Impact of Cyclones and Floods on Seagrass Habitats

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Abstract

Seagrasses are true plants that live in shallow marine water of both tropical and temperate waters. Seagrass meadows are crucial for primary production and biodiversity, carbon sequestration, water purification, coastal protection and food for megafauna like dugongs. This chapter combines desk work (systematic review of existing publications) and field assessment, highlighting multiple impacts of cyclones and floods on seagrass. SPOT 5 and Landsat imagery were used for mapping over 21-year period (1992–2013), and changes in Inhambane Bay are linked to multiple cyclones that prompted a total seagrass area reducing from 12,076 ha to 6199 ha (51% of the original area). In Maputo Bay, seagrasses were impacted by both the 2000 floods and anthropogenically due to poor practices of uprooting seagrasses for clam collection. Seagrasses reduced 7% a year in western Maputo Bay and 1.2% in Inhambane Bay. The study also documents impact of extreme events on the catches of a sardine, *Amblygaster sirm*, in Inhambane Bay and on clams abundance and species diversity in Maputo Bay. The construction of new wave breakers in Maputo city prompted land reclamation and may have led to the disappearance of bivalves *Salmacoma litoralis* and *Anadara antiquata*. This account on seagrass status formed the basis for seagrass restoration initiative.

18.1 Introduction

Seagrasses are true plants, with flowers and fruits, belonging to angiosperms that live in shallow marine water of both tropical and temperate waters across the globe. Seagrass is crucial for primary production, water purification, and protection against erosion, recycling and nutrient transport to neighbouring habitats and high seas, being a nursery for fish and invertebrates, food for dugongs and also attract seabirds. Clams derived from seagrass meadows are valued delicacies within coastal regions and urban centres of Mozambique and elsewhere. Seagrasses are important carbon sink too. They dominate marine

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seascape especially in shallow waters of the Western Indian Ocean and particularly in Madagascar, Mozambique and South Africa. Changes in seagrass coverage and related invertebrates were documented and attributed to both floods, climate-related and anthropogenic causes. In this chapter, we highlight changes that have occurred in Inhambane Bay over quite a long period subjected to several cyclones and also document impacts of 2000 floods in Maputo Bay seagrasses and related edible invertebrates. Inhambane and Maputo Bays are all located in southern Mozambique.

18.2 Literature Review

18.2.1 Seagrass Definition and Distribution

Seagrasses are flowering plants, comprising a group of marine plants which have adapted to live in the marine environment forming meadows in shallow coastal waters around the world. This was achieved through the acquisition of adaptations such as specific morphology with anchorage systems made up of rhizomes and roots, stems, air lacunae, flowers with hydrophilous pollination and vivipary in some species (den Hartog, 1970; Elmqvist & Cox, 1996). Seagrasses have also adapted to take up nutrients into the plant tissue by both roots and leaves (Hemminga, 1998). Seagrasses are mostly clonal plants with shoots (vertical rhizomes) arising from horizontal rhizomes below the ground, and most species have flat linear leaves with parallel veins (Fig. 18.1), except *Halophila* spp., with stalked leaves, and *Syringodium isoetifolium*, with cylindrical leaves.

There are around 70 described species of seagrasses worldwide, within 12 genera, four families and two orders. The most common seagrasses in Mozambique and the Western Indian Ocean region including southern Africa are *Zostera capensis, Cymodocea serrulata, Cymodocea rotundata, Halodule uninervis, Halophila ovalis, Halophila stipulacea, Enhalus acoroides, Thalassia hemprichii, Thalassodendron ciliatum* and *Thalassodendron leptocaule. Thalassodendron leptocaule* is the only species occurring in rocky pools, being also endemic to those sandstone areas of southern Mozambique and KwaZulu-Natal, in South Africa (Duarte et al., 2012; Browne et al., 2013). Being marine plants dispersed by seawater, they occur almost everywhere in the world as well as in all coastal countries in southern Africa (exception to Namibia, with no record).

