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Support for climate adaptation and mitigation actions

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Foreword

Climate change is recognizably a global issue currently affecting natural ecosystems and human society. Immediate and concrete actions need to be taken to reverse the rise in greenhouse gas emissions. The Ocean plays a critical role in regulating the global carbon cycle by absorbing nearly one third of the atmospheric carbon dioxide. This blue carbon is sequestered in coastal ecosystems such as mangroves and seagrasses, which have a great capacity to store carbon in their sediments over long time scales. Vegetated coastal habitats represent one of the most efficient carbon sinks naturally available and are therefore an important tool for climate mitigation and adaptation, in addition to being crucial habitats hosting rich biodiversity and providing key ecosystem services.

Despite their relevance, these habitats are being lost at a critical rate worldwide due to climate change and human activity. Maintaining and enhancing carbon sinks is a crucial aspect of climate mitigation, therefore the protection, restoration and expansion of blue carbon habitats must be considered a priority.

The coastal seascapes of Tanzania and Mozambique host an extensive distribution of carbon-rich blue forest ecosystems. Nonetheless, the climate change mitigation potential of this region remains poorly quantified.

This report provides an assessment of the carbon stocks in the understudied West Indian Ocean (WIO) region; it quantifies carbon stocks and demonstrates the presence of blue carbon hotspots in areas of large, continuous and sheltered mangroves and seagrass meadows. However, these hotspot areas are fragmented due to overexploitation and human activities. Blue carbon hotspots were found within Marine Protected Areas (MPAs), but a significant number of these areas were found to lie outside of legally-protected or locally-managed marine areas, and therefore potentially exposed to a higher risk of degradation. This degree of degradation is alarming when considered alongside the ongoing documented loss of mangrove and seagrass area-coverage in the region and the future loss due to rising temperatures and sea level as predicted by IPCC's latest Special Report on the Oceans and Cryosphere in a Changing Climate.

This report is part of IUCN's Oceans and Climate Change initiative funded by the Swedish government. With this report, IUCN aims to inform coastal management and spatial planning efforts to ensure that carbon capture and storage together with other ecosystem services (e.g. biodiversity) are adequately protected and, where possible, enhanced. This will further ensure that fish, seafood and other resources will continue to benefit some of the most vulnerable and resource-dependent communities in the region.

Climate mitigation, driven by the protection and restoration of blue carbon, should be explicitly considered in the implementation and management of protected areas on the coastlines of Tanzania and Mozambique. Existing MPAs should be effectively managed and monitored to safeguard long-term blue carbon stocks in the WIO region and the identification of blue carbon stocks may provide guidance for increasing MPA coverage to conserve and improve connectivity between hotspots of blue carbon in concert with the protection of other vital ecosystem services. On a broader scale, the design and management of MPAs in blue carbon areas, should consider synergistically the protection and restoration of both biodiversity and carbon stocks.

Further, this report aims to support regional, national, and sub-national resource managers and policy makers to develop strategic frameworks in order to protect existing blue carbon habitats and develop incentive mechanisms for the restoration of these ecosystems. Such actions will benefit climate adaptation and mitigation actions as well as marine spatial planning and integrated coastal zone management.

Minna Epps, Director,
IUCN Global Marine and Polar Programme

Acknowledgements

This report presents the outcome of a comprehensive survey of blue carbon stocks across the coastal regions of Tanzania and southern Mozambique. Extensive field assessments were carried out in different blue forest ecosystems with focus on general patterns of variability and effects of marine protected areas on sedimentary carbon storage levels.

We are deeply grateful for all the support from people working in field and in the laboratory, including Liberatus D. Lyimo, Maria E. Asplund, Said S. Mgeleka, Mathew O. Silas, Miranda Lörstad, Andrius Garbaras, Manuela Amone, Laura Chiluvane, Karen Bowles, Muhidin Mtumwa, Trecy Magati and Debora Mussa. Thanks also to Mwita M. Mangora, Saleh A. S. Yahya, Matern S. P. Mtolera and Salomão Bandeira for general support during the field survey periods.

