapping and change detection do not accomplish a comprehensive assessment of the mangrove ecological condition. In practical terms, a forest may be expanding while its ecological condition is degrading (LeMarie et al., 2007; Macamo et al., 2015).

Figure 7. Collecting soil samples for carbon assessment in mangrove forests. ©Celia Macamo.

There are also several studies that look at coastal pollution. Mangroves (and wetlands in general) have been regarded as dumping sites for a long time (Clough et al., 1983).

Currently, even though somehow protected in many countries, they still remain sewage repository in many coastal cities (Mandura, 1997; Bartolini et al., 2011; Penha-Lopes et al., 2011). Mangroves also receive nutrients and pollutants from different sources through rain and river runoff (Attri and Kerkar, 2011; Khattak et al., 2012). Pollution studies target mainly on the impact of heavy metals and nutrients on mangrove fauna and flora, while others also assess the content of pollutants in animal tissues, particularly of edible species (Wu et al., 2014). The impact of pollutants in physiological process of plants and animals is also investigated in some cases (Penha-Lopes et al., 2009; Rovai et al., 2013).

As the understanding of the role of mangroves in carbon sequestration and storage (a key role in climate change mitigation) improves, more studies on biomass assessment and carbon quantification are being conducted globally – mangroves are able to sequester up to four times more carbon than other mature tropical forests, and can store up to five times more carbon than tropical forests (Donato et al., 2011; Alongi 2014; Doughty et al., 2016). Carbon assessments focus on different carbon pools, including live biomass (above and below ground biomass), litter, and soil carbon (Kauffman and Donato, 2012). Being a key ecological service, carbon storage is largely used to monitor managed and restored forests, particularly when carbon offsetting is involved (Ibrahim et al., 2019ab). Carbon storage however, is not a complete indicator of the ecological condition of a mangrove forest, as in the vast majority of cases the largest amount of carbon is reserved in the soil, and subject to a slower depletion rate when compared to the speed of forest degradation (Ibrahim et al., 2019ab).

In the Western Indian Ocean (WIO) region, mangrove assessments usually cover 6 main topics: mapping and change detection, forest structural assessment, pollution, biomass and carbon assessment, productivity, and restoration (Table 2). Most of the assessments look at the structural attributes of the mangrove forest (number of species, height, diameter, leaf area index, forest fragmentation, regeneration potential, etc.), which are used to derive other indicators of the ecological condition, such as stand density, species diversity, size class distribution, and others. These parameters are used as proxy to assess the impact of disturbance by human and natural causes (Figure 2) (Okello et al., 2013; Bosire et al., 2014; Rajkaran, 2014). In general none of the reviewed studies set any benchmarks or categorization for any given forest parameter, therefore the comparison of two or more forests taking into account several parameters at the same time is complex.

In Mozambique most assessments focus on forest structural condition, mapping and change detection, carbon and biomass assessments and impact of climatic phenomena (e.g.: Bandeira et al.,2009; Macamo et al., 2015, 2016, 2017, 2018; Stringer et al., 2015; Trettin et al., 2016; Amade et al., 2019). Mapping and change detection is perhaps one of the commonest type of assessment of the Mozambican mangroves, with several studies conducted in some of the countries' major formations, such as the Maputo Bay area (de Boer, 2002; LeMarie et al., 2006; Macamo, 2015); the Limpopo estuary (Bandeira and Balidy, 2016); the Save Delta (Macamo et al., 2016); Sofala Bay (Sitoe et al., 2014; Uacane et al., 2016); the Zambezi delta (Shapiro et al., 2015); Pemba Bay and Palma district

(Ferreira et al., 2009; Macamo et al., 2018); and the Rovuma estuary (Ferreira et al., 2009). Most assessments largely lack field validation. Meanwhile, independent studies came up with similar figures for the national cover area around 3 000 km^2 (Fatoyinbo et al., 2008; Fatoyinbo and Simard, 2013; Shapiro, 2018). Little is known about mangrove ecological processes, physic-chemical characterization, productivity, nutrient content, etc., and basically there are no references of any attributes of a natural pristine mangrove forest in Mozambique. Additionally, mangrove associated fauna ecology and its relation with vegetation communities is seldom explored, and the available information is outdated, mostly from the Maputo Bay area and needs more in depth studies (e.g. Kalk et al.,1959, 1996; Macnae and Kalk., 1969, 1995; Paula et al., 2003; Macia, 2004; Cannicci et al., 2009).

None of the studies analysed during our bibliographic research comprehensively assesses the ecological condition of a given mangrove forest, simultaneously covering various ecological aspects such as biotic components (flora, fauna, plankton and other groups), hydrology, physic-chemical parameters, geomorphology, human interference, and others. Because all are restricted to one or a few aspects of forest ecology, none is able to fully assess the system, nor to satisfactorily reflect a reliable offset metric that covers various ecosystem services.

A biodiversity offset metric should be able to reflect important aspects of biodiversity in a given system (Bezombes et al., 2017; Zambello et al., 2018). Mangrove forests are very complex ecosystems, with numerous natural variations (UNEP, 2020). For example, a basin forest and a riverine forest have naturally different structural characteristics: while the basin forest grows in the inner parts of the forest with less influence from rivers or ocean, and therefore with relatively high salinity and reduced input of nutrients, the riverside forest tends to receive more nutrients and sediments of fluvial origin. These differences reflect in the specific composition of the two forests as well as in the structure (height and diameter) of the trees, forest productivity and ability to sequester and accumulate carbon, etc. Other parameters, such as nutrients, salinity and fauna composition can also differ, even if the two forests are at their optimum of ecological functionality. Thus, analysing only one parameter not only fails to consider other important components of biodiversity that must be considered in offsetting, but it can also lead to confusing classifications when comparing the condition of two forests, or the monitoring of the same forest over time. Thus, although the methodologies commonly used to assess the condition of mangrove forests are quite effective for single components, they are not in themselves comprehensive enough to be used as a mangrove metric for offsets.

Table 2. Relevant studies assessing mangrove condition in WIO region

Topic	Site	Studies description	Obs.
Pollution	**Tanzania:** Mtoni, Kunduchi, Mbweni, Chwaka, Makoba, Rufigi (Kruitwagen et al., 2008); Ras Dege, Mzinga Creek (Mtanga and Machiwa, 2008); Dar es Salaam, Zanzibar(Wolf and Rashid, 2008). **Mozambique:** Costa do Sol, Inhaca (Cannici et al., 2009). **Kenya:** Mombasa, Gazi Bay (Cannici et al., 2009) **South Africa:** Richards Bay (Naidoo and Chirkoot, 2004).	Heavy metal, organochlorine pollutants and organotin are assessed from sediment and animal samples (mangrove fish, polychaetes, molluscs). The effect of urban wastewaters in the mangrove ecosystem was also studied (particularly on fauna). In south Africa, the effects of coal dust on the photosynthesis performance of mangroves was assessed.	Only one aspect of the mangrove condition was assessed. Non-polluted forests can still have poor ecological condition. Good monitoring tool though for forest near port and industrial areas. No benchmarks are defined, however, several studies suggest that crabs and molluscs can be used as bio indicators.
Mapping and change detection	**Tanzania:** Rovuma estuary (Ferreira et al., 2009); Rufiji delta (Erftemeijer and Hamerlynck, 2005); **Mozambique:** Cabo Delgado province (Ferreira et al., 2009; Macamo et al., 2018); Maputo Bay (de Boer, 2002); Incomáti Estuary (LeMarie et al., 2006; Macamo et al., 2015); Zambezi delta (Shapiro et al., 2015); Save delta (Macamo et al, 2016). **Kenya:** Mida Creek (Gang and Agatsiva, 1992; Kairo et al., 2002; Alemayehu et al., 2014); the whole coast line (Kirui et al., 2013);Gazi Bay (Obade et al., 2004; Neukermans et al., 2008); Mombasa (Bosire et al., 2014). **South Africa:** Mngazana (Rajkaran et al., 2004); Western Cape (Hoppe-Speer et al., 2015); Eastern Cape (Adams et al., 2004).	Analysis of mangrove dynamics based on satellite imagery. Most studies use Landsat, while others use higher resolution images (e.g.: QuickBird). A few also used aerial photographs. Species distribution mapping is not common, but there are some studies.	It might be or not combined with in ground assessments of mangrove structure. Some studies combine with NDVI as a proxy for forest condition (ex.: Macamo et al., 2016).

	Madagascar: whole country (Giri and Muhlhausen, 2008). West Africa: Gambia to Casamance river (Carney et al., 2014).		
Structural assessment	**Mozambique:** Inhaca Island and Cabo Delgado province (Bandeira et al., 2009); Incomáti Estuary (Macamo et al., 2015); Pemba Bay, Vamizi and Palma District (Macamo et al., 2018); Costa do Sol, Bons Sinais estuary, Metuge (Amade et al., 2019). **Kenya:** Mida Creek (Gang and Agatsiva, 1992; Kairo et al., 2002); Mombasa (Mohamed et al., 2009; Bosire et al., 2014); Mtwapa (Okello et al., 2013). **South Africa:** Stainke et al., 2005; Mngazana (Rajkaran et al., 2005; Rajkaran and Adams, 2010; Rajkaran and Adams, 2012); Kwazulu Natal (Rajkaran et al., 2009).	Most studies collect data on: diameter-at-breast height (DBH), tree height (derive stand density, complexity index, dominant species; etc.) and regeneration potential.	There is no clear benchmarks for these parameters (most studies compare pristine and impacted sites). Regeneration potential assessements consider proportions below 6:3:1 or less than 2500 seddlings/ha unsustainable (FAO, 1994).
Biomass and carbon assessment	**Mozambique:** Zambezi delta (Stringer et al., 2015); Sofala Bay (Sitoe et al., 2014); Maputo Bay (Magalhães, 2018). **Kenya:** Gazi Bay (Slim et al., 1996; Kirue et al., 2006; Kairo et al., 2009; Huxham et al., 2017); Mida Creek (Alemayehu et al., 2014); Vanga (Gress et al., 2017). **Tanzania**: Carbon Stocks in Tanga, Tanzania (Mangora at ., 2016). **Madagascar**: Carbon Stock Estimates of Mangrove Ecosystems in Northwestern Madagascar (Jones et al., 2014).	Data on DBH and height are collected on site. Most studies consider live biomass and soil as the main carbon pools (therefore do not measure other pools). Comparisons between impacted and pristine sites are uncommon. Site and species specific allometric equations developed for a few sites (including site specific wood densities). Other studies tested different models, including remote sensing tools.	Biomass and stored carbon can vary greatly due to site specific factors, including geomorphology, species composition, and age of the forest. No benchmarks are defined for each type of forest. There are however a few regional global ranges.

Productivity	**South Africa:** Mngazana estuary (Rajkaran and Adams 2007). **Mozambique:** Costa do Sol and Inhaca (Fernando and Bandeira, 2008). **Kenya:** Tudor Creek (Mohamed et al., 2008)'; Mida Creek (Gwada and Kairo, 2001).	Most studies quantify the amount of litter that is produced, comparing impacted and non-impacted (pristine sites). Rajkaran and Adams (2007) also estimates a sustainable wood extraction rate that would have minimal impact in the forest sustainability.	No benchmarks defined.
Mangrove restoration	**Kenya**: Gazi Bay (Crona and Ronnback, 2007; Ronnback et al., 2007; Bosire et al., 2003; Bosire et al., 2005; Bosire et al., 2006; Tamooh et al., 2008; Wang'ondu et al., 2014). **Mozambique:** Limpopo estuary (Bandeira and Balidy, 2016).	The majority of published restoration studies in the WIO region were conducted in Gazi bay, and compare forest structure and the provision or return of ecological and socio-economic services (e.g.: productivity, litter fall and degradation; poles/wood provision; nursery role) between natural and planted stands; factors influencing plantation success rates; change detection; etc. No benchmarks are set for any of the services, only relative comparisons being made. Exception for natural regeneration.	Most parameters are similar to those used for structural assessments previous mentioned.

8. Mangrove condition indices: a worldwide overview and applicability in Mozambique

In this chapter, four methodologies for assessing the ecological condition of mangrove forests were selected, and their feasibility and applicability in Mozambique were analysed as described in Table 3. Results were discussed in a stakeholders workshop held in December 2019 in Maputo city in collaboration with representatives from government, academia, private sector, NGOs, protected areas, and other interested parties.

In our literature review we only found two sites where a quality index for mangrove forests had been developed. These are the Matang mangrove forests (Ibrahim et al., 2019a) and Tampa Bay, USA (Wilson, 2009). In both studies indicators that measure the quality of main attributes such as hydrologic flow, water quality, soil, biota and socioeconomic livelihood were selected upon an analysis of the relationship with the ecosystem quality. Thus, the overall Mangrove Quality Index (MQI) was obtained based on the score of ecosystem-socio-economic indices used to indicate a range from the most pristine conditions to the most impacted. The major difference between these two studies remains in the fact that Ibrahim et al. (2019) used a list of more complex variables which were also selected based on standardized procedures, while Wilson (2009) selected a shorter list of ecosystem-socio-economic indicators (Table 3). Both methods were considered in our analysis.

The third method was structural characterization of mangrove forests, which is a commonly methodology used in Mozambique (and the WIO Region) to assess the conservation condition of mangroves (Kairo et al., 2002; Bosire et al., 2014; Macamo et al., 2018). The method consists of collecting structural data (mostly related to forest structural parameters) that are used to describe the specific composition, dominance and frequency of species, complexity of the forest, potential for regeneration, among others. These parameters can then be used to monitor forest structural condition or to compare two or more forests, provided they have similar geomorphology and general environmental characteristics (e.g. temperature).

The fourth method was the Normalized Difference Vegetation Index (NDVI), a measure of the photosynthetic capacity of the plants and of the resistance of leaves to water vapor transfer (Ruimy et al., 1994). Thus, high NDVI values are indicative of high vegetation activity (Alatorre et al., 2016). NDVI is an indicator of vegetation health, because degradation of ecosystem vegetation, or a decrease in green, would be reflected in a decrease in NDVI value (Meneses-Tovar, 2011). Therefore, a negative trend in NDVI in the observation period is considered as a sign that the mangrove forest health decreases. NDVI have been widely used to understand mangrove forests dynamic along the time worldwide (Meneses-Tovar, 2011; Alatorre et al., 2016) including in Mozambique (Macamo et al., 2016).