Seagrass species can also differ in terms of the breadth of their distributional ranges (broad vs. restricted), their reproductive strategies (e.g. rapid seeding, seed banks and vegetative reproduction), the degree of their persistence (ephemeral vs persistent), physiology (e.g. growth dynamics, nutrient cycling and response to disturbance) and their ecological interactions (e.g. the influence of grazing, leaf canopy structure, detritus and epiphyte production). Assemblages of seagrass species give rise to a series of dynamic as well as temporally and spatially variable seagrass meadows. Changes in the species composition of seagrass meadows may indicate slow but important changes in the environment (United Nations Environment Programme, 2020).

Seagrass meadows typically occur in most shallow, sheltered soft-bottomed marine coastlines and estuaries. These meadows may be monospecific or may consist of multispecies communities, sometimes with up to 12 species present within one location (Green & Short, 2003; Bandeira, 2002). Seagrasses are closely ecologically linked with other coastal habitats such as mangroves and coral reefs in the tropics, tidal marshes and kelp forests in temperate areas (Huxham et al., 2018).

18.2.2 Seagrass Importance: Ecosystem Services, Benefits and Goods Provided

Seagrass together with mangrove forest and coral reefs, in addition to rocky shores, shallow waters including estuarine areas and coastal forests, are key habitats helping sustaining livelihoods and life in the nearshore and beyond. Global extent of
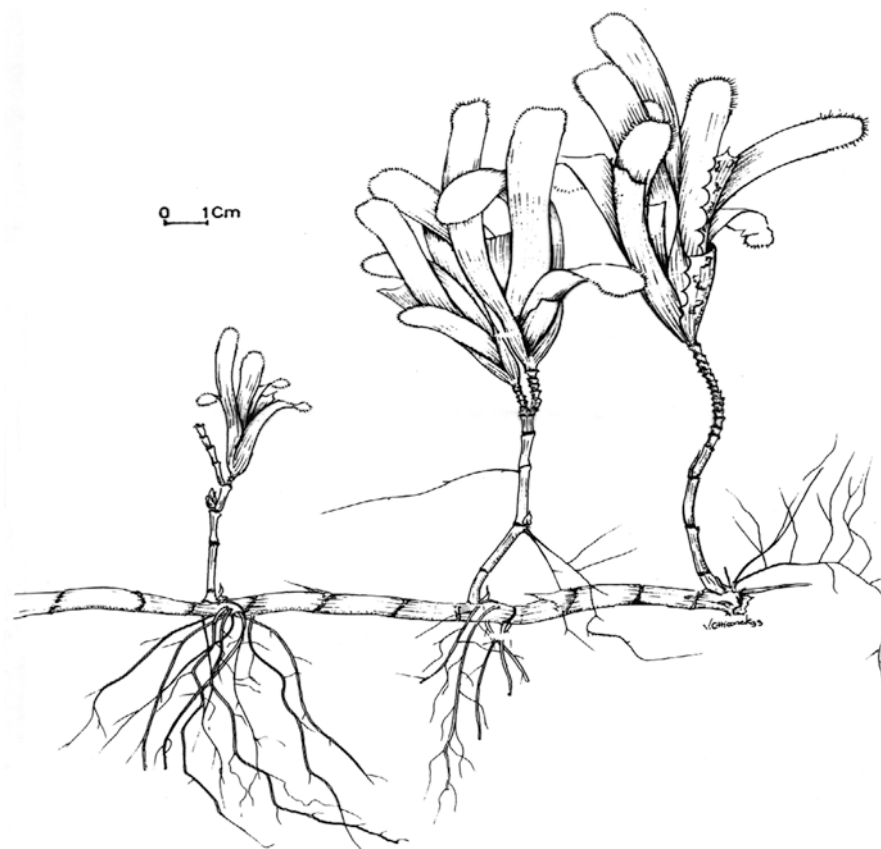
Fig. 18.1 Seagrass *Thalassodendron ciliatum* from Inhaca Island, Mozambique. (Source: Drawing supplied by Viriato Chiconela)

seagrass is conservatively estimated at 300,000 km² although challenges in assessment of seagrass cover, and the resulting absence of a global, regularly updated database of seagrass meadows, mean that this figure is acknowledged to be approximate and their actual extent may be 600,000 km² or even more (Green & Short, 2003; Mcleod et al., 2011).