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Executive summary

Global climate change occurs at an unprecedented rate and is a near impossible challenge for policy- and decision makers around the world. The global mean warming has already reached c. 1°C above the pre-industrial level, which primarily is the result of a response to the continuous and increasing greenhouse gas input into the atmosphere from various anthropogenic activities. In the latest reports (published 2019), the Intergovernmental Panel on Climate Change (IPCC) highlights the exigency of prioritizing timely, ambitious and coordinated mitigation actions. The oceans play a critical role in regulating global temperatures, and a multitude of climate mitigation and adaption options are related to and adaption options are dependent on the bio-physical functions of oceans and coasts. Hence, several conservation and restoration activities may play a role in mitigating the impacts of climate change.

Globally, there is a general interest in marine ecosystems due to their potential in mitigating climate change. Several marine and coastal ecosystems have the potential to significantly sequester and store organic carbon. Blue carbon stored in vegetated coastal habitats (mangroves, seagrass meadows and salt marshes) is today considered important because of their ability to absorb atmospheric carbon. Unfortunately, the accelerating degradation and loss of these ecosystems is releasing carbon. Therefore, the development of strategic policy frameworks to protect and restore these ecosystems is of upmost importance. This report presents the status of blue carbon habitats in the understudied Western Indian Ocean. The report provides new data from a comprehensive assessment of blue carbon stocks from coastal habitats (mangroves and seagrass meadows) within and outside existing protected areas of Tanzania and southern Mozambique. Hotspot areas of coastal blue carbon sequestration and storage were primarily identified in areas of large, continuous and relatively sheltered mangroves and seagrass meadows. These areas were, however, commonly found outside of marine protected areas. The identification of blue carbon hotspot areas in this report can provide guidance for increasing MPA coverage to conserve the blue carbon sink function together with other vital ecosystem services (see section 6.6 for key findings and policy recommendations). The report aims to support national, regional and local resource managers and policy makers to develop strategic frameworks in order to protect existing blue carbon habitats and develop incentive mechanisms for the restoration of these ecosystems. Such actions will benefit climate adaptation and mitigation actions as well as marine spatial planning and integrated coastal zone management.

1. Introduction

Global climate change is affecting everything and everyone on the planet. The processes that force climate change are largely the same as those driving the world economy and geopolitics. In face of these challenges, there is an urgent need to assess all potential possibilities in order to mitigate climate change. At the historic UN Climate Change Conference (COP 21) in Paris in December 2015, countries agreed to the Paris Climate Agreement and policy makers from across the world decided to embark on an ambitious action plan in order to keep the global temperature rise below 2°C and to strive to limit the rise to 1.5°C. To avoid the risk of catastrophic climate change effects, during the last several decades, many initiatives have been launched with the goal of trying to reduce the input of greenhouse gases into the atmosphere. As a complement to these efforts, attempts to identify, and if possible, stimulate, natural processes that may contribute to decreasing atmospheric carbon dioxide concentrations have been suggested. Hence, conservation, restoration and management actions of ecosystems, which are particularly efficient in carbon sequestration and storage, have been proposed. As efficient sequestration and long-term storage of carbon is an action of critical importance, blue forest ecosystems should be given high priority in coastal management.

The ocean functions as a vital carbon sink by absorbing atmospheric CO_2. Carbon sequestration includes carbon absorbed in the water column, and carbon stored in sediments. Blue carbon is the term used for the carbon captured by marine organisms and subsequently stored and can be divided into coastal- and oceanic blue carbon. The capture rate of organic carbon is estimated to be particularly high in shallow coastal and estuarine ecosystems, such as mangroves, salt marshes and seagrass beds. In addition, these shallow-water ecosystems receive substantial amounts of carbon produced on land by terrestrial plants as well as carbon from other marine environments, such as phytoplankton from the pelagic water masses. Photosynthesis by aquatic primary producers, such as macroalgae, seagrass and microalgae, captures the organic carbon, part of which is stored in the sediments. Detailed measurements of the quantities and dynamics of organic carbon in mangroves, seagrass meadows and saltmarshes are being reported from across the world (e.g. Mcleod et al., 2011; Fourqurean et al., 2012; Serrano et al., 2019), although very few studies have been reported from the western Indian Ocean (WIO).