Table 3. Comparing MQI methods (Wilson, 2009 and Ibrahim et al., 2019b), structural analysis and NDVI

	Methods			
Index name	**Mangrove Quality Index**	**Mangrove Quality Index**	**Structural analysis**	**Mapping and NDVI**
Reference	**Wilson (2009)**	**Ibrahim et al. (2019b)**	**Kairo et al., 2002; Bandeira et al, 2009; Trettin et al., 2016**	**Ruimy et al. (1994)**
Site where created	Tampa Bay, Florida (USA)	Matang, Malaysia	WIO region, Asia, South America	Global
Selected variables	Biotic: composition and abundance of mangrove species, crab holes; neighbouring land use Soil: organic content; sediment composition Water: turbidity and chlorophylla Hydrology: neighbouring land use; modifications; mosquito ditch density	43 on total: biotic (5); soil (8); marine-mangrove (10); hydrology (14) and socio-economy (6) Biotic: above ground biomass; crab abundance Soil: soil carbon; soil nitrogen marine-mangrove: n of phytoplankton species; n of diatom species Hydrology: dissolved oxygen; turbidity socio-economy: time spent; education	Measures structural parameters of a mangrove forest includes tree diameter and height; quality of poles; human cut pressure; regeneration potential; crab holes	Forest cover/leaf reflectance
Selection of variables	Based on wetland function indicators	Based on PCA	Based on the study needs	Software requirements
Field and material requirements	probes (ex. To measure pH, dissolved oxygen, etc.)	probes (ex. To measure pH, dissolved oxygen, etc.)	Tree calliper, graduated stick or clinometer, ropes, measuring tape	Satellite imageries remote sensing software and equipment (ex. GPS, computer, etc.), qualified personnel

Validation	Based on GIS and field observations	Results validated with GIS mapping and NDVI	Based on GIS and field observations	GIS validation
Strengths	Integrates different components of the ecosystem	Integrates different components of the ecosystem	Easy to apply and to monitor Low cost Benchmarks defined for regeneration potential Benchmarks for human pressure can be easily defined in terms of % Complexity index can be used to compare sites with similar ecological	Easy to apply and monitor Positive results/correlation when tested against MQI by Ibrahim et al (2019)
Weakness	Skilled personnel to collect data (probes) and phytoplankton/diatom identification and/counting; Complex integrated formula	Skilled personnel to collect data (probes) and phytoplankton/diatom identification and/counting; Complex integrated formula	Site specific variabilities may influence the results in a non-quantifiable way; benchmarks may vary according to site specific conditions It only considers one aspect of the ecosystem (forest structure)	No benchmarks defined for the different levels of degradation
Testing location	Only in Florida (USA)	Matang (Malaysia)	Throughout Mozambique	Save delta (Mozambique) by Macamo et al., (2016) Gulf of California (USA) by Alatorre et al., 2016
Applicability for Mozambique	Applicable (3) Highly skilled personnel expensive capacity building	Applicable (3) Highly skilled personnel expensive capacity building	Applicable (1) Low skilled personnel Easy to build capacity.	Applicable (2) Requires skilled personnel Easy to build capacity

	Expensive field and laboratory material (probes) Quality control might require field visits a skilled personnel (3)	Expensive field and laboratory material (probes) Quality control might require field visits a skilled personnel	Cheap and accessible field material Quality control might require field visits	Satellite images can be acquired from freely available sources Easy quality control

The **Mangrove Quality Index (MQI)** developed in Florida and Tampa Bay is an easy and valuable tool to quantify human impact and monitor quality of mangrove forests. The method provides a comprehensive and integrative approach combining ecological and socio-economic attributes to measure the overall performance and health status of the ecosystem by exploring a range of key biological, hydrological, ecological and socio-economic perspectives covering the whole range of conditions from disturbed to pristine states. However, there would be a few challenges to its implementation in Mozambique. Firstly, it requires a benchmark and data collection for a range of indicators and variables that can be integrated into a local based MQI, which are currently not available in Mozambique. It also requires high expertise in areas that are underdeveloped in Mozambique (e.g.: phytoplacton and diatoms identification), specific technology and local capacity in operating the equipment and interpreting the results. Although this resources could be built in the country, it does not seem realistic that this will happen within the timeframe of the implementation of the first offsetting projects, which are expected for the next few years.

Mangrove structural assessments are based on forest structural attributes, mainly species diversity, stand density, basal area, mean height, regeneration potential (proportion between seedlings, saplings and young trees), tree phenology, the quality of the main trunk (as indicative of the environment quality and selective logging) and mangrove cut level (Kairo et al., 2002; Bandeira et al., 2009; Amade et al., 2019). These variables are measured in most of the mangrove assessments in Mozambique and in Western Indian Ocean region (Rajkaran et al., 2004; Okello et al., 2013; Bosire et al., 2014). The approach provides very useful information, particularly on the purely forestry management perspective in those areas where mangrove wood resources are intensively used. For instance, based on this information it is possible to anticipate whether selective wood extraction has changed the forest natural structure (Figure 2), or if the natural regeneration capacity of the forest has been altered (FAO, 1994).

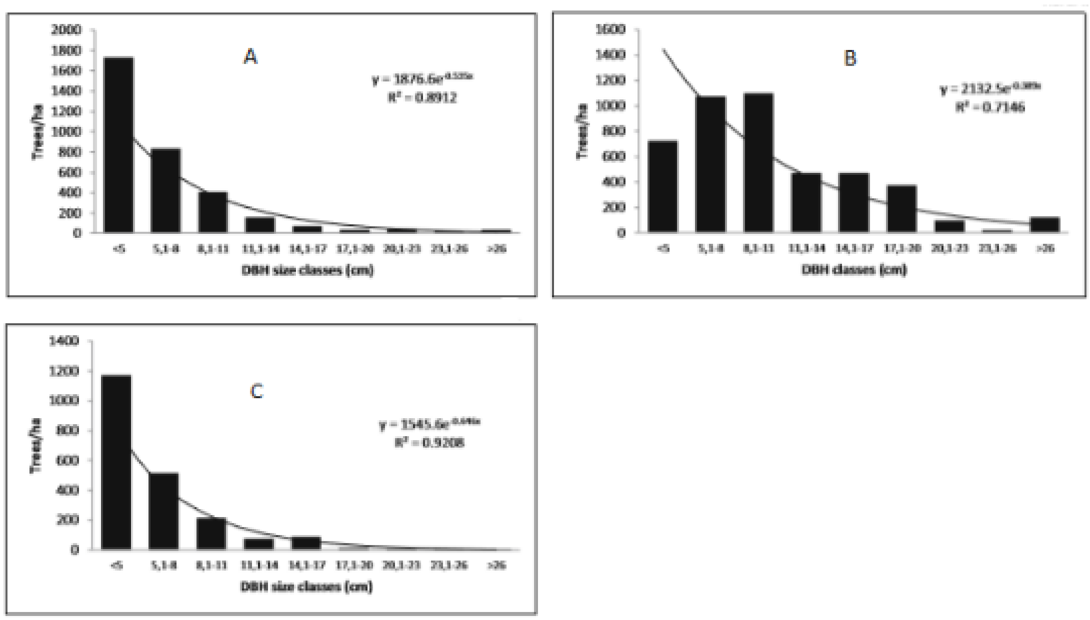

Figure 8 DBH size class distribution graphs for 3 sites in Mozambique. According to the results of the study, all sites were impacted by human action. However, B (rural Island) was the most impacted, followed by C (rural) and A (peri-urban). These are confirmed by the changes in the curve. Note missing classes in A and C (despite following the J trend) and how B does not follow the J shape.

The main downfall of this method is that there is currently no way to integrate the various components analysed, allowing the classification of forests in different levels of condition. Therefore, the comparison between different forests or the monitoring of the same forest remains confusing, since the fragmented analysis of the components does not clearly show the trends. A forest can, for example, increase the number of species but decrease the density of trees. Or increase the density of trees but reduce the regeneration potential. The method also does not assess abiotic factors, nor biotic components other than vegetation. It is also necessary to identify benchmark values for Mozambique, which may vary depending on the type of forest. However, the method is very accessible and requires little training. Based on available data it is possible to create benchmarks, which can be updated as more data is collected in the country.

9. Developing a metric to assess mangrove condition: a tool to support biodiversity offsets scheme in Mozambique

A metric to assess mangrove forests condition in Mozambique that can be applicable for biodiversity offsets, has to consider the following aspects:

- The need to create an accessible tool to assess mangrove condition in Mozambique for project proponents, practitioners, regulating agencies and other stakeholders, taking into account the country's human and financial capabilities;
- The need to integrate key components of mangrove ecosytem that contribute to an optimal ecological functioning of the ecosystem. In this regard, it was taken into account that mangrove forests are a very complex ecosystem, providing a wide range of ecological and social services that cannot be accurately reflected in a single metric;
- The possibility of developing a mangrove metric that can be useful and improved as knowledge about mangroves in the country is enriched, thus making the metric increasingly robust;
- The need to create a metric that could be readily tested and validated with existing data, or data that could be easily collected within the scope of the project's implementation;
- The fact that the condition of an ecosystem is a priority criteria for a “like for like or better” offset system.

For the development of this metric it is assumed that structurally healthy mangrove forests are capable of providing optimal key ecosystem services, such as maintenance of biodiversity, carbon storage, thermal regulation and nursery (Kathiresan and Bingham, 2001), while in degraded and human impacted forest such services are limited. Moreover, such services benefit a wide range of stakeholders that go beyond local communities, and therefore are appropriate for offsetting at a national scale.

Thus, the metric developed is largely based on the methodologies currently applied on mangrove ecological assessments in Mozambique and many countries in the WIO region (emphasis on Kenya, Tanzania, Madagascar, and South Africa). This also creates a solid basis for testing the metric in these countries, where Mozambique has several partnerships in the context of sustainable management and protection of mangrove forests. Next we present the methods commonly used to asses the structure of mangrove forests, and based on which the metric for mangroves biodiversity was developed.

9.1. Common structural parameters used to assess mangrove condition

The condition of the mangrove forest is usually assessed using the following parameters:

9.1.1. Structural assessments

Several aspects can be analysed in a mangrove structure assessment. In Mozambique and WIO region the commonest are species identification, average height, average diameter at breast height and regeneration (DBH).

These parameters are then combined into forest structure indicators, such as stand density, absolute and relative species dominance and frequency, species ecological importance, diameter and height size class distributions, basal area, forest biomass, forest carbon, forest complexity index and others (Kairo et al., 2002; Kauffman and Donato, 2012; Stringer et al., 2015; Trettin et al., 2016).

The approach consists in setting several 10 x 10 quadrats along a transect perpendicular to the coast line (to reflect the forest zonation pattern) or randomly scattered in the forest (Bandeira et al., 2009; Bosire et al., 2014; Amade et al., 2019). All trees within each quadrat are identified to species, and its diameter and height measured.

For the purpose of the metric developed in this study, it is important to understand:

a. Stand density – which measures the number of adult trees that occur per unit area. Stand density is usually presented in hectares, following the formula below:

$$\textbf{Stand density: D (trees/ha)} = \frac{N}{A}$$

Where,

D = stand density

N = number of trees within the quadrat (unit area)

A = sampled area

b. Basal area – defined as the total cross-sectional area of all stems in a stand measured at breast height, and expressed as per unit area. The formula is:

$$\textbf{Basal area: BA}=\frac{\pi DBH^2}{4}cm^2$$

Where,

BA - Basal area

π = 3,14 area

DBH - diameter at breast height average

c. Mean height and mean DBH – this is basically the average of all tree height and all tree DBH. It is an important characteristic to describe the forest structure.

d. Complexity index – a forest structural complexity index is a mathematical expression that summarises the effect of the forest structural attributes in a single number. Being a summary of a large pool of structural attributes, the complexity index is a reliable indicator of stand level biodiversity and rank stands in terms of their potential contribution to biodiversity (McElhinny 2005). In mangroves assessment the Complexity Index developed by Holdrighe (1974) is commonly used, which combines the basal area, stand density, height and number of species according to the formula below:

$$CI = \frac{s \; x \; D \; x \; Ba \; x \; h}{100000}$$

Were,

s = number of species

D = stand density

Ba = basal area

h = mean height

Figure 9. Measuring mangrove *Rhizophora mucronata* diameter at breast height. Angoche, Nampula. ©Denise Nicolau.

9.1.2. Forest Regeneration Potential

The forest regeneration potential assesses the establishment of new seedlings after a forest has been disturbed, whether by a natural or human induced factor. The following factors can reduce the forest regeneration potential (Hamilton and Snedaker, 1984; FAO, 1994; Dahdouh-Guebas et al., 1999; Duke, 2001; Clarke and Kerrigan, 2002):

- Incomplete removal of overwood and excessive wood debris

- Excessive logging
- Unfavourable soil conditions
- Excessive tidal wash (due to the removal of protective fringe trees)
- Unfavourable environmental conditions (ex.: salinity, sedimentation, erosion)
- Weed competition (e.g.: reeds)
- Absence of seed bearing trees
- Propagule predation

To assess the forest regeneration potential, all seedlings (juveniles with less than 2.5 cm diameter and 300 cm height) within a quadrate are identified to species-level and counted. They can also be classified into 3 categories or regeneration classes (RC) according to height: RCI: <40cm height; RCII: 40 - 150cm height and RCIII: 150 - 300cm height (Kairo et al., 2002; Bandeira et al., 2009).

In general, the number of seedlings decreases from RCI to RCIII, as the first class is more vulnerable to predation and other environmental pressures. With these measurements, one can identify the most successful regenerating species and whether the forest has enough understory to ensure its continuity.

Figure 10. Mangrove natural regeneration stand in Pebane, Zambézia. ©Denise Nicolau.

9.1.3. Quality of poles

This parameter assesses the quality of existent poles in a forest according to one of the main use of mangrove wood resources in Mozambique, which is wood extraction. The main trunk of all adult tree is classified as straight (quality 1, or QI), semi-straight (quality 2, or QII) and crooked (quality 3, or QIII). Basically this measure gives information on the amount of wood available in a forest for human use, and alone it may not be a good indicator of the forest conservation condition. Mangroves can grow crooked or stunted due to natural causes, such as high salinity and nutrient poor soils. However, logging tends to be selective in terms of species and pole form. Therefore, when combined with other parameters (such as human cutting pressure) it can also support management decision making.

9.1.4. Human pressure (cutting)

To assess human pressure, all adult trees (DBH> 2.5cm) contained within the 10m x10m quadrat are observed, counted and classified in the following categories (Bandeira et al., 2009):

- Intact: trees with no visible cut
- Partially cut: trees with lateral brunch cut, however 50% of branches remain intact
- Severely cut: when 50% of more of tree brunches are cut
- Stumps: for trees fully cut in the main trunk
- Die back: for trees that died from other causes, such as disease, sedimentation, etc

The density of each class provides a clear indication of the human pressure in a forest, mainly by the local communities (high or low density of cut trees); of the management practices (e.g. whether trees are cut in block or dispersed; or if the communities cut only branches and not the entire tree, which is less damaging to the forest health when the species can sprout), or the existence of a natural threat (lots of die back). It can also indicate the preferred species and sizes for cut. Based on this information, adequate decision making for sustainable management can be achieved.

Figure 11. Stumps in a mangrove stand in Angoche, Nampula. ©Denise Nicolau.

9.2. Mangrove Conservation Index for Mozambique

The development of this metric was based on the above described mangrove structural parameters, and it assesses the forest conservation condition. It does not assess the overall ecological condition, as physic-chemical parameters are not included, however we consider it a useful metric assuming that a healthy mangrove forest in the best ecological conditions will be able to provide successful ecosystem services such as coastal protection, carbon sequestration and storage, biodiversity, and others. The application of this index requires basic knowledge of mangrove ecology to avoid comparing forests whose difference derives from geomorphological differences, for instance (e.g.: fringing mangroves vs. riverine mangroves) as well as understanding the local drivers.