Seagrass ecosystems provide a wide variety of services that support human well-being around the world. It is estimated that at least 1 billion people live within 100 km of a seagrass meadow (Small & Nicholls, 2003), as per the assessment of the population leaving within the coastal areas, covering around some 60%, 19 million people in Mozambique. These include provisioning services such as regulating services (including carbon sequestration, coastal protection and water purification, also making the system less acidic), cultural (including education and tourism) and supporting services (including habitat for commercial species) (Nordlund et al., 2016). We highlight the following main global functions of seagrasses.

18.2.2.1   Food Security

Seagrasses support essential commercial and artisanal fisheries, the communities and economies that rely on them. Seagrass meadows are of fundamental importance to world fisheries production of both vertebrates and invertebrates in a variety of ways (Unsworth et al., 2019). Seagrass meadows provide valuable nursery habitat to over 1/5th of the world's largest fisheries (United Nations Environment Programme, 2020).

In cases where seagrass is close to coastal communities, such as in coastline Mozambique, the seagrass meadow is often a fishing habitat important for the supply of local food. Invertebrate gleaning fisheries occurring within seagrass meadows are considered to be an accessible fishing activity mainly due to their shallow nearshore environment and the ease of collecting such fauna (Nordlund & Gullström, 2013; Fernando et al., 2014). As an example, data from Maputo Bay indicate that seagrasses function as important nursery grounds for fish and crustaceans, many of which are of commercial importance (Gullström & Dahlberg, 2004; Inguane Vicente & Bandeira, 2014).

18.2.2.2 Maintaining a Healthy Climate

Seagrasses account for less than 2% of the world's oceans area but are responsible for 18% of the organic carbon (C_{org}) annually stored in the oceans (United Nations Environment Program, 2020). Up to 19.9 Pg (pentagrams) of C_{org} is stored in seagrass ecosystems; twice as much as the carbon stored in temperate and terrestrial forests (Fourqurean et al., 2012), making them a vital component in combating global climate change. Carbon sequestration of seagrasses at Inhaca Island reached around 2500 gm^{-2} of organic carbon; sink capacity may vary concerning factors such as seagrass species, plant morphology, sediment type (e.g. proportion of calcium carbonate), sediment depth and latitude (Gullström et al., 2017).

Seagrass captures carbon in above-ground biomass (plant leaf and stem tissues), below-ground biomass (root and rhizome tissues) and, most significantly, in the underlying sediment. This sediment carbon may be autochthonous (generated by the plant itself) or allochthonous (generated elsewhere and captured by seagrass ecosystems).

Seagrass is one of three 'blue carbon' ecosystems (seagrass, mangroves and saltmarsh) so-called for their capacity to sequester atmospheric CO_2. This carbon accumulation is due to a combination of high autochthonous productivity (the ability to convert CO_2 into plant biomass), the capturing of allochthonous carbon (Geraldi

et al., 2019) and low rates of decomposition of buried carbon (in part due to the anoxic conditions of underlying soils.

18.2.2.3 Improving Water Quality

Seagrass meadows contribute to human and ocean health. Seagrass produces oxygen as a by-product of photosynthesis, which helps rid the waters they grow in of pathogens and bacteria that could be harmful to human health. Seagrass meadows also regulate the chemistry of seawater by the uptake of dissolved carbon dioxide. This helps regulate the pH of seawater, making it less acidic and less harmful to marine organisms with calcium carbonate skeletons such as corals and crustaceans (United Nations Environment Programme, 2020).

18.2.2.4 Supporting Rich Biodiversity

Crustacean and fish abundances are higher in seagrass meadows compared to adjacent bare sand areas (United Nations Environment Programme, 2020). Many species of commercial importance of mangrove and reef fish rely on seagrass meadows as nurseries and foraging grounds (Berkström et al., 2020). Seagrass is also an essential food source for endangered species such as dugongs (Fernando et al., 2014). Dugong feeding tracks are observed in multiple locations around Inhaca Island (Fernando et al., 2014) and Bazaruto archipelago.

18.2.2.5 Cultural and Resource Value of Seagrasses

Few publications are detailing the cultural value of seagrasses in this region, however, known that seagrasses, in general, have a role as a cultural resource and wider component as a sense of place unmatchable if the seagrasses were to be replaced by unvegetated area. To these communities, such areas represent an important location that resonates with their traditional livelihoods, resources and well-being. There is a wide variety of seagrass ecosystem services supporting human well-being around the world (Nordlund et al., 2016).