In 2017, the IUCN Global Marine and Polar Programme initiated a scoping project to assess marine carbon stores in protected habitats in the WIO region with an initial focus on Tanzania and Mozambique. The project aims to use best available information to estimate the extent, diversity and spatial distribution of blue carbon habitats in the region. With focus on the WIO region, particularly Tanzania and Mozambique, the outcome includes a review of coastal blue carbon habitats and protection areas, compilation of new and previous carbon stock data and recommendations for coastal managers and policy makers. This will serve as input to coastal management and protection planning to ensure that carbon capture and storage together with other ecosystem services (e.g. biodiversity) are adequately protected and where possible enhanced.

2. Blue forest ecosystems and carbon storage

2.1 General information about blue carbon habitats

The increasing concentrations of greenhouse gases in the atmosphere have generated a very large interest in climate mitigation, where natural carbon sinks play a significant role in absorbing carbon dioxide and buffering against global warming (Sabine et al., 2004; Canadell and Raupach, 2008). So far, about half of the carbon dioxide emissions have been absorbed by the world's ecosystems (Ballantyne et al., 2012) and the ocean is undoubtedly a key environment for deposition of greenhouse gases. All plant ecosystems, where primary production and plant growth are ongoing processes, can store carbon dioxide. However, to be considered a significant sink of carbon and thereby have an impact on the atmospheric carbon dioxide levels, the primary productivity must be efficient and the storage of carbon needs to be long-term, covering decades or even centuries (Belshe et al., 2017). The process of capturing carbon dioxide through primary production and storing of carbon in the biomass or sediment is known as carbon sequestration.

The carbon stored in the oceans is known as "blue carbon", which is a subsection of "green carbon" that is commonly used as the general term for the carbon captured in ecosystems through photosynthesis by plants. To separate carbon stored in the coastal and oceanic environments from the carbon storage in terrestrial ecosystems (e.g. forests and peatlands), the blue carbon term was successfully introduced about a decade ago (by Nellemann et al., 2009). Since then, there has been an intensified research interest in understanding coastal carbon processes related to sequestration and storage of blue carbon (Johannessen and Macdonald, 2016) as well as for the natural variation in the capacity of blue carbon habitats to contribute to climate change mitigation (Duarte et al., 2013).

To our knowledge, the most efficient carbon sinks on the planet are the vegetated coastal habitats, i.e. mangrove forests, seagrass meadows and salt marshes, which are storing substantial amounts of carbon along the world's coasts (Mcleod et al., 2011; Figure 1). Compared to these important vegetated coastal blue carbon habitats, other marine ecosystems such as kelp forests and coral reefs are less efficient in carbon sequestration (Nellemann et al., 2009) and generally not considered long-term carbon sinks (Howard et al., 2017). Furthermore, the deep sea covers an enormous area, and therefore, it constitutes a vast reservoir for atmospheric carbon dioxide.

The deep sea carbon is generated by e.g. coastal plankton, nekton and associated faeces, which sink to the seabed sediment. The carbon burial rate per unit area of the open ocean is, however, comparatively low (Mcleod et al., 2011), so in contrast to coastal blue carbon habitats this environment is clearly not as efficient as blue carbon sinks on an area basis. Macroalgae communities (including kelp forest) are highly productive and widespread habitats, while they do not favour the build-up of deposits containing refractory carbon within the habitat (Howard et al., 2017). Recently, however, new research on macroalgae has emphasized their potential contribution to blue carbon burial (Hill et al., 2015; Trevathan-Tackett et al., 2015; Krause-Jensen et al., 2018; Raven, 2018; Ortega et al., 2019). They do contribute significantly to the carbon storage in seagrass meadows, mangroves and salt marshes, by being a large source of allochthonous carbon (Hill et al., 2015), i.e. the organic material that they produce is to a large degree eventually transported to either of these coastal blue carbon habitats, where carbon is subsequently buried as refractory carbon, or to the deep sea (below 1 km depth), where it is sequestrated (Krause-Jensen and Duarte, 2017). Macroalgae are also largely contributing to the primary production and biomass accumulation in seagrass meadows (Hemminga and Duarte, 2000) and therefore promoting further carbon storage. Coral reefs, rhodolith beds and other habitats dominated by calcifying organisms also make up substantial stocks of carbon bound in calcium carbonate.