The structural parameters that were used to develop the Mangrove Conservation Index for Mozambique were: tree height (meters), tree basal area (m^2/ha), number of species, stand density (trees/ha), seedling density (ind/ha) and human exploitation. We developed three sub-indices obtained from (1) an adjustment of the complexity index; (2) the forest regeneration potential and (3) human and nature driven mortality.

9.2.1. Sub-index 1: Adjusted Complexity Index

For the purpose of the Mangrove Conservation Index, we logaritmized the formula so that the values of the index would fall within a limited range to facilitate ranking. We then defined benchmarks of structural parameters for the "best" and "worst" forest, based on data collected in previous forests surveys at healthy and degraded sites, such as the Costa do Sol, Zambezi delta, Limpopo estuary and Pemba Bay to find maximum and minimum values for height, basal area and stand density (Fatoyinbo et al., 2008; Bosire et al., 2012; Trettin et al., 2016; Macamo et al., 2018; Amade et al., 2019). These benchmarks were found to be similar to those in other mangrove forests in the region (Okello et al., 2013; Bosire et al., 2014). The maximum number of species is that of the country (Macamo et al., 2016).

Table 4. Complexity index (CI) benchmarks for "the best" (highest) and "the worst" (lowest) mangrove forest in Mozambique.

Structural parameter	Country benchmark		Reference
	Lowest	Highest	
Number of species	1	9	Bandeira et al., 2009; Macamo et al., 2015; Macamo et al., 2016; Amade et al., 2019
Stand density (tree/ha)	2 500	6 000	Bandeira et al., 2009; Macamo et al., 2015; Macamo et al., 2018; Amade et al., 2019
Basal area (m^2/ha)	0.75	60	Bandeira et al., 2009; Amade et al., 2019
Mean height (m)	1	35	Bandeira et al., 2009; Fatoyinbo et al., 2008; Bosire et al., 2012; Amade et al., 2019
ACI	7.5	18.5	Proposed in the present study

The final formula for the Adjusted Complexity index is:

$$\mathbf{ACI = Log_e (s*d*b*h)}$$

were:

ACI = complexity index

s = number of species

d = stand density

b = basal area

h = mean height

Five categories for the complexity index from very low to very high where then defined. Therefore, forests with a fewer number of species, lower basal area, lower height and lower stand density will tend to have a lower complexity index (Loria-Naranjo et al., 2014). In general, the better the condition of a forest, the higher the complexity index.

Table 5. Benchmarks for the Adjusted Complexity Index in mangrove forests.

Adjusted Complexity Index	Range	Score
Very high	]16.3 – 18.5]	5
High	]14.1 – 16.3]	4
Average	]11.9 – 14.1]	3
Low	]9.7 – 11.9]	2
Very low	]7.5 – 9.7]	1

Comments and considerations regarding the ACI:

- The logaritmization of the index was useful for its values to fall within a limited range. However logaritmization skews the data. Attempts to overcome this limitation (e.g.: adition and weightning of variables) were not successful. Other options, such as normalizing the data, should be tested in future studies;
- The benchmarks can and should be adjusted according to the type of forest. In Mozambique we identified up to 4 mangrove types which should have distinct structural characteristics. These are: fringe mangroves, reverine mangroves, basin mangroves and dwarf mangroves[8];
- The benckmarks should also be updated as more information is collected in the country;
- The maximum number of species that occur in the country is 9. However, according to the available data, the vast majority of Mozambican forests have between 4 and 6 species and this does not limit their ecological functionality. Therefore, lowering the benchmark to 6 (instead of 9) could be a more realistic option;

[8] See annex 2 for definition and ecological differences between the four types of mangrove forest

9.2.2. Sub-index 2: Regeneration Potential Index

For the regeneration stock of a forest to be considered adequate, it must correspond to the proportion 6:3:1 for (seedling to saplings to young trees) (Chong, 1988). However, several variations to this proportion may occur, depending on the forest age and conservation. Some of these are:

- For adequate natural regeneration, a minimum of 2500 seedlings/ha is necessary in a young stand (FAO, 1994);
- Slighlty disturbed forests (e.g.: small scale logging; natural death of a large tree, etc.) may have even higher regeneration stocks, particularly for RCI. Disturbances can create canopy gaps that facilitate the establishment of new seedlings, as competition for sun and nutrients is reduced (FAO, 1994). In this scenario, the typical relative abundance between seedlings, saplings and small trees is seedlings > saplings> small trees;
- However, disturbances at a large scale (e.g.: cyclones, extensive logging, fire, desease, etc.) may have the opposite effect, as large canopy gaps may change soil properties (eg.: salinity and temperature) and impair the establishment of new seedlings. Disproportionate losses of adult trees can also reduce the forest's ability to produce seeds. In such cases, RCI may therefore attain low densities;
- In mature forests, the stocking density can reduce to 788 seedlings/ha or less (21-30 years old) (FAO, 1994);

As RCIII is the effective regeneration stocking and represent 10% of the total regeneration potential; the benchmark was set in the proportion of RCIII to the sum of RCI and RCII; ie: RCIII:(RI+RII) = 0.11. A decision matrix was then created, considering the 3 most frequent scenarios:

Scenario A: RCI > RCII> RCIII

This scenario is common to young forests or slightly disturbed. The regeneration potential is classified in 5 categories, with a score that varies from 1 to 5 (Table 6).

Table 6. Benchmarks to assess the mangrove forest regeneration potential in young or slightly disturbed forests. The benchmarks were obtained by dividing RCIII per (RCI + RCII).

RCIII:(RCI+RCII)	Benchmark	Score
High	]0.088 – 0.110]	5

Sustainable	]0.066 – 0.088]	4
Worrying	]0.044 – 0.066]	3
Unsustainable	]0.022 – 0.044]	2
Low	]0.0 – 0.022]	1

Scenario B: RCIII > (RCI+RCII) in young or disturbed forests

If the sum of RCI and RCII is lower than RCIII, it means that seedlings mortality rate is very high. In that case we should consider in the formula the density of RCI only. In general, if RCI density is above 2500 seedlings/ha, the forest shall be sustainable (FAO, 1994). Nonetheless those forests need to be studied further to understand the cause of the high mortality rates, which is in general a red flag for the forest in the medium and long term. Therefore the score ranges from 1 to 3. Usually artificial planting is recommended if the situation remains for 3 years or more (FAO, 1994).

Table 7. Benchmarks for the mangrove forest regeneration potential when RCIII > (RCI+RCII) in disturbed forests

Seedling density (RCI only)	Benchmark RCI/ha	Score
Sustainable	> 2500	3
Worrying	]1000 – 2500]	2
Unsustainable	]0 – 1000]	1

Scenario C: RCIII > (RCI+RCII) in mature low-disturbed forests

In mature forests (large dispersed trees, high canopy cover of 70% or more), the density of seedlings, saplings and young trees is very low or virtualy inexistent, mainly due to the high competition for sun which is high in closed canopy forests. In such case, a score of 4 or 5 should be attributed depending on whether signs of disturbance are observed or not in given 20 x 20 m area. Signs of disturbance include those of natural (eg. sedimentation, die back) and human (logging, land use change) causes.

Table 8. Benchmarks for the mangrove forest regeneration potential in mature low-disturbed forests

Forest condition	Score
No signs of disturbance in a 20 x 20 m area	5
signs of disturbance in a 20 x 20 m area	4

The figure below summarizes the decision matrix for the regeneration potential:

Forest condition	Young/low disturbed forests	Highly disturbed young/mature forests	Mature undisturbed forests
Indicator	RCI > RCII> RCIII	RCIII > (RCI+RCII)	70% canopy cover
How to score	RCIII/(RCI+RCII)	RCI 0 - 2500	Signs of disturbance
Score range	1 - 5	1 -3	4-5

Figure 12. Decision matrix to assess regeneration potential in a mangrove forest.

Comments regarding the regeneration potential index:

- The adition of classes (RCI and RCII) may dilute important information. For instance, if RCII > RCI but the sum of these classes remains higher than RCIII, that information will not be reflected in the index. However RCII being higher than RCI might be indicative of a disturbance;
- Ideally the best way to assess the reproduction potential of a forest would be to asses how near or far a given forest proportion is from the ideal 6:3:1. Several attempts were made for this approach during the course of the project, however none produced satisfactory results.

Figure 13. Mature *Avicennia marina* stand, showing saplings growing only in the canopy gaps. Mussoril, Nampula. ©Celia Macamo.

9.2.3. Sub-index 3: Intactness Index

This sub-index considered one of the biggest mangrove threats in Mozambique and the WIO region, which is wood extraction. It also contemplates tree die back, which may be human induced or caused by natural phenomena. Either way, massive die back may have a significant impact in the forest ecological functioning, therefore it should be accounted for. Trees can be classified as (1) Intact, (2) Partially cut, (3) Severely cut, (4) Stumps and (5) Natural death. This sub-index considers the sum of the percentages of severely cut trees, stumps and natural death (CSD), as indicative of deforestation and/or degradation.

Table 9. Reference values for forest intactiness in a mangrove forest in Mozambique

Forest category	Sum of % of trees	Weight in the final formula	Assumptions
Semi-intact	[0 – 5[	5	Degraded forests have high density of cut trees or die back, and are unable to deliver key ecosystem services such as biodiversity, nursery and coastal protection
Healthy	[5 – 10[	4	
OK	[10 – 15[	3	
Unhealthy	[15 – 25[	2	
Degraded	>25	1	

Figure 14. Mangrove mass mortality due to uncertain causes, with 100% mortality of trees and no regeneration. Maputo river mouth. November 2019. ©Celia Macamo.

Comments regarding the Intactness Index

- The percentages need to be adjusted according to what is observed in the field;
- More than the percentage of CSD, their distribution/dispersal is also important. A forest stand with 10% of stumps will deliver different ecological services if such 10% is concentrated in one area or dispersed throught the forest. However, the percentage is still a valid indicator.

9.2.4. Combined Mangrove Conservation Index

The mangrove conservation index results from the combination of the 3 sub-indices. The index varies between 1 and 15. A qualitative assessment of the forest could be based on this scale, where 1 – 5 would indicate a poor forest condition, 5 – 10 would indicate moderate condition and 11 – 15 would indicate good condition. However, when comparing two forests (or the same forest in diferent periods) it is important to consider the quantitative information to assess the magnitude of change. For instance, a forest that changes from MCI = 1 to MCI = 2, had a "1 unit" improvement, and remains as poor. Similarly, another forest that changes from MCI =10 to MCI = 11 also had a "1 unit"mangnitude change, even though it went from "moderate"to "good" condition. Thus this qualitative assessment can be used for references, but the biodiversity offsitting must be based on the quantivative assessment or magnitude of change (units).

The final formula for the Mangrove Conservation Index can be obtained from the following formula:

MCI = ACI + RPI + FII

Where,

MCI – mangrove conservation index

ACI = Adjusted Complexity Index

RPI = Reproduction Potential Index

FCI = Intactiness Index

10. Testing the Mangrove Conservation Index for Mozambique

To test the mangrove conservation index for Mozambique we used data obtained from previous mangrove assessment studies. For the validation we used data collected from other studies which have already been published. These were:

a. Macamo et al., 2018. The study assesses the forest condition of 3 sites at Cabo Delgado province, namely Pemba Bay, Olumbi and Vamizi Island. The data was colected in 2013.

b. Amade et al., 2019. The study characterizes structural attributes of mangrove forests of Costa do Sol, Bons Sinais Estuary and Pemba-Metuge.

c. Nicolau et al., 2017. This study was conducted at the Quirimbas National Park in northern Mozambique. The forest was divided into 3 regions: south, center and north, with a similar number of sampling points in each region being collected. This aimed at ensuring representativeness of all parts of the forest. Therefore, for the purpose of our testing, we considered each part as a different forest, thus being able to tell whether there are differences in the condition of the forest in these regions.

We extracted the necessary information from the papers and/or spreadhsheets and calculated the Adjusted Complexity Index, as well as Regeneration Potential and Human Disturbance Index. All studies followed a similar methodology for data collection (Kairo et al., 2002) with the following exceptions:

- Amade et al. (2019) and Nicolau et al. (2017) used transects perpendicular to the coast line, while Macamo et al. (2018) used random sampling points. This does not have implications in the assessment of the forest condition.

We then presented the results of our analysis to the authors for validation and comments in the method.

10.1. Test 1

Macamo et al. (2018) compared the condition of 3 mangrove forests in Cabo Delgado province. The data were collected in 2013 in Pemba Bay, Olumbi and Vamizi Island. The results of the study showed that, despite being a peri-urban forest, the mangroves of Pemba Bay were in a better condition than those of Olumbi and Vamizi Island. In the study it is stated that the communities that live nearby Pemba are essentially agricultural communities, while those of Olumbi and Vamizi are more dependent on mangrove resources. When comparing the forest of Olumbi and Vamizi, the study also found that the Olumbi forest was in a better condition then that of Vamizi, even though Vamizi had a higher complexity index. The high complexity index of Vamizi was due to the existence of wider trees and denser stands. However, the Vamizi forests had a low regeneration potential (with some missing renegeration classes) and a high levels of human utilization.

MCI was tested for these 3 forests and found similar results. The condition of Pemba and Olumbi were “Moderate” scoring 10 and 6, respectively, while Vamizi was “Poor”.

Table 10. Testing the Mangrove Conservation Index for 3 known forests in Mozambique. ACI = adjusted complexity index; RPI = Regeneration Potential Index; FII = Forest INtactiness Index and MCI = Mangrove Conservation Index. Data from Macamo et al. (2018).

Adjusted Complexity Index			
Site	**Pemba Bay**	**Vamizi**	**Olumbi**
Number of species	4	5	7
Stand density (trees/ha)	3537	4475	2113
Basal area (m2/ha)	1,85	5,10	0,90
Mean height (m)	3,50	3,50	2,90
ACI	11,40	12,90	10,60
Score	2	3	2

Regeneration Potential Index			
Site	**Pemba Bay**	**Vamizi**	**Olumbi**
RCI	190	428	1921
RCII	50	48	316
RCIII	26	1	25
RP	0,40	0,11	0,18
Score	5	1	1

Forest Intactness index			
Site	**Pemba Bay**	**Vamizi**	**Olumbi**
% of severerly cut trees	0,26	5,73	3,23
% of stumps	8,56	20,26	10,53
% of natural death	4,28	0,88	0,56
FII	13,1	26,87	14,32
Score	3	1	3

Mangrove Conservation Index	10	5	6

10.2. Test 2

Amade et al. (2019) compared 3 mangrove forests from southern, central and Northen Mozambique, namely Costa do Sol I, Bons Sinais Estuary and Pemba-Metuge. The study was unclear in ranking the 3 forests, but gave indications that Bons Sinais Estuary could be in a better condition. Additionally, data from an unpublished study at Costa do Sol (Costa do Sol II) were also analysed. These data were collected by Macamo et al. in 2019.

The MCI showed that Bons Sinais Estuary is in a better condition, followed by Costa do Sol I and then Pemba Metuge. However, Costa do Sol II had a high MCI when compared to Costa do Sol I.

Bons Sinais and Pemba Metuge had the same score for ACI, while Costa do Sol I and II had a lower ACI. Bons Sinais had a much higher RPI, followed by Costa do Sol I and Pemba-Metuge. This differences were clearly reflected in the score of the sub-indexes. However, Costa do Sol II had a higher RPI, scoring 5. Finally, the MCI indicates that Costa do Sol I and II is more impacted, followed by Pemba Metuge and then Bons Sinais.