Resource wise seagrasses are linked to the artisanal fisheries as documented in several studies assessing biodiversity, abundancy of meiofauna and endofauna (Inguane Vicente &

Bandeira 2014; Fernando et al., 2014). Seagrass meadows are an important cultural resource for coastal communities and are intrinsic to the socio-economic-cultural landscape of these communities. For Maputo Bay, seagrass is associated with cultural traditions that are intricately linked to livelihoods derived from seagrasses such as:

– Place where mostly woman gather and talk on their daily life while collecting invertebrates (clams and crayfish). The dishes produced from the clams (*Eumarcia paupercula* and *Meretrix meretrix*) from Maputo Bay are usually rated unique in the entire Western Indian Ocean (WIO) region. This is added to shrimps from the bay; while these are caught in a muddy area, some shrimp species have part of their life cycle in nearshore and within seagrass meadows.
– A souvenir industry is also based on items collected in seagrass beds (sea stars, dried fish, shells, etc.). While some of this may threaten the natural populations of these species, they need to be well regulated and reinforced.
– Seagrasses has considerable value for descriptive, experimental (e.g. restoration) and on socio-anthropological studies. Examples are the ongoing research on seagrass meadows in southern Africa (e.g. South Africa, Mozambique, Tanzania).
– As part of a sense of belonging and sense of place, seagrass meadows also provide many educational, recreational and tourism benefits and opportunities. Inhaca is home to one of the oldest training stations in the Indian Ocean, and over the 70 years of Estação de Biologia Maritima da Ilha da Inhaca (EBMI) existence, it has catered for marine research (local, from the region and overseas).

18.3   Materials and Methods

This document was compiled based on existing publications on seagrasses focusing on Mozambican sites namely Inhambane Bay (Amone-Mabuto et al., 2017) and Maputo Bay (Bandeira, 2002; Bandeira et al., 2014). Mapping

of seagrass coverage in Inhambane Bay and Maputo Bay (southern Mozambique) was performed by combining remote sensing (SPOT 5 and/or Landsat imagery methods) with support of extensive groundtruthing (direct observation on the ground). Information on the status of invertebrates was also derived from literature (mostly Murrube, 2018).

To assess and monitor the impact of the rehabilitation of the coastal zone of Maputo city, a study was carried out on richness, abundance and similarity between bivalves community before and after rehabilitation in selected areas of Maputo city coastal areas, namely Marítimo and Bairro dos Pescadores (Murrube, 2018). Data before rehabilitation were derived from available literature (e.g. Bandeira & Paula, 2014).

18.4   Presentation and Discussion of Findings

18.4.1   Impact of Extreme Events on Seagrass – Case of Multiple Cyclones in Inhambane Bay and the 2000 Floods in Mozambique

Maputo and Inhambane Bays (Mozambique) have experienced both anthropogenic and climate-related impact on seagrass integrity. According to Amone-Mabuto et al., (2017), in Inhambane Bay in 1992, seagrass covered 12,076 ha, and between 1992 and 1998, large areas of seagrass (5714 ha, 47.3%) were lost as it appears that this dramatic decline in seagrass area could have been an impact caused by cyclone Bonita (winds of around 180 mm/h), which struck the region in 1996. Further, 721 ha of seagrass were lost between 1998 and 2001 coinciding with cyclone Eline that transited the region with winds of around 200 km/h in February 2000. In 2001, Inhambane Bay had the lowest seagrass cover (23% of its original area) in the period analysed. Cyclone Eline brought very strong winds associated with intense rainfall and created one of the worst natural disasters according to Mavume et al. (2014). Rainfall and flooding might have brought sediments into the bay,

impacting the seagrass meadows. During the period between 2001 and 2004, some 960 ha (4%) of seagrass area was gained, the largest gain in Inhambane Bay. Between 2004 and 2013, 400 ha was lost, possibly from an anthropogenic impact, but it should be noted that the cyclone Favio (approx. 200 km/h winds) struck the region in 2007 as well. Figure 18.2 depicts the variation of seagrass area coverage over the period impacted by four cyclones.