Biological calcification, however, might drive CO_2 from the seawater to the atmosphere (Figure 1) and therefore these habitats are generally not considered carbon sinks (Frankignoulle and Gattuso, 1994). The amount of carbon lost from the seawater as CO_2 in relation to the level of calcium carbonate ($CaCO_3$) precipitation varies in marine vegetation and depends on the buffering capacity of water, which is on average about 0.6 in "normal" seawater (estimated by Ware et al., 1992). This means that for a mol of $CaCO_3$ formed, pH decreases, and there is a release of ~0.6 mol of CO_2 to the atmosphere. Sedimentary $CaCO_3$ can constitute large and important carbon stocks in coastal vegetated habitats (e.g. Mazarrasa et al., 2015; Gullström et al., 2018; Saderne et al., 2019). The question is how much of this inorganic carbon stock can be considered a source of CO_2 (as suggested by Mateo and Serrano, 2012) rather than a sink. To assess accurate net carbon sequestration rates in coastal blue carbon habitats, it is hence of critical importance to consider the variability of primary productivity as well as calcification.

2.2 Coastal blue carbon habitats

All organic matter produced within - or transported to - marine and coastal areas potentially captures blue carbon. What matters is where this material ends up. The most efficient blue carbon habitats are those where the conditions favour a build-up of refractory organic material (resistant to further

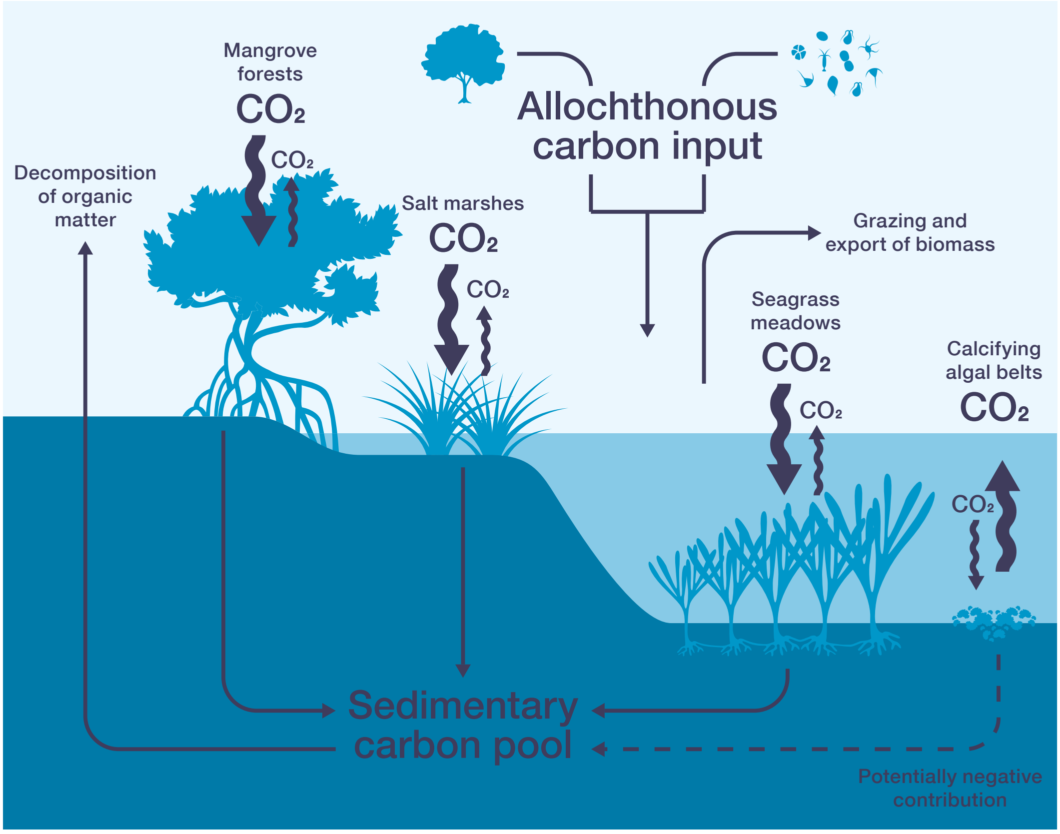


Figure 1. Blue carbon sequestration in coastal habitats (mangrove forests, salt marshes, seagrass meadows and calcifying algal belts) through the process of photosynthesis, allochthonous carbon input and long-term storage in the sediment. Figure adapted from image by Ian Image Library (www.ian.umces.edu).