Table 11. Testing the Mangrove Conservation Index for 4 known forests in Mozambique. ACI = adjusted complexity index; RPI = Regeneration Potential Index; FII = Forest Intactiness Index and MCI = Mangrove Conservation Index.

Adjusted Complexity Index				
Site	**C. do Sol I**	**C. do Sol II**	**B. Sinais**	**P-Metuge**
Number of species	3	2	5	4
Stand density (trees/ha)	1790	3960	2680	3580
Basal area (m^2/ha)	24,20	1.34	51,80	50,70
Mean height (m)	2,30	1.68	3,30	2,50
ACI	12,60	9.78	14,60	14,40
Score	3	3	4	4

Reproduction Potential Index				
Site	**C. do Sol I**	**C. do Sol II**	**B. Sinais**	**P-Metuge**
RCI	1211	278	750	455
RCII	333	34	578	39
RCIII	15	34	10	43
RP	0,01	0.10	0,007	0,087
Score	1	5	1	4

Forest Intactiness Index				
Site	**C. do Sol I**	**C. do Sol II**	**B. Sinais**	**P-Metuge**
% of severerly cut trees	45,43	2.9	33,66	38,38
% of stumps		29.7		
% of natural death				
FII	45,43	27.6	33,66	38,38
Score	1	1	1	1

Mangrove conservation index	5	9	6	9

The final scoring indicates that Costa do Sol I is in bad condition, and Bons Sinais, Pemba Metuge and Costa do Sol II are "Moderate". When comparing Costa do Sol I and Costa do Sol II it is notable that what makes the difference between the two sites is the RPI. The RPI may need to be analysed further to make sure it really reflects the proportions of the 3 reproduction classes and the respective ecological implications.

10.3. Test 3

Nicolau et al. (2017) assessed the condition of mangrove forests in the Quirimbas National Park, northern Mozambique. Despite being a protected area, there are communities living within the Park's limits who have access to the mangroves. Mangrove cut is mostly for subsistence purposes, however in some areas it could be critical. The study concludes that the mangroves of the Park are under pressure and that more management efforts are needed to avoid deforestation and degradation in the near future. The study provides a detailed comparison between the 3 mangrove areas (north, center and south) of the mangrove area in the park. This data was used in our analysis.

Based on the MCI all forests (south, centre and south) are in the same condition, with an MCI of 7 (Moderate forests). The complexity index of the 3 sites is very similar (13.55, 13.99 and 13.81), as expected, since the structural parameters are essentially the same. The ACI falls, thus, within the same range. To assess the RPI we used the second principal. When using this principal, we consider that 2500 seedlings/ha is an effective stocking (FAO, 1994). This was observed in all sites. However, a recommendation to monitor the forest regeneration potential for at least consecutive 3 years seems reasonable (FAO, 1994), particularly on Site A, where RCI had the lowest density. This could be an indicator that seedlings are struggling to recruit, either due to predation or harsh environmental conditions. On what regards to FII, the numbers are the same for the 3 sites, except that at Site C tree die back seems a bit higher.

Table 12. Testing the Mangrove Conservation Index for 3 known forests in Mozambique. ACI = adjusted complexity index; RPI = Regeneration Potential Index; FII = Forest Intactiness Index and MCI = Mangrove Conservation Index.

Adjusted Complexity Index			
Site	**North QNP**	**Centre QNP**	**South QNP**
Number of species	5	6	5
Stand density (trees/ha)	3094	3315	4016
Basal area (m2/ha)	8,70	8,70	8,70
Mean height (m)	5,70	6,90	5,70
ACI	13,55	13,99	13,81
Score	3	3	3

Reproduction Potential Index			
Site	**North QNP**	**Center QNP**	**South QNP**
RCI	375	1143	757
RCII	164	786	326
RCIII	347	660	357
RP	1.36	1.27	0.90
Score	3	3	3

Forest Intactiness Index			
Site	**North QNP**	**Center QNP**	**South QNP**
% of severerly cut trees	19	19	19
% of stumps	19	19	19
% of natural death	8	8	12
FII	46	46	50
Score	1	1	1

Mangrove condition index	7	7	7

11. Discussion

The data from Macamo et al. (2018) (Test 1), Amade et al. (2019) (Test 2) and Nicolau et al. (2017) (Test 3) used to test the MCI, provide a picture of the forest condition in 9 different mangrove forests in Mozambique, according to 10 variables grouped into 3 sub-indices namely, the Adjusted Complexity Index (ACI), Regeneration Potential Index (RP), and Forest Intactiness Inde(FII). MCI varies from moderate to good condition among the different forests (Table 12).

The MCI reflected the overall authors considerations from the 3 studies used for the testing, and it was able to separate mangrove condition into conservation condition score. For example, Olumbi scored a Moderate condition, while QNP A scored Good. Both facts were observed on the ground by both authors.

Analysing specific variables in each sub-index, it is possible to observe slight differences between forest structure data, e.g.: average density, basal area, tree height and regeneration potential. Thus, further analysis are required to understand intrinsic data of each sub-index.

In terms of the significance of individual variables in each sub-index we could understand that the MCI is very sensitive to removal of stand density, number of species, basal area and species. Removal stand density shown a significant change in the ACI index according to our categorization scheme. Removal of ACI variable (stand density) created significant decrease in average score of the total sub-index (Figure 15), and it also contributed for the changing of the mangrove condition overall score (Figure 16).

Table 13. Comparison of the Mangrove Conservation Index for 3 known forests in Mozambique.

Index	Test 1			Test 2			Test 3		
	Pemba Bay	Vamizi	Olumbi	C. do Sol I	B. Sinais	P-Metuge	North QNP	Center QNP	South QNP
ACI	2	3	2	3	4	4	3	3	3
RP	5	1	1	1	1	4	3	3	3
FII	3	1	3	1	1	1	1	1	1
Mangrove Conservation Index	10	5	6	5	6	9	7	7	7
Score	Moderate	Bad	Moderate	Bad	Moderate	Moderate	Moderate	Moderate	Moderate

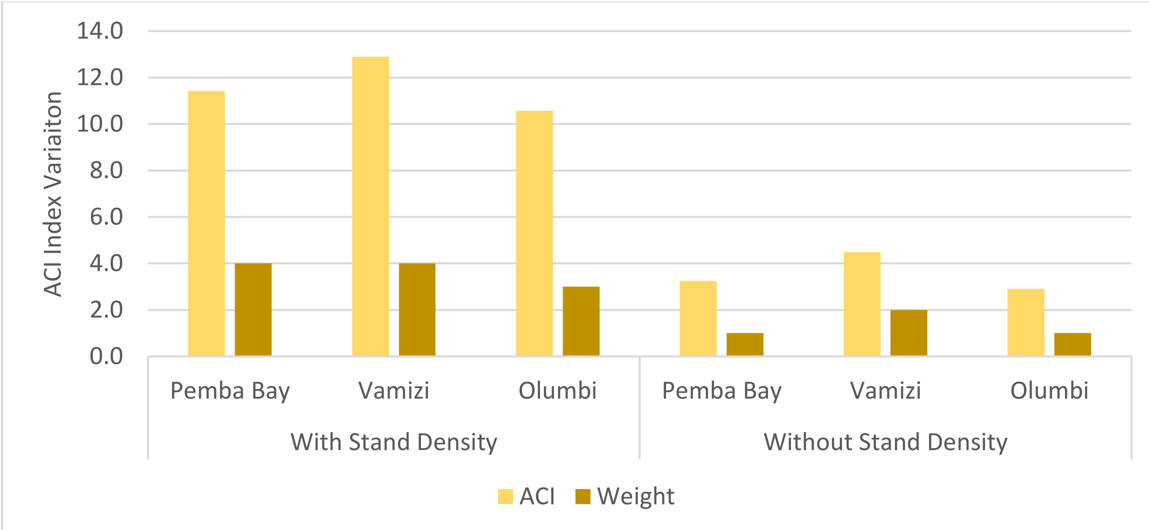

Figure 15. Sensitivity analysis of the Adjusted Complexity Index (ACI) to stand density removal (Test 1 data).

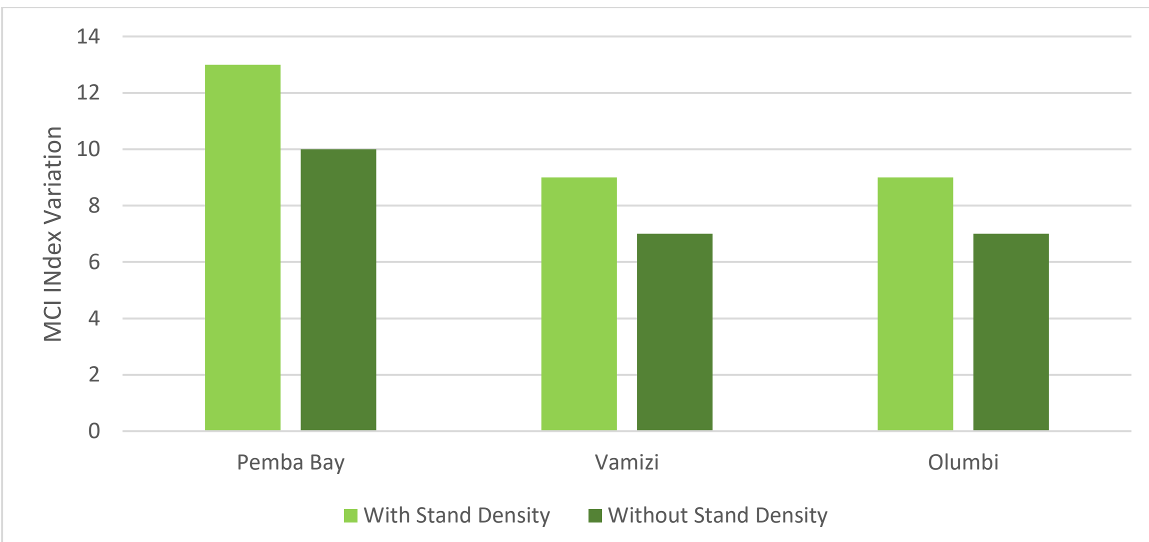

Figure 16. Sensitivity analysis of the MCI to stand density removal (Test 1 data).

This result showed a clear dependence of the metric to stand density data. Further analysis will have to conducted to understand stuctural variables relevance in the MCI for Mozambique.

12. Study Limitations

Mangrove forests are very complex ecosystems, and their health and optimal ecological functioning are dependent on physical and biological factors. Isolating these factors proved to be a great challenge, as there are no unique factors that can be absolute determinants for its health. In addition, the health of a mangrove forest is also influenced by the health of adjacent ecosystems or even more distant ones. Thus, it is essential to know in depth the ecology of the system, which is often specific to each place.

Mozambique, has a long coastline and one of the most extensive mangrove areas in Africa. The biogeographic and geomorphological variety of the coast is immense, which in turn introduces many factors of variation in mangrove forests. Developing a single index that covers all possible variations is a great challenge. Ideally, for each type of forest and location, specific indices should be developed taking into account local climatic and biophysical factors such as temperature, soil type and composition, type of forest, biota, and the type of human stressors.

There are some limiting factors that have been verified during the current study as described below:

1. The complexity of mangrove ecosystem itself, where factors interact in an interconnected and complex way;
2. Absense of comprehensive indices to determine the status of mangrove forest condition at the global level and literature scarcity in the matter;
3. The diversity of mangrove forest types in Mozambique, at least five classes known with each specific dynamic and interactions;
4. Poor knowledge of the biology and ecology of mangrove forests in Mozambique;
5. Data deficiency on mangroves in Mozambique - few studies collect physic-chemical data, such as pH, nutrients, etc;
6. The MCI developed in this study covers structural elements of the mangrove forest; other elements are not covered such as nutrients, pH, fauna, redox potential, carbon and salinity.

   The ecological implications of the variability of some parameters are not fully understood. One that requires particular attention is the variability of the regeneration classes, as the number of possibilities other than 6:3:1 and those hiphotesised in this study can be found.

13. Conclusions

This study developed a metric to assess mangrove condition in Mozambique – the Mangrove Condition Index (MCI). The metric is based on forestry parameters, such as basal area, height, tree density, number of species, regeneration potential, human exploitation and natural impacts. The metric allows comparison and ranking of mangrove forests in different conservation conditions throughout the country. Since the index is composed of 3 sub-indices that analyze different components of the forest structure, it also allows an independent analysis of each component. Thus, it is possible to identify areas of intervention to improve the ecological condition of a specific mangrove forest.

Although the metric has limitations, it is still a valuable tool to qualify mangrove forests in a specific area. The tool may be useful for management purposes including biodiversity offsetting projects, assuming that forests in similar conservation condition are able to provide similar biodiversity and ecological services. It can also be used to support management and decision making to ensure sustainability of mangrove ecosystem for current and future generations by providing means to monitor ecological condition of mangrove forests.

This index is a simple tool that can be adopted elsewhere, including other countries of the region, by simply adjusting the benchmarks of a country or site, if they fall oustside those defined for the purpose of the study.

Despite its usefulness, there are limitations to this index that will require further research work to collect addional data that was not included in the study in order to develop a comprehensive index from Mozambique.

14. Recommendations

This index analyses the conservation status of mangrove forests allowing for a pragmatic numerical comparison between different forests. It considers several structural aspects of the forest that are suitable for assessing the sustainability of the forest, however other ecological parameters are not covered.

Biodiversity is one of the important feature that is not covered by this index. Ideally, being a condition index, it should also contemplate species diversity in the mangrove forest, or at least the diversity of key groups. Mangrove forests are habitat for several species such as birds and marine animals. The key recommendations are:

- In future studies, we recommend analysing the sub-indices individualy and compare the results of this assessment with the combined sub-indeces;
- Develop, validate and update on a regular basis mangrove benchmarks for each forest type occurring in Mozambique (fringing, basin, riverine and dwarf);
- For dwarf mangrove forests a special protocol must be designed and used to accurately identify the seedlings;
- Only mangroves within the same biogeographic zone and geomorphological types can be compared;
- Mangrove species of global importance must be identified at project site, and it is desirable that the same species (or with similar ecological function) occurs in the offsetting site;
- Future mangrove field surveys in Mozambique should be oriented to collect as much data as possible, as in the future that data can enrich the development of a comprehensive index of mangrove condition in Mozambique that should result from a combination of ecosystem-socio-economic categories such as a

mangrove conservation index, a mangrove biodiversity index, a physic-chemical index, socioeconomic index and so on;

- Conduct mangrove fauna inventories, with emphasis on species of special attention and incorporate this information in the Mangrove Conservation Index;
- Map of mangrove vulnerable areas (climate and human-related vulnerable sites) so that these sites are not chosen for project development purposes or either offsetting and tentatively understand the main drivers of change in mangrove forests (natural and human induced erosion and sedimentation);
- Build country capacity to respond the current needs on mangrove ecology information, and expertise to key analysis such as on plankton;
- The MQI developed for mangrove forests in Malaysia should be tested in Mozambique and the results compared to the MCI. In that matter a multi-parameter probe was acquired and a field sampling is being prepared to collect part of the missing data (e.g.: on crabs, pH) to test the index.