Inhambane Bay has an estimated area of 24,152 ha of which half was covered by seagrass area (50%). This can be seen as baseline area, subsequently reduced to 26.3% and 23.3% as referred to be related with cyclone Bonita and Eline, respectively. In subsequent years, the sea-

grass area increased but never reached the 1992 baseline (Table 18.1). We believe that the cyclones were the main contributing factors in changing seagrass areas over the years. Inhambane Bay does not have a major activity impacting directly to seagrass reduction, apart from sea urchin *Tripneustes gratilla* grazing reported as intense in some areas near Guiduane Island.

The heavy 2000 floods that strut Maputo city and Maputo Bay as a whole did impact the sea-grass coverage especially in the western Maputo Bay, thought anthropogenic impact, through an intense collection of clams by using sand revolving tolls have also contributed to seagrass reduction. Communities intensively dig for clam
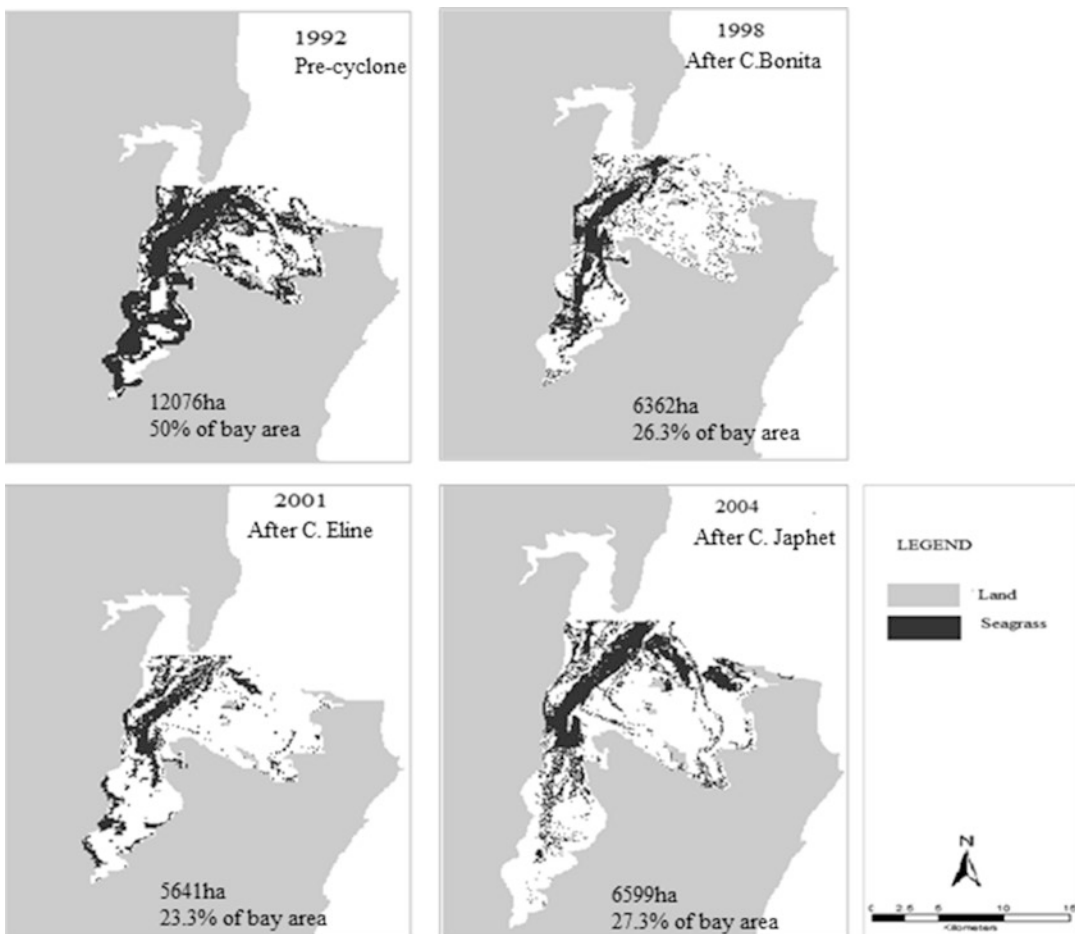

Fig. 18.2 Distribution of seagrass cover in Inhambane Bay in 1992, 1998, 2001 and 2004. (Source: Amone-Mabuto et al., 2017)

collection, a recurring activity mostly during spring tides. Inhambane seagrass meadows have reduced at a rate of 1.2% a year, whereas the highest known rate was 7.2% observed in the western Maputo Bay (Table 18.2), causing a reduction 86% of seagrass area between the years 1991 and 2003.