degradation), e.g. in sediment of low oxygen content (Benner et al., 1984). Coastal vegetated habitats, i.e. mangroves, seagrass meadows and salt marshes, represent highly productive environments and are considered the most efficient blue carbon sinks, as they can sequester and store substantial amounts of carbon removed from the atmosphere and oceans (Mcleod et al., 2011; Figure 1). Therefore, the most cost-effective way is to focus the protection and management efforts on the coastal vegetated habitats (Duarte et al., 2013, Howard et al., 2017). The efficiency of coastal blue carbon habitats for the long-term burial of sedimentary organic carbon (Smith, 1981; Duarte et al., 2005; Duarte et al., 2010; Serrano et al., 2016) depends on flow pathways of carbon (Duarte and Cebrián, 1996; Cebrián, 1999) and is primarily promoted by high net primary production, low decomposition rate in the sediment and proficient trapping of suspended organic matter derived from nearby environments (Fonseca and Cahalan, 1992; Agawin and Duarte, 2002; Hendriks et al., 2008; Kennedy et al., 2010; Duarte et al., 2013). In addition, due to vertical accretion, the sediment in the coastal blue carbon habitats cannot be carbon-saturated (McKee et al., 2007; Mcleod et al., 2011; Howard et al., 2017).

2.2.1. Mangroves

Mangroves are forests found in tropical and subtropical coastal areas that are regularly flooded by tidal water. The dominating species in the mangrove ecosystem is the mangrove tree, which makes up most of the biomass and creates a complex and diverse habitat for other organisms to utilize. Globally, there are more than 70 species of mangroves (Spalding, 2010), which differ in appearance and characteristics. A common feature among several species is the "prop roots", which function as an adaptation to the tidal fluctuations. The "prop roots" also help to reduce tidal velocity, increase sedimentation and prevent the sediment from eroding. This results in an accumulation of carbon in the sediment, which is strengthened by a low rate of degradation of organic matter. The carbon can be stored over longer (millennial) time scales and therefore coastal mangrove forests (as well as seagrass meadows and salt marshes) have a higher carbon storage efficiency than terrestrial forests (Mcleod et al., 2011).

2.2.2. Seagrass meadows

Seagrasses are angiosperms (marine flowering plants that originated from land) that grow in tidal and subtidal marine environments. Among the coastal blue carbon habitats, seagrasses have the most widespread geographical distribution and are highly abundant on all continents in tropical, temperate and polar regions (Green and Short, 2003; Marbá et al., 2018). Therefore, it is a diverse group of plants with different morphological characteristics, although they all share some similar features, including an extensive underground root-rhizome system that anchors them to the substrate. This below-ground system stabilises the sediment (Terrados and Duarte, 2000; Ganthy et al., 2011) and supports accumulation of carbon (Trevathan-Tackett et al., 2020). Despite their widespread distribution,

Tropical mangrove forests in Tanzania. Photos by Martin Gullström.

Subtropical seagrass meadow dominated by *Syringodium isoetifolium*. Photo by Martin Gullström.

seagrass meadows occupy less than 0.2 % of the seabed of the world's oceans (Duarte, et al., 2005), but are estimated to bury roughly 10 % of the yearly estimated organic carbon in the oceans (Cebrián, 1999).

2.2.3. Salt marshes

Salt marshes are coastal tidal wetlands with relatively low-sized vegetation, such as herbs, bushes and grasses. Similar to the other coastal blue carbon habitats, they stabilize the sediment with the roots of the vegetation and form deep carbon-rich peat soils, which are built up over time (Serrano et al., 2019). Salt marshes are found in shallow waters on mud flats of sheltered bays, lagoons and estuaries, or behind sandbars. They are often formed where the salinity is high, ranging from 20 to 30 (or sometimes even more), but may also be found in almost fresh water. Salt marshes can be found on all continents, with the main areal distribution in temperate and subtropical regions and to a lesser extent in tropical regions (Nellemann et al., 2009). Salt marshes are globally important carbon sinks and sequester as much, or higher amounts, of carbon compared to terrestrial forest, despite covering much less area (Mcleod et al., 2011).