15. References

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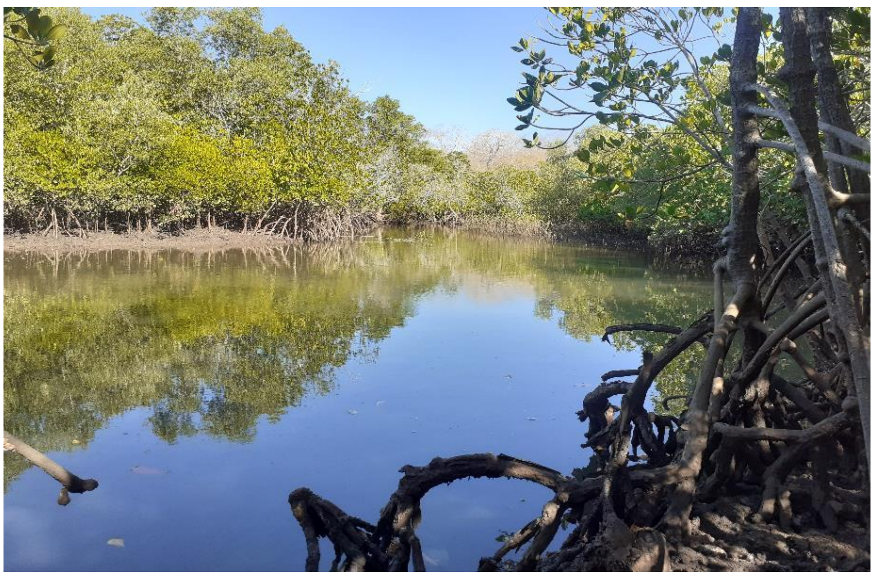
Appendix I. Mozambique’s mangrove species and diagnostic characters (Tomlinson, 1986; Bentjee & Bandeira, 2007).

1. Avicennia marina (Forssk.) Avicenniaceae; 2. Ceripos tagal (Perr.) Rizophoraceae; 3. Sonneratia alba (J. Smith) Sonneratiaceae; 4. Acrostichum aureum (L) Parkeriaceae; 5. Rizophora mucronata (Lam.) Rizophoraceae; 6. Bruguierra gymnorhiza (L) Rizophoraceae; 7. Xylocarpus granatum (J.Köning) Meliaceae; 8. Lumnitzera racemosa (Willd.) Combretaceae; and 9. Heritirera littoralis (Aiton.) Sterculaceae

Protocolo de campo para avaliação da condição das florestas de mangal no âmbito da aplicação dos contrabalanços de biodiversidade em Moçambique



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Maputo, Agosto de 2021

Índice

Lista de figuras

Lista de tabelas

Definições

Contrabalanços de biodiversidade – Resultado mensurável da conservação através de acções destinadas a compensar impactos residuais adversos significativos sobre a biodiversidade decorrentes do desenvolvimento de um projecto após terem sido tomadas medidas apropriadas de prevenção e de mitigação.

Desmatamento – conversão de florestas para outras formas de uso da terra ou a redução a longo prazo da cobertura florestal abaixo do limite de 30% de cobertura de copas.

Mangal ou Ecossistema de Mangal – refere-se ao conjunto de árvores e outra plantas associadas bem como os recursos pesqueiros, invertebrados, aves, insectos e animais marinhos que crescem e ocorrem na zona costeira, entre as linhas de maré alta e baixa, e ao longo da zona entre-marés banhada pelos rios. O ecossistema de mangal forma uma comunidade vegetal adaptada a ambiente hidrológico costeiro muito variável, uma vez que deve fazer face as alterações dos níveis de água, oxigénio e salinidade.

Função do ecossistema – processos envolvidos nos fluxos de energia e matéria entre os diferentes níveis tróficos e o meio ambiente num ecossistema.

Impacto antropogénico – alterações provocadas pelo homem.

Impacto natural – alterações causadas por processos ou fenómenos naturais.

Mercados de Carbono - operações de créditos de carbono em mercados sem obrigações de entrega de direitos ou créditos com a finalidade de redução das emissões de gases efeitos estufa (GEE).

Pagamento por Serviços do Ecossistema (PSE) – mecanismo de avaliação económica do meio ambiente e capital natural com instrumentos que permitem a concessão de incentivos económicos e financeiros como benefícios prestados pela natureza e imprescindíveis para o bem-estar humano.

Restauração – restituição de um ecossistema ou de uma população bravia degradada, o mais próximo possível da sua condição natural.

Serviços do ecossistema - refere-se ao conjunto de funções do ecossistema que correspondem a uma variedade de "benefícios", classificados como "bens" (Exemplo:

provimento de invertebrados e outros produtos como materiais para construção e medicamentos) e "serviços" (Exemplo: recreação, turismo, valor cultural-espiritual, protecção costeira ou os benefícios derivados de determinadas funções de regulação ecológica e habitat como o ar puro, a paisagem e função no combate às mudanças climáticas).

1. Introdução

Na última década houve um aumento significativo na exploração de recursos naturais em Moçambique, bem como o desenvolvimento de infraestruturas, com impacto ambiental severamente negativo sob a biodiversidade. Assim sendo, existe uma necessidade urgente de conciliar o desenvolvimento económico com a manutenção da biodiversidade, sobre a qual depende a maior parte da população moçambicana para a sua subsistência.

Um mecanismo para reconciliar a conservação da biodiversidade e o desenvolvimento económico é a implementação da hierarquia de mitigação por parte de projectos de desenvolvimento, que requer (1) evitar impactos sobre o ambiente, (2) minimizar os impactos não-evitáveis sobre o ambiente, e (3) restaurar a biodiversidade e os serviços dos ecossistemas perdidos nas áreas impactadas, e por último, havendo impactos residuais não negligenciáveis sob a biodiversidade, (4) contrabalançar os impactos noutra biodiversidade importante fora do local de impacto.

A hierarquia de mitigação é chave para o processo de Avaliação do Impacto Ambiental (AIA) e demanda que após terem sido implementados os passos para (1) evitar, (2) minimizar e (3) restaurar, sejam implementados os contrabalanços de biodiversidade com base num Plano de gestão de biodiversidade por forma a alcançar Nenhuma Perda Líquida de biodiversidade (NPL), ou ainda um Ganho de biodiversidade (GL) (BBOP, 2012; IFC, 2012; IUCN, 2016). Actualmente, o Governo de Moçambique encontra-se a colaborar com os seus parceiros para o desenho do Regulamento dos Contrabalanços de Biodiversidade, instrumento crucial para viabilizar a implementação do conceito em Moçambique.

Os contrabalanços da biodiversidade são o último passo da hierarquia da mitigação e segundo o decreto 54/2015 define-se como "o resultado mensurável da conservação resultante de acções destinadas a compensar impactos residuais (não mitigáveis) adversos significativos sobre a biodiversidade, decorrentes do desenvolvimento de um projecto, após terem sido tomadas as medidas apropriadas de prevenção e de mitigação". A sua implementação é feita geralmente fora do local do projecto, em áreas com condições sociais e ambientais viáveis.

O desenho de um sistema de contrabalanços da biodiversidade a nível nacional, é assim, primordial para a viabilização da proposta de regulamento acima descrito e dos princípios definidos no Regulamento de Avaliação de Impacto Ambiental.

Moçambique é o décimo-terceiro país com a maior área de mangal a nível global (Spalding *et al.,* 2010). Em África é o segundo país com a maior área de cobertura de mangal, e na região possui a maior extensão, estimada em cerca de 3 054 km^2 (Spalding *et al.,* 2010; Fatoyinbo e Simard, 2013; Bosire *et al.,* 2016).

Apesar da relevância social e ecológica dos mangais, estes se encontram sob ameaça de impacto severo devido o desenvolvimento costeiro e expansão urbana (Macamo et al., 2016), pelo que, uma métrica para avaliar a sua condição é oportuna e permitirá que os proponentes de projectos de desenvolvimento possam avaliar a condição do mangal no local de impacto bem como na área definida para o contrabalanço. Este manual descreve os procedimentos para a avaliação da condição de florestas de mangal em Moçambique seguindo os princípios e procedimentos definidos na métrica para avaliação da condição das florestas de mangal recentemente desenvolvida pela BIOFUND e a UEM. A métrica, ainda em fase de testagem, foi desenvolvida com base em metodologias para a avaliação da estrutura e estado de conservação de mangais largamente utilizadas em Moçambique e na região ocidental do Oceano Índico.

Neste contexto, o presente manual pretende ser um guião base de avaliação ecológica do ecossistema de mangal no contexto de Moçambique visando padronizar o levantamento e análise de informação ecológica em estudos de avaliação de impacto ambiental no âmbito da implementação dos contrabalanços de biodiversidade em Moçambique.

2. Breve Descrição dos Mangais

2.1. Ecologia dos mangais

Os mangais são uma comunidade vegetal que cresce na zona costeira, entre as linhas de maré alta e baixa, e ao longo da zona entre-as-marés banhada pelos rios, formando uma comunidade vegetal adaptada a ambiente muito variável uma vez que devem fazer face as alterações dos níveis de água, oxigénio e sal. Constituem ecossistemas costeiros normalmente encontrados nas regiões subtropicais (Wang *et al.,* 2019) e tropicais do globo terrestre, entre as coordenadas 25º N e 25º S (Donato *et al.,* 2011).

Os mangais ocorrem ao longo da costa de Moçambique. A zona norte é caracteristicamente rochosa, mas possui florestas bem estabelecidas em zonas como Angoche, Mossuril, Quissanga-Ibo e foz do rio Rovuma. O sul do país possui as menores extensões de mangal, entretanto formações importantes podem ser encontradas nas Baías de Maputo e Inhambane. O Sul marca também o limite da distribuição de *Sonneratia alba* na região oriental de África, não ocorrendo a sul da Baía de Inhambane. Outras 8 espécies ocorrem no país, sendo estas: *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritriera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata, Xylocarpus grannatum* e *Xylocarpus mullocensis*.

Figura 1. Mapa dos mangais em Moçambique. Fonte: WCS, 2021.Adaptado de Shapiro, 2018.

A distribuição das espécies de mangal no seu ecossistema segue um padrão (Liu *et al.,* 2018) que lhes é determinado de acordo com a tolerância das plantas a factores como a disponibilidade de nutrientes, o nível de oxigénio no solo e principalmente pela hidrologia (Charrua *et al.,* 2020), isto é, pelas flutuações de salinidade no substrato que se relaciona com o tempo de duração da inundação pela maré (Alvez e Souza, 2007).

Espécies como *R. mucronata* e *S. alba* são geralmente encontradas em zonas com fraca variação da maré caracterizadas por inundações constantes, enquanto que *C. tagal, X. grannatum* e *B. gymnorhiza* são restritas em zonas intermediárias com inundações ocasionais. As espécies *Heritriera spp.* e *Lumnitzera racemosa* ocorrem em zonas onde as inundações das marés raramente ocorrem e a espécie *A. marina* é encontrada tanto em zonas com inundações constantes como em zonas raramente inundadas (Figura 3 e 4) (Sreelekshmi *et al.,* 2020). As duas figuras a baixo ilustram o padrão de zonação das espécies de mangais no país, e podem ser observados na província de Inhambane.

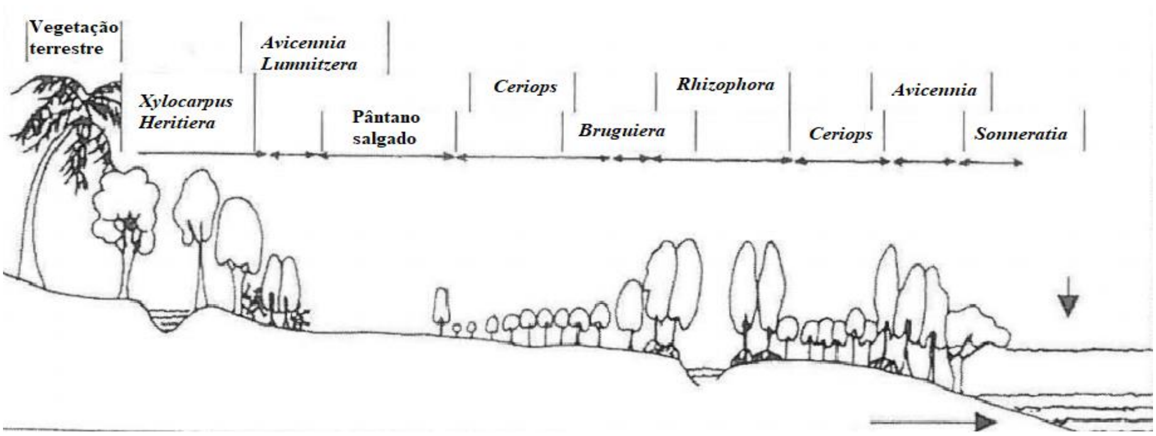

Figura 2. Padrão de zonação das principais espécies de mangal no norte de Moçambique). Fonte: Barbosa et al. (2001).

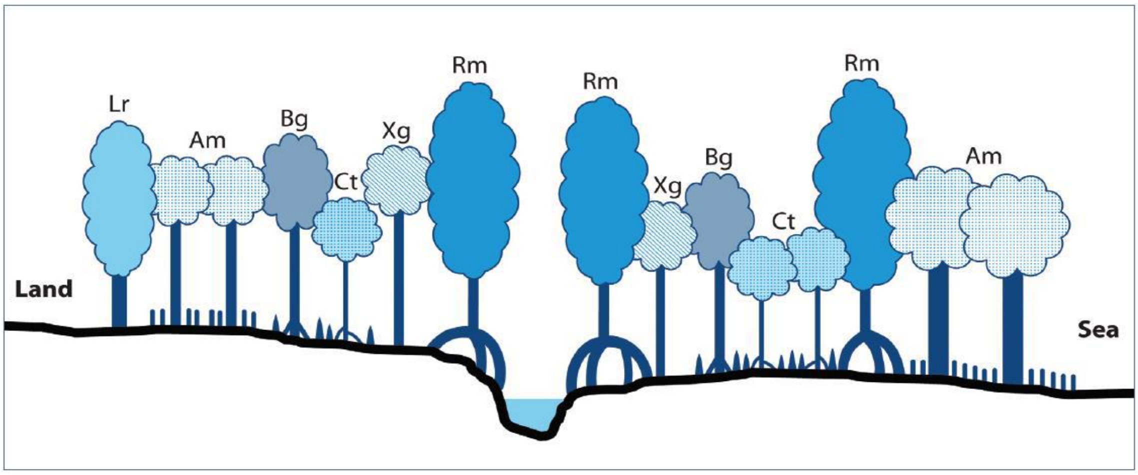

Figura 3. Padrão de zonação das principais espécies de mangal no sul de Moçambique). Fonte: Bandeira e Paula (2014).

Comunidades de mangal albergam uma grande variedade de espécies associadas tanto de plantas como animais. Fazem parte as bactérias e fungos, algas, fetos, líquenes, esponjas, celenterados, minhocas e poliquetos, crustáceos, insectos, aracnídeos, moluscos, equinodermos, acídias, peixes, répteis, anfíbios, aves e mamíferos. Alguns desses organismos vivem nos mangais em apenas uma parte do seu ciclo de vida, enquanto outros vivem no mangal de forma permanente (Arksornkoae, 1995).