18.4.2 Impact on Seagrasses Fauna

Little is known about the impact of cyclones on region marine fauna; however, for Inhambane Bay, a lower annual catch reduction was observed from 166 to 60 metric tons (from year 2000 to 2001) corresponding to 64% reduction of a Indo-West pacific spotted sardinella *Amblygaster sirm*, a pattern probably also representing an indicator of seagrass losses in Inhambane Bay during this period (Halare, 2012; Amone-Mabuto et al.,

2017). This is a pelagic species, partly occurring in shallow waters and lagoons, and those reductions coincide with the passage of cyclone Eline (in 2000) that landed the Inhambane province wider region, causing the death of people and widespread loss of properties. Data of this fish species just before and after Japhet cyclone (in 2003) indicated a reduction in annual catches from 115 to just 2 metric tons (98.3% reduction) (Halare, 2012). Catches of this species attained almost pre-cyclone levels 2 years after a cyclone (Halare, 2012), a pattern that may be linked to seagrass recovery than impact on fisheries effort. At Inhambane/Guiduane Island – Inhambane Bay, local communities associate cyclone Dineo (2017) with the reduction of mangroves and seagrass areas, with a direct impact on coastal protection role causing erosion; some indirect impact on the fauna may have occurred, however, not estimated.

Two species of bivalve namely *Eumarcia paupercula* and *Meretrix* were abundant on seagrass beds of Bairro dos Pescadores and scattered intertidal sandbanks area along Costa do Sol, both contiguous in the north of Maputo town. However, the continue large-scale collection of invertebrates within, climatic events and the building of barriers along Costa do Sol prompted extensive reduction of these species in Bairro dos Pescadores and mentioned sandbanks along Costa do Sol. Currently, for marketing purposes of these species already a delicacy in Maputo, large quantities are captured in other sheltered and estuarine areas of the Bay, in peri-urban and rural locations such as Gazene, Muntanhana and further inland from the Incomati Estuary.

Table 18.1 Summary of contributing factor in seagrass area change within Inhambane Bay

Seagrass maps	Seagrass area (in ha)	Trend	Climatic contributing factor
1992	12,076	Baseline data	–
1998	6362	Decrease	Cyclone Bonita in 1996
2001	5641	Decrease	Cyclone Eline in 2000
2013	6599	Increase	Cyclone Japhet in 2003 Cyclone Fávio in 2007
Present (2020)	Unknown	Unknown	Cyclone Dineo in 2017

Table 18.2 Seagrass cover changes

Site	Area cover change per year	Period of measurement	Causes of seagrass degradation	References
Inhambane Bay	1.2%	1992–2013	Several cyclones	Amone-Mabuto et al. (2017)
Eastern Maputo Bay/Inhaca Island	0.26%	1992–2003	Mainly sand accretion, trampling	Bandeira et al. (2014)
Western Maputo Bay	7.2%	1992–2003	Sedimentation from flooding and seagrass uproot for clams collection	Bandeira et al. (2014)

18.4.3 Impact of Rehabilitation Process on Intertidal Fauna

The coastline dynamics in southern Mozambique is dominated by the prevailing wind patterns and hydrology typical of southern Mozambique coastline that enables continue deposition of sand and dune build-up (Tinley, 1985). The underlining erosion prompted by weather events and anthropogenic activity in Maputo city northern coastal areas was rehabilitated in 2012 with the purpose to limit the natural dynamics of the coast and the mobility of the coastline. An integrated plan to protect public and private properties and reduce the deterioration of the environment is believed set with this coastline reclamation and rehabilitation. The rehabilitation of Maputo seashore area consisted in designing the Avenida da Marginal including the pedestrian tours and the coastal protection wall. This coastal touristic area of Maputo city undergone a land reclamation through the upgrading of new road infrastructure and construction of several new sea-breaks (finalized in 2013). These enable some degree of protection on coastline infrastructure as it allowed sand accretion and coastline built-up along the seashore of around 10 km. The groyne implant or sea-breaks (Fig. 18.3) priory to the upgrade of the marginal road enables an increase of up to a 130.8 m of the coastline since 2012.