2.2.4. Climate change projections

According to the Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC), seagrass meadows and saltmarshes and associated carbon stores are at moderate risk from global warming with 20–90% of current coastal wetlands projected to be lost by 2100 (IPCC 2019). However, this risk increases if temperatures increase 2°C above pre-industrial levels. Restoration and improved management of all blue carbon ecosystems can increase both carbon uptake and storage of global carbon emissions (IPCC 2019). Most importantly, the report notes with high confidence that improving the quantification of carbon storage and greenhouse gas fluxes of these coastal ecosystems will reduce current uncertainties around measurement, reporting and verification (IPCC 2019).

Subtropical salt marsh landscape in Mozambique Photo by Amber Pariona, 2017 (from "What is a salt marsh and how is it formed?" in WorldAtlas, https://www.worldatlas.com/articles/what-is-a-salt-marsh-and-how-is-it-formed.html/)

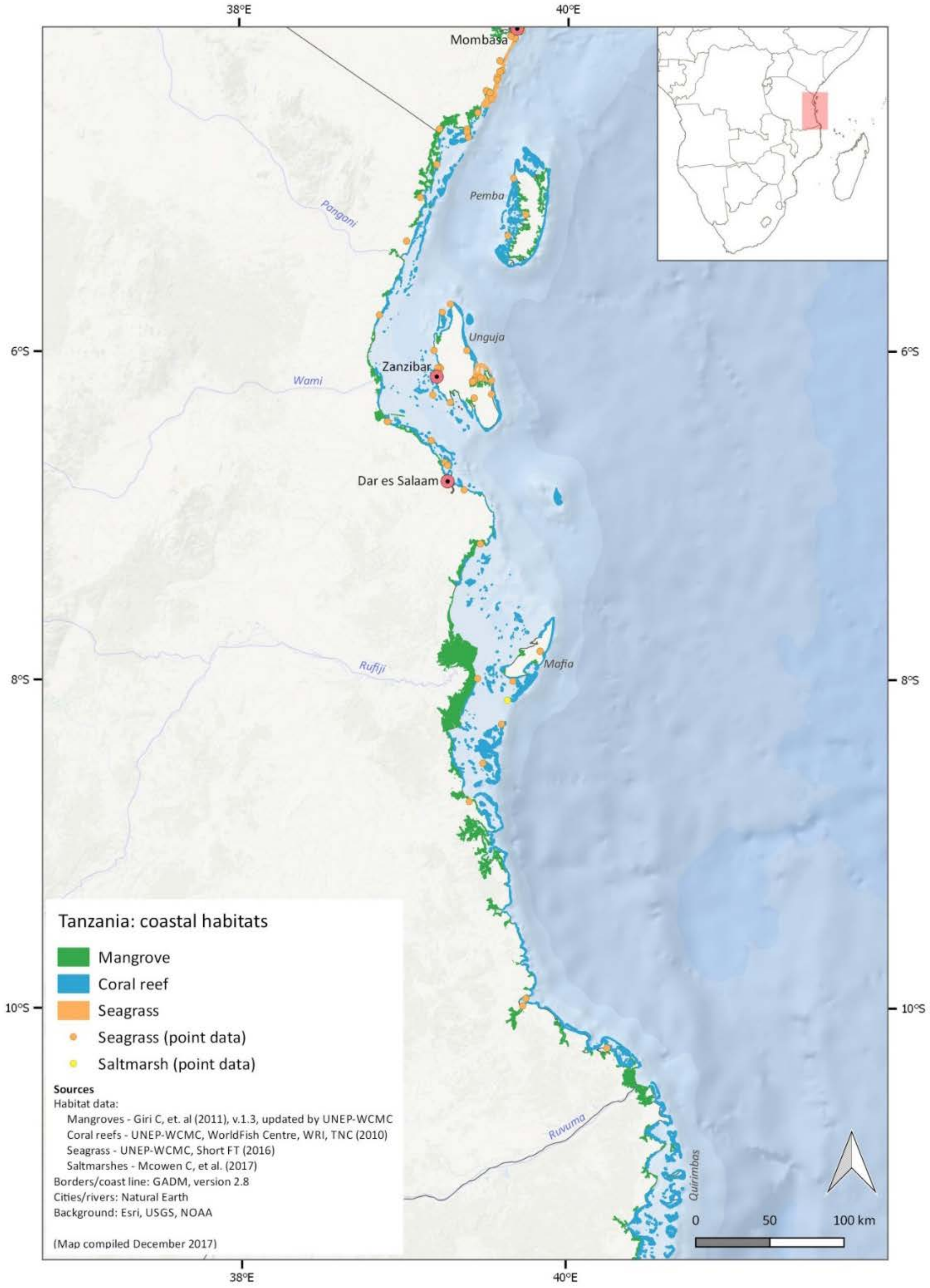
2.3 Coastal blue carbon habitats in Tanzania and Mozambique