As espécies de plantas encontradas nestas florestas, crescem sob condições adversas como a constante inundação pela água do mar e de rios (Maia e Coutinho, 2012), o que implica variações (às vezes extremas) de salinidade no ambiente (Wang *et al.,* 2019). Devido a esta característica, é notável a acumulação de sedimentos (Fatoyinbo *et al.,* 2008) resultando na presença de um substrato maioritariamente não consolidado (Maia e Coutinho, 2012) e baixa disponibilidade de oxigénio no solo (Fatoyinbo *et al.,* 2008). Outros constrangimentos incluem pressões de maré, acção das ondas e ventos fortes (Alappatt, 2008). Assim os mangais possuem várias adaptações, com destaque para a presença de raízes aéreas, mecanismos fisiológicos para a excreção e/ou eliminação de sal e viviparia (Balidy *et al.,* 2005; Wang *et al.,* 2011).

Figura 4. Adaptações dos mangais para o ambiente marinho, incluindo viviparia, frutos flutuantes e glândulas de excreção de sal nas folhas.

Nas adaptações associadas às raízes podem ser mencionadas as raízes laterais também chamadas de raízes de suporte (ex.: *R. mucronata*), pneumatóforos ou raízes tipo lápis (ex.: *S. alba* e *A. marina*), raízes do tipo joelho (ex.: *B. gymnorhiza* e *C. tagal*), raízes do tipo fita (ex.: *X. granatum*) e contrafortes (*H. littoralis)* (Alappatt, 2008).

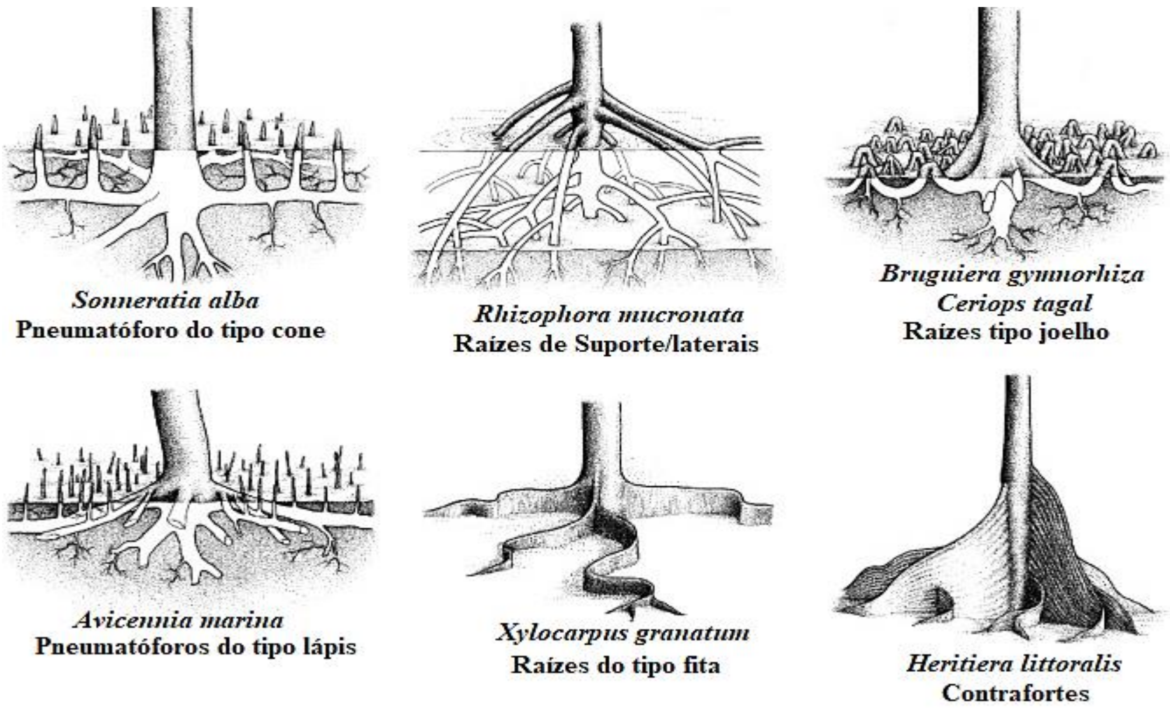

Figura 5. Representação dos diferentes tipos de raízes desenvolvidas pelas espécies de mangal. Fonte: http://ars.els-cdn.com/content/image/3-s2.0-B9780444527394500115-f15-05-9780444527394.jpg

As comunidades de mangal albergam uma grande variedade de espécies associadas tanto de plantas como animais. Fazem parte as bactérias e fungos, algas, fetos, líquenes, esponjas, celenterados, minhocas e poliquetos, crustáceos, insectos, aracnídeos, moluscos, equinodermos, acídias, peixes, répteis, anfíbios, aves e mamíferos. Alguns desses organismos vivem nos mangais em apenas uma parte do seu ciclo de vida, ou, alternadamente, os mangais servem habitat permanente (Arksornkoae, 1995).

A fauna de mangal é rica, e tende a ser mais diversa perto da costa e diminuir à medida que se avança para dentro do continente (Bosire *et al*., 2016). Adicionalmente, esta fauna exibe um gradiente latitudinal, onde a diversidade e abundância das espécies aumenta do Sul para o Norte, em resposta à mudança do clima subtropical para tropical (Guerreiro *et al*., 1996; Abreu *et al*., 2008).

Nos invertebrados destacam-se os crustáceos como o grupo mais abundante, e inclui caranguejos, camarão e barnáculos (ex. *Amphibalanus amphitrite* e *Chthamalus dentatus*). Os caranguejos constituem a macrofauna mais abundante e inclui espécies como *Cardisoma carnifex,* e o caranguejo de mangal, *Scylla serrata* (Bosire *et al*., 2016). Os camarões peneídeos

(Penaeidae) são o grupo mais importante em Moçambique devido ao seu alto valor económico (Kalk, 1995; Macia, 2004; Paula *et al*., 2014; Macamo *et al*., 2016).

Figura 6. Espécies comumente encontradas no mangal. Da esquerda para a direita: *Cardisoma carnifex*, *Scylla serrata*, *Uca sp.* e *Penaeus indicus*.

Os gastrópodes são um grupo bem representativo nos mangais. As espécies mais comuns incluem a *Littoraria scabra*(Littorinidae) que ocupam as margens da floresta em áreas de *Rhizophora*; *Cerithidia decollata, Terebralia palustres* (Potamididae)ocorrendo dentro das florestas (Bosire *et al*., 2016). Os Bivalves são representados pelas espécies *Saccrostea cuculata* (Ostreidae). Poliquetos (família Nereididae) e os vermes da família Sipunculidae dominam a endofauna, ocorrendo nas franjas dos mangais mais perto da água (Bosire *et al*., 2016).

Figura 7. Espécies de moluscos que se podem encontrar no mangal. Da esquerda para a direita os gastrópodes *Littoraria sp.*, *Cerethidea decollata*; e o bivalve *Saccostrea cucculata*.

Entre as espécies de peixe comumente encontradas, pode-se listar *Periophthalmus argentilineatus*, *Hilsa kelee*, *Sigaus sutor e Sillago sihama* (Bosire *et al*., 2016).

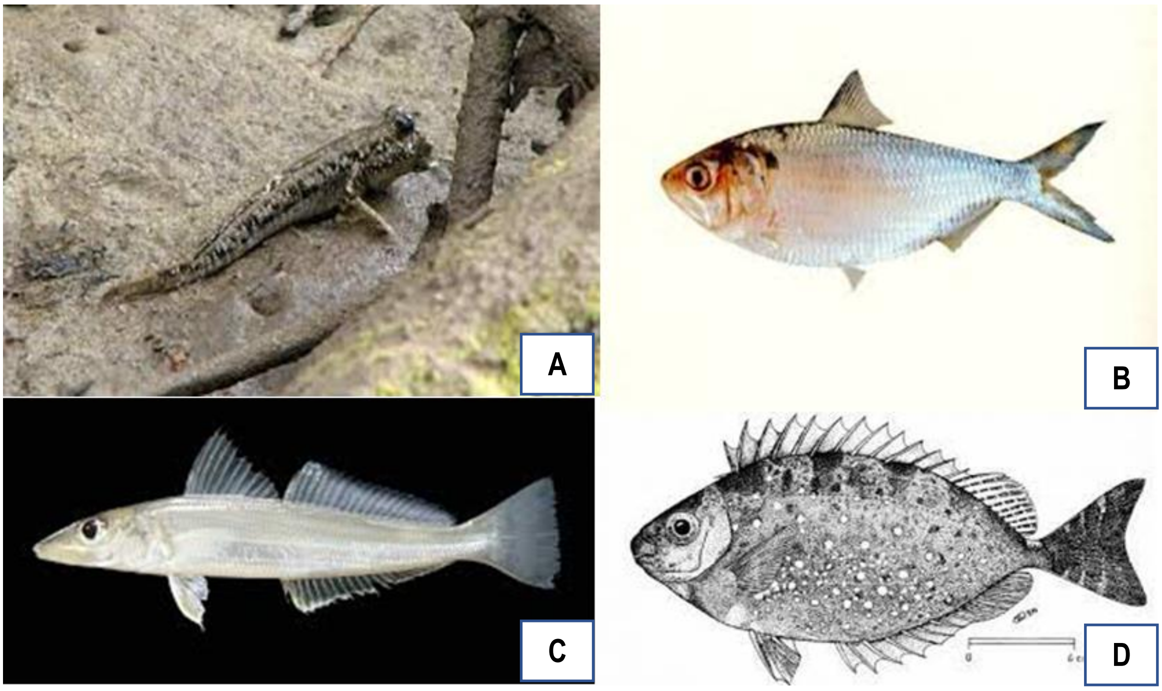

Figura 8. Espécies de peixe comumente encontradas nos mangais. A. *Periophthalmus argentilineatus*; B. *Hilsa kelee*; C. *Sillago sihama*; D. *Siganus sutor*.

Outro grupo de fauna importante nos mangais é o das aves. Espécies comuns são as garças (*Egretta garzzeta, E. gularis*, *Ardea goliath* e *A. Melanocephala)*, Cegonhas (*Ciconia ciconia* e *C. nigra*), e flamingos *Phoenicopterus minor* e *P. ruber* e *Butoroides striatus* (Impacto, 2013; Bento, 2014).

Figura 9. Aves comumente encontradas nos mangais. Da esquerda para a direita: *Egretta garzzeta* e *Ciconia ciconia*.

3. Importância dos mangais

Os mangais de Moçambique providenciam uma grande variedade de bens e serviços para as comunidades costeiras e não só, contribuindo para a criação de fontes de rendimento de numerosas famílias. As florestas de mangal possuem grande importância ecológica e socio económica, uma vez que constituem fonte de nutrientes e funcionam como habitat, berçário e local de alimentação para várias espécies marinhas (Boer, 2002), fornecem serviços como protecção da linha de costa e funcionam como barreira para eventos extremos como ciclones e tsunamis (Macamo *et al.,* 2016). Os mangais fornecem serviços indirectos como a regulação do clima. Também sequestram grandes quantidades de carbono atmosférico, contribuindo para a mitigação das mudanças climáticas (Chevallier, 2013). Também são berçário para numerosas espécies de fauna com importância económica e alimentar (ex.: peixe, camarão, caranguejo de mangal). Os mangais proporcionam um espaço para o desenvolvimento de actividades económicas, como a produção de sal, apicultura, ecoturismo e aquacultura. Também fornecem produtos madeireiros para a construção assim como combustível na forma de lenha, extração de taninos, medicamentos, e são locais de prática de rituais culturais. Também servem de locais de pesca e recoleção de espécies com importância económica (Barbosa *et al.,* 2001).

Nos últimos anos os mangais têm atraído maior atenção a nível global devido ao seu papel na adaptação e mitigação das mudanças climáticas. No que diz respeito à adaptação, a sua capacidade de reduzir o impacto de eventos naturais extremos como tempestades, ciclones, cheias e tsunamis foi comprovada em vários locais (Dahdouh'Guebas *et al.,* 2005; Massanguanhe *et al.,* 2015). Em Moçambique estudos mostram que os mangais do delta do Save protegeram a vila de Nova Mambone contra os impactos do ciclone Eline no ano 2000 (Macamo *et al.*, 2016).

Quanto á mitigação das mudanças climáticas, sabe-se que os mangais estão entre os sistemas naturais que mais sequestram e acumulam o dióxido de carbono, um dos gases com efeito de estufa mais importantes. O carbono é acumulado na forma de biomassa viva no extenso sistema radicular (biomassa abaixo do solo), assim como no tronco, ramos e folhas (biomassa acima do solo). Porém, a reserva mais importante de carbono nos mangais é o solo, que pode chegar a acumular duas vezes mais carbono que as restantes componentes da floresta (Murray *et al.,* 2011; Donato *et al.,* 2011).

4. Ameaças aos Mangais

Apesar da sua importância reconhecida, os mangais estão globalmente ameaçados e Moçambique não constitui uma excepção (Valiela *et al.,* 2001). No País, as principais causas de degradação do mangal são a extracção não sustentável de madeira para construção e combustível lenhoso, a conversão para outras formas de uso (sobretudo salinas), a expansão urbana e desenvolvimento costeiro, poluição, entre outras (Macamo *et al.,* 2016).

Florestas de mangal são também alvo da fragmentação e degradação devido à sobre-exploração de recursos madeireiros e à poluição. Entretanto, fenómenos naturais ligados às mudanças climáticas (tais como ciclones, tufões, elevação do nível do mar, tempestades e regimes de temperatura) são também associados à degradação destes ecossistemas (IPCC, 2006; FAO, 2007; Gilman *et al*., 2008).

Estimativas locais indicam que o grau de degradação das florestas de mangal é maior em locais de maior assentamento urbano, enquanto os mangais existentes nas áreas remotas permanecem intactos ou crescem significativamente (Bosire *et al*., 2016). Um exemplo disso foi a degradação do mangal próximo à cidade na Baía de Maputo observado por Boer (2002), enquanto o mangal localizado longe da cidade permanecia intacto e apresentava algum desenvolvimento. O mesmo foi observado no Estuário do Incomáti por LeMarie *et al*., (2006) e por Ferreira *et al*., (2009) nos estuários do Rovuma e Quiterajo.

Em Moçambique os maiores vectores de degradação dos mangais são de origem antropogénica, nomeadamente: exploração de recursos madeireiros, que causou, por exemplo, a degradação dos mangais do Estuário do Incomáti (severamente impactado), Xefina pequena (20% da área total) e a Ilha Benguelene (40% da área total) na Baía de Maputo (Bosire *et al*., 2016); Salinas (conversão de extensas áreas de mangal em Mussoril); e a alteração do regime hidrológico, que, por exemplo, causou a perda de 1/3 da área de mangal do Chiveve devido às obras de dragagem do local para o controle de inundações na Cidade da Beira. A aquacultura converteu extensas áreas de mangal no país (850 ha), distribuídos entre

Costa do Sol em Maputo (18.5 ha), na Beira (132 ha), Quelimane (450 ha) e Pemba (250 ha), e apesar dos danos permanentes, todas estas farmas encontram-se actualmente inoperacionais (Macamo *et al*., 2016; Bandeira *et al*., 2016).