It appears that such accreting coastline prompted the modification of sand texture, enabling therefore the disappearance of some clam species. *Salmacoma litoralis* and *Anadara antiquata* are two species of bivalve that occurred before the intertidal zone land reclamation along in Avenida Marginal. However, after the rehabilitation, these two species were not found (Murrube, 2018) only north ward (at Bairro dos Pescadores where such groyne construction did not take place).

While a climate adaptation programme that put in place wave breakers and upgraded the road was to respond to the vulnerability of the beach-front regions within Maputo city, it appears that these interventions have galvanized the change and disappearance of clam species (*Salmacoma litoralis* and *Anadara antiquata*) apparently related with change in pattern of the sedimentation. We highlight that coastal restoration in Maputo was primarily to protect infrastructure and people from tide surges. Mavume et al. (2014) raised awareness regarding the need to understand and document high-risk areas from intense cyclones coupled with storm surge: also floods. Maputo city northern coastline was reported having high change of being flooded if no infrastructure adaptation occurred.

A global analysis of seagrass decline by Waycott et al. (2009) indicates various root causes, mostly anthropogenic, for seagrass decline mainly in North America, Europe and Australia. It includes some localized cases of seagrass increase as well, but with fewer examples of widespread seagrass decline in South America, Africa and NE and SE Asia. Inhambane Bay is surrounded by a relatively small rural and peri-urban population of up to 200,000 inhabitants with limited activities that impact on seagrasses, such as motor boating, point sewage discharges and earthmoving operations that are likely to have major impacts on seagrasses.

Seagrass restoration initiative in Mozambique comes as a corollary of quite a detailed research for management carried out over decades mainly in Maputo Bay, targeting mostly seagrass mapping, structure dynamics including invertebrate socio-ecological assessments (Nordlund & Gullström, 2013; Bandeira et al., 2014) that has, in recent years, culminated with testing several restoration techniques for the most impacted species.

18.5   Conclusions

In conclusion, this study documents total seagrass area reduction from 12,076 ha to 6199 ha (51% of the original area) in Inhambane Bay. 2001 was the year when seagrass occupied the smallest area in Inhambane Bay with 5641 ha, apparently related to the impacts of Tropical Cyclone Eline with winds of around 200 km/h, and lasting for 29 days with widespread damage on human and natural infrastructure. A steady seagrass recovery was observed afterwards

Fig. 18.3   Section of Maputo city Avenida Marginal (coastal line). (**a**) Without groyne (sea-break) and (**b**) with groyne allowing sand accretion up to 130 m into the sea

between 2001 and 2004, where 958 ha of seagrass restored naturally. Catches of a known Indo-West pacific spotted sardinella *Amblygaster sirm* reduced 64% and 98.3% in the years 2000–2001 and 2003–2004, respectively, coinciding with the passage of cyclones Eline (in 2000) and Japhet (in 2003). The seagrass beds in Maputo Bay are reported under pressure especially in the northwest Maputo Bay but also to a minor scale around Inhaca Island (eastern Maputo Bay). Northwest of Maputo Bay is subjected to two pressures: sedimentation due to 2000 floods that hit Maputo city and anthropogenic impacts due to digging for clam collection that prompted an 86% decrease of seagrass cover as documented for the period 1991–2003. A moderate impact on seagrasses around Inhaca Island (3.2% reduction, 129 ha during the period 1991–2003), due to both natural disturbances, such as sand accretion and sedimentation, and anthropogenic causes (trampling, motorboats and a jetty construction), was observed (eastern Maputo Bay). The rehabilitation process of seashore in Maputo city bathing areas may have led to the extinction of *Macoma coastalis* and *Anadara antiquata* in the area. These monitoring methods and information gathered create a basis for better management and prediction of impacts on marine habitats. Thought regular updates of status of seagrasses and

impacts or recurrent climate events such as floods in Mozambique are needed. Furthermore, such studies are being used as a basis for a pioneering experimentation of seagrass restoration in Maputo Bay.

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