2.3.1. Mangroves

Mangrove habitats in Tanzania and Mozambique generally fall into two categories, including fringe communities along the open coastline and creek communities found at river mouths and deltas. The WIO region counts a total of ten mangrove species (Bosire et al., 2016), with different salinity tolerances and specific distributions along tidal gradients. Because the tides reach farther inland at river mouths compared to open coastlines, the fringe communities generally display greater patterns of zonation among species compared to the creek communities. There is also a considerable size variation (dwarf to massive) among the different mangrove species across the eastern coast of Africa (The Blue Carbon Initiative, 2015).

In Tanzania, mangroves comprise the dominant coastal ecosystem and the most extensive mangrove areas are found in the Rufiji Delta, extending over 480 km^2 along 70 km of coast (Figure 2). The mangrove area in the Rufiji Delta is one of the largest mangroves stands on the East African coast. Extensive mangrove areas are also found at the mouth of Ruvuma river (ASCLME/SWIOFP, 2012), encompassing coastal environments of both Tanzania and Mozambique. Mangroves in Tanzania provide livelihoods for approximately 150,000 people (ASCLME/SWIOFP, 2012), and with the recognition of their national importance, mangrove areas have been designated as forest reserves since 1928 (ASCLME/SWIOFP, 2012). There are ten management blocks, with the most important ones being Rufiji (50% of the countries' mangrove areal) and Pemba Island. Fisheries, including crab, mollusc and finfish fisheries in the mangrove channels, constitute the major source of income in the coastal areas. Shrimp trawling, including artisanal trawl operations conducted in mangrove-lined estuaries, is particularly important in Tanzania. For instance, offshore industrial shrimp trawling contributed US$ 6.6 million in revenue in 2002 through export royalties (ASCLME/SWIOFP, 2012).