Os mangais estão também sujeitos à influência de catástrofes naturais como ciclones e cheias, e fenómenos como erosão e sedimentação (Shapiro *et al*., 2015; Macamo *et al*., 2016). Algumas florestas de mangal estão mais vulneráveis a esses fenómenos, como os mangais de Govuro, no Delta do Save que foram severamente impactados por três ciclones de grande magnitude num período de 7 anos (Ciclone Eline- categoria4 - em 2000; Japhet – categoria4 – 2003; e o ciclone Favio – categoria3 - 2007) causando mortalidade massiva, associada a longos períodos de submersão, sedimentação e danos mecânicos (devido a acção dos ventos e das ondas) (Macamo *et al*., 2016a e b). Recentemente, estima-se que cerca de 2 500 ha do mangal arredores da cidade da Beira foram afectados aquando da passagem do ciclone Idai em 2019 (MRV, 2019); o mangal do Estuário do Incomáti foi de alvo de inundações por várias vezes durante os últimos 50 anos, sendo a pior a do ano 2000, onde a floresta ficou inundada por 45 dias causando alteração do sedimento e a degradação do mangal (Balidy *et al*., 2015).

A erosão causou a perda de vários hectares de mangal no Delta do Zambeze (S. Bandeira, comunicação pessoal Shapiro *et al*., 2015). Entretanto, a tendência observada neste mangal é de aumento, estima-se que tenha se recuperado cerca de 3 723 há (10% da área total) (Shapiro *et al*., 2015). Hatton e Coutto (1992) citado por Macamo e Sitoe (2017), aponta a sedimentação como principal causador da extinção do mangal na Ilha dos Portugueses, Baía de Maputo.

5. Método de avaliação da condição das florestas de mangal

O cálculo da métrica de biodiversidade para as florestas de mangal se baseia em dados biométricos dos mangais, tais como altura e diâmetro médio das árvores, potencial de regeneração da floresta e estado de conservação. Estes dados são colhidos no campo e depois combinados em sub-índices para (1) estrutura geral da floresta, (2) potencial de regeneração e (3) estado de conservação. Os 3 sub-índices são depois combinados num índice único.

Para o desenvolvimento da métrica foram estabelecidos valores de referência (benchmarks) baseados nos dados existentes até ao momento. Estes valores podem ser ajustados à medida que o conhecimento sobre os mangais é melhorado. Também podem ser ajustados para distinguir os diferentes tipos de floresta de mangal, desde que as diferenças ecológicas se reflictam em parâmetros estruturais como densidade e número de espécies, padrão de regeneração, diâmetro e altura, e assim por diante.

A seguir é apresentada a metodologia detalhada para cálculo da métrica.

5.1. Material de Campo

- Fita métrica (100 m);
- Fichas de registo;
- Lápis;
- Borrachas;
- Cordas de 50m graduadas de 10 – 10m;
- Suta para medição do Diâmetro do Caule (DAP – Diâmetro á Altura do Peito);
- GPS Garmin 64s;
- Sacos plásticos (ziplocks);
- Papel vegetal;
- Pranchetas;

5.2. Modelos de amostragem

Em estudos da estrutura dos mangais, os parâmetros estruturais são descritos através dos resultados obtidos da medição da altura das árvores, do diâmetro à altura do peito (DAP), da contagem das espécies no local e da determinação da composição específica, da estimação da biomassa e da zonação (Salum *et al.,* 2020; Wang *et al.,* 2019; Magalhães *et al.,* 2020).

Os locais de amostragem devem, preferencialmente, ser selecionados anteriormente à saída de campo, utilizando-se imagens de satélite pré classificadas em diferentes categorias, como por exemplo, mangal denso, mangal disperso, mangal degradado e mangal em regeneração.

Posterior a classificação das imagens são delimitados os transectos perpendicularmente à linha de costa, rio ou canal. A escolha dos transectos é feita de forma aleatória tendo como base uma tabela de números aleatórios, mas por forma a garantiam que todas as categorias de mangal estejam representadas de modo mais ou menos equilibrado. Cada transecto é dividido em um número variável de quadrados de 10 x 10m. Um mínimo de 3 pontos de amostragem (sendo um por quadrado de transecto) é selecionado para amostragem e em cada ponto de amostragem estabelecida uma quadricula para amostragem. A distância mínima entre os pontos de amostragem é de 100 m, podendo ser variável tendo em conta o comprimento do transecto. Mas nunca abaixo de 25 m.

Outra forma de seleção dos pontos de amostragem é a definição dos pontos após a chegada ao local de amostragem, onde nos locais escolhidos para a colheita de amostras deverão ser escolhidas quadrículas posicionadas ao longo de um transecto perpendicularmente ao curso de água e/ou à linha de costa ao longo de vários transectos (espaçados a cada 25-50 metros, ou mais, em função da extensão da área). Cada uma das quadrículas deve apresentar uma área de $100m^2$ $(10\text{m} \times 10\text{m})$ (Nicolau *et al.,* 2017; Macamo *et al*., 2018; Bandeira *et al.*, 2009), separadas por 25 m entre cada quadrícula. A delimitação das quadrículas é feita com o auxílio de uma fita métrica de 100m e cordas graduadas.

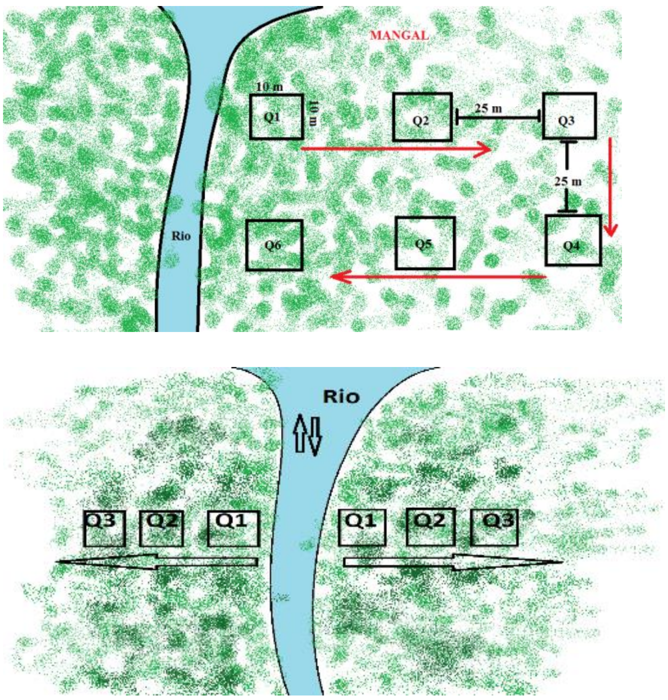

Figura 10. Esquema de amostragem para colheita de dados estruturais na floresta de mangal.

Dentro de cada quadrícula são colhidos todos os dados estruturais da floresta, incluindo amostras de solo para quantificação de carbono. Em zonas de densidade de plantas muito alta, as quadrículas podem ser reduzidas para 5 x 5 m ou 2.5 x 2.5 m, e depois extrapolado os números para o equivalente de 10 x 10 m.

Kauffman e Donato (2012) descrevem o método de amostragem em *plots* circulares, invés de quadrados (vide figura 4). Onde cada centro do círculo está a 25 m do outro e o raio (R) para colheita de informação sobre as árvores de mangais é de 7 m.

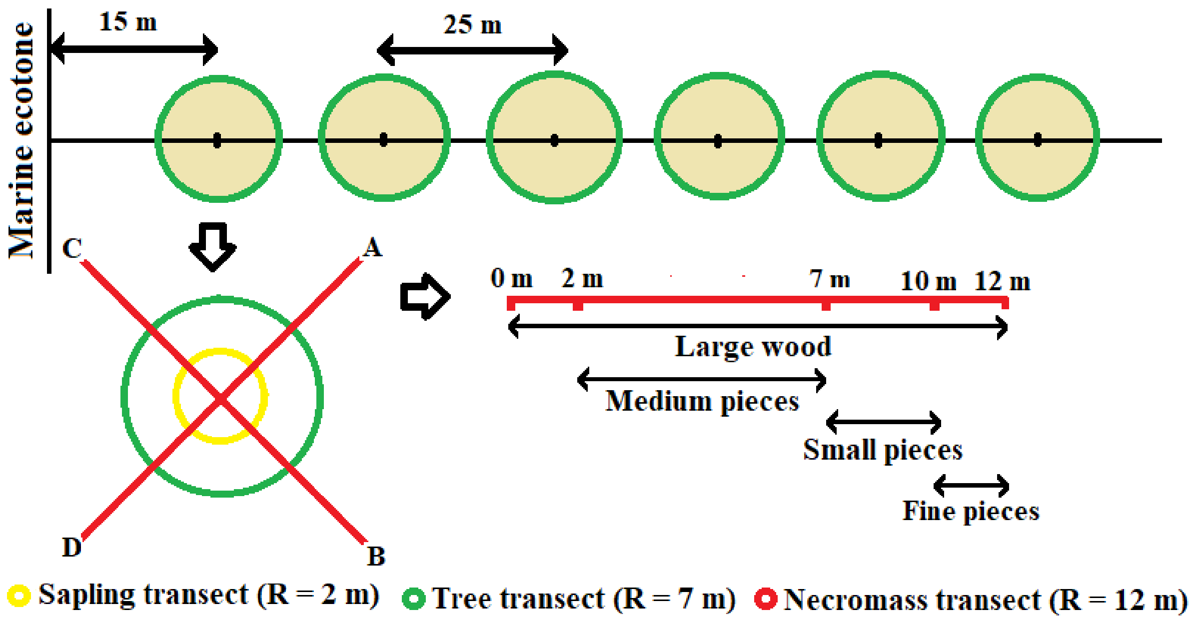

Figura 11. Método de amostragem descrito por Kauffman e Donato (2012).

Após a selecção dos pontos de amostragem, são também recolhidas as coordenadas geográficas de cada quadrícula com recurso a um GPS para a sua localização no Sistema de Informação Geográfica (GIS – ArcMap Versão 10.5).

5.3. Identificação das espécies e caracterização dos locais de amostragem

Em cada uma das quadrículas faz-se a caracterização do ambiente. As características tomadas em conta para esta caracterização, incluem: o Tipo de Solo, Tipo de floresta, Classes de inundação, Espécie visualmente mais abundante assim como a identificação de todas as outras espécies vegetais presentes nas quadrículas e anotadas na ficha de dados. Deve ser também descrita a comunidade faunística encontrada em cada quadrícula, dentre os quais Caranguejos e Gastrópodes.

5.4. Estimativa da altura e medição do diâmetro a altura do peito (DAP) das árvores

Para a estimativa da altura de árvores adultas (cumulativamente com diâmetro a altura do peito acima de 2.5cm e altura acima de 300 cm) usa-se métodos combinados: (1) fita métrica ou pau graduado para alturas até 3-4 m; (2) pau graduado ou a altura conhecida de um amostrador alto como referência para estimar a altura de árvores mais altas.

Para a medição do diâmetro a altura do peito (DAP) usa-se uma suta ou, na falta desta, uma fita métrica graduada. No último caso, no entanto, deve-se ter em conta que a medição corresponde ao perímetro, que deverá posteriormente ser convertido a diâmetro. Para as árvores com altura acima de um metro (1 m) o DAP é medido a uma altura de 1,3 m acima do chão (à altura do peito do medidor) (Kauffman e Donato, 2012; Malone *et al.,* 2009). Para os indivíduos menores será considerado, como DAP, o diâmetro do caule abaixo da primeira ramificação seguindo a metodologia de Soares (1999). DAP da espécie *Rhizophora mucronata* é medido acima da última raiz.

Indivíduos que apresentavam o caule dividido em dois ou mais são medidos individualmente e consideradas como sendo árvores diferentes ou efetua-se a soma das medidas obtidas para cada uma das ramificações desse caule. Em florestas onde se observe a presença de várias árvores com DAP inferior a 2,5 cm serão consideradas adultas aquelas árvores que apresentavam flores e/ou propágulos.

São seguidos protocolos para as diferentes possíveis situações a serem encontradas no campo segundo Malone *et al*., (2009):

- Se uma árvore estiver crescendo sob um declive a medição do DAP será feita do lado alto desse declive numa altura de 1,37m.
- Se a árvore estivesse inclinada, o seu DAP será medido do lado superior da árvore

- Para árvores que apresentarem o caule bifurcado à altura do peito, será medido o DAP de cada um dos caules formados e somar-se-á as medidas. Quando a bifurcação iniciar na base do caule, estes serão medidos como árvores separadas.
- Caso a árvore tiver um tronco deformado na altura do peito, tornando a medição não precisa, a medição será feita acima ou abaixo da deformação.
- Quando encontradas árvores com caules achatados, a medição do DAP será feita do ângulo que permitisse obter a menor espessura do caule.

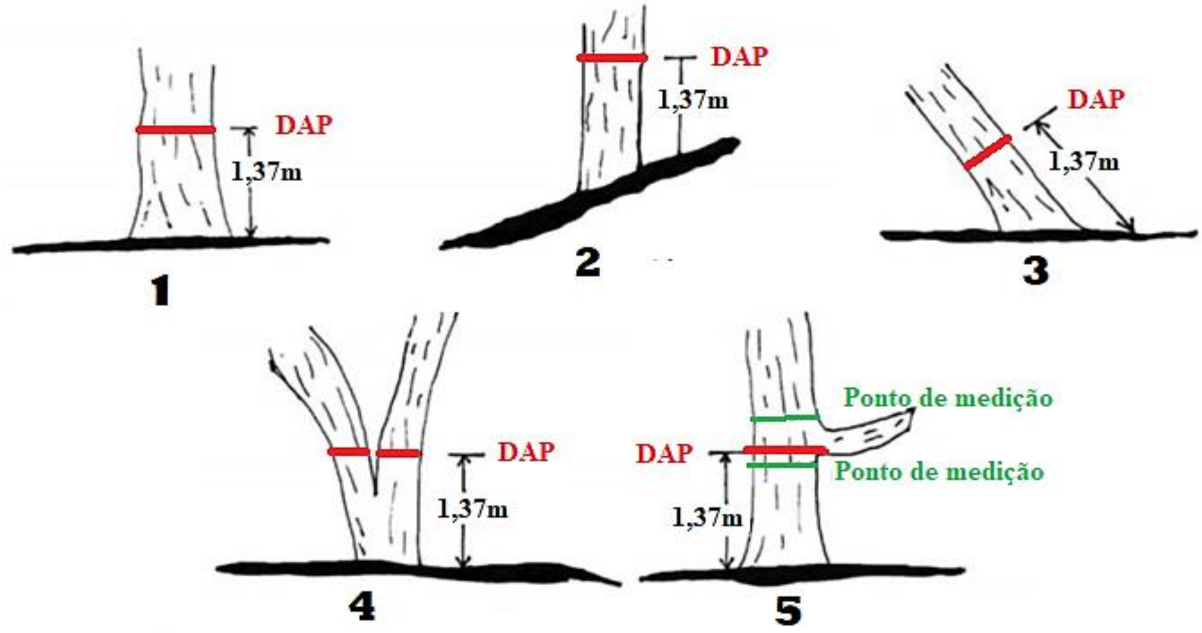

Figura 12. Pontos de medição do diâmetro acima do peito (DAP) sob diferentes condições em que as árvores podem ser encotradas: árvore erecta (1), em declive (2), árvore inclinada (3); bifurcada (4) e deformada (5).

As medidas do DAP e altura para cada árvore são devidamente anotadas na folha de campo para posterior análise.

5.5. Integridade da floresta

A avaliação da integridade da floresta é baseada na metodologia de Kairo *et al.,* (2001) e Bandeira *et al.,* (2009):

- *Árvore intacta* (I) – para árvores que não apresentam nenhum sinal de dano;

- *Árvore parcialmente cortada* (PC) – para árvores que apresente um ou poucos ramos cortados correspondentes a uma percentagem menor de 50% dos ramos, e com o seu tronco principal intacto;
- *Árvore severamente cortada* (SC) – para árvores que apresentem muitos dos seus ramos cortados, em mais de 50%, especialmente com o tronco principal cortado;
- *Cepo* (C) – para árvores que foram completamente cortadas na base, sem caule e/ou ramificações saudáveis;
- *Morte natural* (MN)– para árvores secas, cuja morte tenha sido causada por factores naturais, tais como doença, sedimentação ou velhice.

A condição da árvore pode ser usada para aferir a integridade da floresta, bem como o nível de exploração, uma floresta com grande percentagem de indivíduos intactos sofre pouca pressão, ao passo que uma dominância de cepos reflecte uma grande pressão antropogénica. Por outro lado, a predominância do Arvore morta pode indicar doença ou mudança brusca nas condições ambientais (ex. uma cheia, ciclone ou sedimentação acelerada).

5.6. Potencial de regeneração

Nas quadrículas onde forem efectuadas as medições das árvores adultas, será feita a contagem para cada espécie de mangal, as mudas e plantas jovens que, são plantas com DAP inferior a 2,5 cm e altura até 300 cm (Kairo *et al.,* 2002). As mudas serão classificadas em 3 Classes de Regeneração dependendo da altura (Macamo *et al.,* 2016; Macamo *et al.,* 2018; Kairo *et al.,* 2002; Komiyana *et al.,* 2005; Bandeira *et al.,* 2009; Kauffman e Donato, 2012) onde:

- RCI – mudas com menos de 40 cm de altura;
- RCII – mudas com altura entre 40 cm a 1,5 m;
- RCIII – pequenas plantas com altura entre 1,5 a 3 m.

No caso de florestas onde observa-se elevado número de mudas, a contagem é feita em sub-quadrículas de 5m x 5m (25 m^2) ou de 2,5m x 2,5m (6,25m^2) e os resultados obtidos utilizados para estimar o número de mudas numa área de 100 m^2 correspondente à quadrícula original (Mchenga e Ali, 2014; FAO, 1994).

Cuidado especial é necessário nas florestas anãs, onde pode ser difícil distinguir dos indivíduos adultos das plantas em regeneração. A presença de flores e propágulos bem como o diâmetro do caule principal podem servir de instrumentos de suporte para identificar as árvores realmente jovens das adultas anãs.

5.7. Aplicação do Índice de Conservação dos Mangais

Com base nos parâmetros estruturais do mangal acima descritos, foi desenvolvida esta métrica que avalia o estado de conservação da floresta. Não avalia a condição ecológica geral, já que os parâmetros físico-químicos não estão incluídos, no entanto, considera-se uma métrica útil assumindo que uma floresta de mangal saudável nas melhores condições ecológicas será capaz de fornecer serviços ecossistémicos de sucesso, como proteção costeira, sequestro e armazenamento de carbono, biodiversidade e outros. A aplicação deste índice requer um conhecimento básico de ecologia de mangais para evitar a comparação de florestas cuja diferença deriva de diferenças geomorfológicas, por exemplo (por exemplo: mangais de franja vs. mangais ribeirinhos), bem como compreensão dos fatores locais.

Os parâmetros estruturais usados para desenvolver o Índice de Conservação de Mangais para Moçambique foram: altura das árvores (metros), área basal das árvores (m^2 / ha), número de espécies, densidade de árvores (árvores / ha), densidade de mudas (ind / ha) e exploração humana. Foram desenvolvidos três sub-indices obtidos de (1) um ajuste do índice de complexidade; (2) o potencial de regeneração da floresta e (3) o nível de exploração humana.

Sub-índice 1: Índice de Complexidade Ajustado

A fórmula do Índice de Complexidade Ajustado (ICA) é essencialmente a logaritmação da fórmula do Índice de Complexidade, ajustada aos valores de referência para Moçambique, conforme a tabela abaixo.

Tabela 1. Parâmetros de referência para o Índice de Complexidade (IC) para as florestas em melhor estado (mais alto) e em pior estado (mais baixo) em Moçambique. As referencias são aplicáveis em Moçambique e em outros países da Região Ocidental do Oceano Índico.

Parâmetro estrutural	**Referências**		**Referência**
	Mais baixo	**Mais alto**	
Número de espécies	1	9	Bandeira et al., 2009; Macamo et al., 2015; Macamo et al., 2016; Amade et al., 2019
Densidade de árvores (árvores/ha)	2 500	6 000	Bandeira et al., 2009; Macamo et al., 2015; Macamo et al., 2018; Amade et al., 2019
Área basal (m^2/ha)	0.75	60	Bandeira et al., 2009; Amade et al., 2019
Altura média (m)	1	35	Bandeira et al., 2009; Fatoyinbo et al., 2008; Bosire et al., 2012; Amade et al., 2019
ICA	7.5	18.5	Proposto no seguinte estudo

A fórmula final para o índice de Complexidade Ajustado é:

$$\mathbf{ICA = Log_e\,(s * d * b * h)}$$

Onde:

ICA = índice de complexidade ajustado

s = número total de espécies que ocorrem na floresta

d = densidade média de árvores na floresta (árvores/ha)

b = área basal média (m^2/ha)

h = altura média das árvores na floresta

Para o cáclulo da densidade média das árvores da floresta usa-se a fórmula:

$$D_{(\text{árvores/ha})} = N/A,$$

Onde:

d = densidade

N = número total de árvores

A = unidade de área (ha)

Para cálculo da área basal média usa-se a fórmula:

$$Ab_{(\text{espécies})}\ (m^2) = \pi DAP^2/40\ 000$$

Área basal média $_{(m2/ha)}$ = soma da Ab de todas as espécies/área do quadrado em m^2 x 10 000 m^2

Para o cálculo da altura média das árvores usa-se a fórmula:

$h_{(m)}$ = soma da altura de todas as árvores medidas/número total de árvores medidas

Cinco categorias para o índice de complexidade de muito baixo a muito alto foram então definidas. Portanto, florestas com menor número de espécies, menor área basal, menor altura e menor densidade de árvores tenderão a apresentar menor índice de complexidade (Loria-Naranjo et al., 2014). Em geral, quanto melhor for a condição de uma floresta, maior será o índice de complexidade.

Tabela 2. Referências para o Índice de Complexidade Ajustado em florestas de mangal. Os valores ajustados usam como referência dados estruturais das florestas de Moçambique e da região do Oceano Índico Ocidental.

Índice de Complexidade Ajustado	Variação	Pontuação
Muito alto	]16.3 – 18.5]	5
Alto	]14.1 – 16.3]	4
Médio	]11.9 – 14.1]	3
Baixo	]9.7 – 11.9]	2
Muito baixo	]7.5 – 9.7]	1

Sub-índice 2: Índice de potencial de regeneração

Para que o potencial de regeneração de uma floresta seja considerado adequado, deve corresponder à proporção 6: 3: 1 para (propágulos, mudas e árvores jovens) (Chong, 1988). Esta proporção é de valores absolutos e obtém-se pela divisão do valor absoluto de cada classe pelo valor absoluto mínimo das classes (por exemplo, numa floresta onde a soma total de RCI = 94, RCII = 45 e RCIII = 12, a proporção será 8:4:1).

No entanto, diversas variações nessa proporção podem ocorrer, dependendo da idade e da conservação da floresta. Alguns deles são:

- Para uma regeneração natural adequada, um mínimo de 2500 mudas / ha é necessário em uma floresta jovem (FAO, 1994).
- Em florestas maduras, a densidade de mudas pode reduzir para 788 mudas / ha ou menos (21-30 anos) (FAO, 1994).
- Florestas levemente perturbadas (por exemplo: exploração madeireira em pequena escala; morte natural de uma árvore grande, etc.) podem ter um maior número e densidade de mudas, particularmente para RCI. Perturbações podem criar lacunas no dossel que facilitam o estabelecimento de novas mudas, à medida que a competição por sol e nutrientes é reduzida (FAO, 1994). Neste cenário, a abundância relativa típica

entre propágulos, mudas e pequenas árvores é: propágulos> mudas> pequenas árvores.

- No entanto, distúrbios em grande escala (por exemplo: ciclones, extração de madeira extensa, incêndio, doenças, etc.) podem ter o efeito oposto, pois grandes lacunas no dossel podem alterar as propriedades do solo (por exemplo: salinidade e temperatura) e prejudicar o estabelecimento de novas mudas. Perdas desproporcionais de árvores adultas também podem reduzir a capacidade da floresta de produzir sementes. Em tais casos, RCI pode, portanto, atingir baixas densidades, alterando a proporção acima descrita.

Cenário A: RCI> RCII> RCIII (florestas jovens ou levemente perturbadas)

Este cenário é comum a florestas jovens ou ligeiramente perturbadas. O potencial de regeneração é classificado em 5 categorias, com pontuação que varia de 1 a 5 (Tabela 6).

Tabela 3. Referências para avaliar o potencial de regeneração da floresta de mangal em florestas jovens ou levemente perturbadas. Os intervalos de variação foram obtidos dividindo RCIII por (RCI + RCII).

RCIII:(RCI+RCII)	Variação	Pontuação
Alto	]0.088 – 0.110]	5
Sustentável	]0.066 – 0.088]	4
Médio	]0.044 – 0.066]	3
Insustentável	]0.022 – 0.044]	2
Baixo	]0.0 – 0.022]	1

Cenário B: RCIII> (RCI + RCII) em florestas perturbadas

Se a soma de RCI e RCII for maior que RCIII, significa que a taxa de mortalidade das mudas é muito alta. Nesse caso, devemos considerar na fórmula a densidade de RCI apenas. Em geral, se a densidade RCI for superior a 2500 mudas/ha, a floresta deve ser sustentável (FAO, 1994).

No entanto, essas florestas precisam ser melhor estudadas para entender a causa das altas taxas de mortalidade, o que em geral é uma bandeira vermelha para a floresta a médio e longo prazo. Portanto, a pontuação varia de 1 a 3. Normalmente, o plantio artificial é recomendado se a situação permanecer por 3 anos ou mais.

Tabela 4. Valores de referência para o potencial de regeneração da floresta de mangal quando RCIII > (RCI + RCIII) em florestas perturbadas.

Densidade de mudas (RCI apenas)	**Variação da RCI apenas (propágulos/ha)**	**Pontuação**
Sustentável	> 2500	3
Médio	]1000 – 2500]	2
Insustentável	]0 – 1000]	1

Cenário C: RCIII> (RCI + RCII) em florestas maduras pouco perturbadas

Em florestas maduras (grandes árvores dispersas, alta cobertura de dossel de 70% ou mais), a densidade de mudas, mudas e árvores jovens é muito baixa ou praticamente inexistente, principalmente devido à alta competição pelo sol, que é alta nas florestas fechadas de dossel. Nesse caso, uma pontuação de 4 ou 5 deve ser atribuída, dependendo se os sinais de perturbação são observados ou não em uma determinada área de 20 x 20 m. Os sinais de perturbação incluem aqueles de causas naturais (por exemplo, sedimentação, morte) e humanas (extração madeireira, mudança no uso da terra).

Tabela 5. Valores de referência para o potencial de regeneração da floresta de mangal em florestas maduras e não perturbadas.

Condição da floresta	Pontuação
Sem sinais de perturbação numa área de 20 x 20 m	5
Sinais de perturbação numa área de 20 x 20 m	4

Sub-índice 3: Índice de Integridade da Floresta

Este sub-índice considera uma das maiores ameaças aos mangais em Moçambique e na região da WIO, que é a extração de madeira. Também contempla a morte de árvores, que pode ser induzida pelo homem ou causada por fenômenos naturais. De qualquer forma, a morte massiva pode ter um impacto significativo no funcionamento ecológico da floresta, portanto, deve ser considerada. As árvores podem ser classificadas como (1) intactas, (2) parcialmente cortadas, (3) severamente cortadas, (4) cepos e (5) morte natural. Este sub-índice considera a soma das percentagens de corte severo de árvores, cepos e morte natural (SCM), como indicativos de desmatamento e/ou degradação.

Tabela 6. Valores de referência para a integridade da floresta de mangal em Moçambique

Categoria da floresta	Soma da % das árvores	Pontuação na fórmula final	Premissas
Semi-intacta	[0 – 5[	5	Florestas degradadas têm alta densidade de árvores cortadas ou mortas e são incapazes de fornecer serviços ecossistémicos essenciais, como biodiversidade, viveiro e proteção costeira
Saudável	[5 – 10[	4	
Em risco	[10 – 15[	3	
Não saudável	[15 – 25[	2	
Degradada	>25	1	

5.8. Índice de Conservação dos Mangais

O Índice de Conservação de Mangais resulta da combinação dos 3 sub-índices. O índice varia entre 1 e 15, onde:

Índice: 1 - 5 (estado de conservação mau)

Índice: 5 - 10 (estado de conservação moderado)

Índice: 11 - 15 (estado de conservação bom)

O índice de conservação dos mangais é obtido a partir da seguinte fórmula:

ICM = ICA+ IPR + IIF

onde,

ICM - Índice de Conservação de Mangais

ICA = Índice de Complexidade Ajustado

IPR = Índice de Potencial de Reprodução

IIF = Índice de Condição da Floresta

1. Ficha de Campo de levantamento de dados em florestas de mangal

Data: ___/___/____ Local_____________ No de transecto _____Nº do quadrado_____
Local_______________________.
Coordenadas Y________________ X__________________
Tipo de Floresta________________ Espécie Dominante________________________
Colector ______________________

Composição do Solo:	Classes de inundação:		Fenologia:	Vulnerabilidade:	% de Cobertura:	Tipo de solo:
Turfa	Maré morta		Flores	Alta	0-20	Solto
Turfa/Argila	Maré viva		Frutos	Média	21-40	Intermédio
Argila	Viva alta			Baixa	41-60	Firme
Lodo	Muito alta	2x/ano			61-80	
Areia					81-100	

pH________ p. Redox________Temp. _______Sal. ______ Condu. Electr. _________ OD________ Turbidez________ Sólidos Suspensos________ Nitro. ____
Fauna ____
____
Observações ____ ____

	Plantas adultas					Regeneração			
	Tamanho do quadrado _____x_____					Tamanho do quadrado ____x_____			
No	Espécie	DAP (cm)	Altura (m)	Condição da árvo	Qualidade da estaca	Espécie	Classes de Regeneração		
							I	II	III
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
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