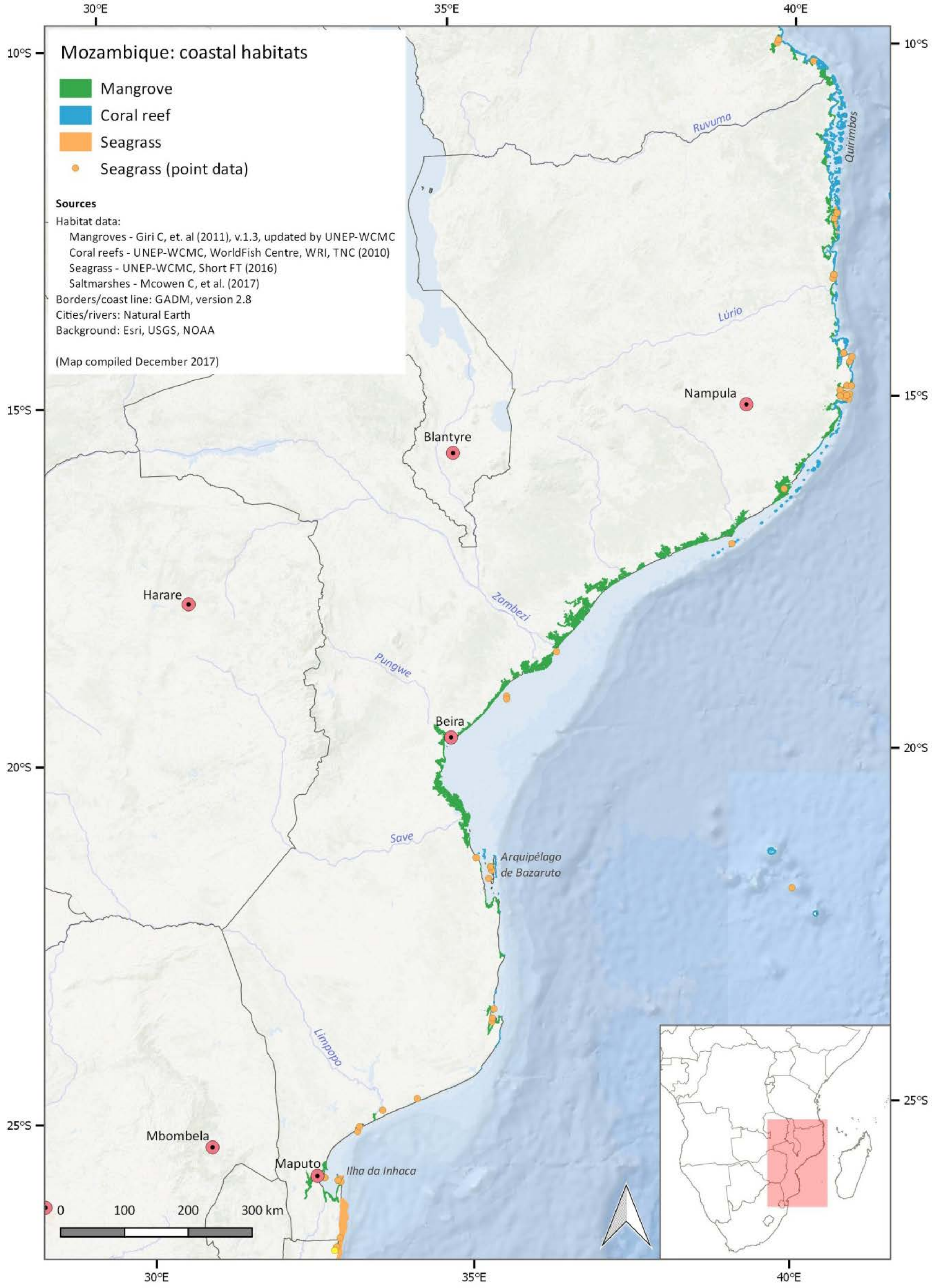
The mangrove vegetation in Tanzania is composed of ten species of mangroves, including *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*,



Sources
Habitat data:
Mangroves - Giri C, et. al (2011), v.1.3, updated by UNEP-WCMC
Coral reefs - UNEP-WCMC, WorldFish Centre, WRI, TNC (2010)
Seagrass - UNEP-WCMC, Short FT (2016)
Saltmarshes - Mcowen C, et al. (2017)
Borders/coast line: GADM, version 2.8
Cities/rivers: Natural Earth
Background: Esri, USGS, NOAA

(Map compiled December 2017)

Figure 2. Distribution of mangroves, seagrass, saltmarshes and coral reefs in Tanzania.



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Cities/rivers: Natural Earth
Background: Esri, USGS, NOAA

(Map compiled December 2017)

Figure 3. Distribution of mangroves, seagrass and coral reefs in Mozambique.

Lumnitzera racemosa, *Pemphis acidula*, *Rhizophora mucronata*, *Sonneratia alba*, *Xylocarpus granatum* and *Xylocarpus moluccensis* (Bosire et al., 2016).

In Mozambique, mangroves form large, continuous belts along the north and central coastlines, while becoming less common in the southern part of the country (Figure 3). Detailed surveys showed an estimated mangrove cover ranging from 290,900 to 318,800 ha (Fatoyinbo et al., 2008; Giri et al., 2011). The most extensive areas are found in the central provinces of Zambézia and Sofala (Fatoyinbo et al., 2008). Much of the coastline in these two provinces is classified as delta coast (Lundin and Linden, 1997).

The Zambezi River Delta, where almost 180 km of coastline is covered by continuous mangrove forest, contains 50% of Mozambique's mangrove area and is also one of the largest mangrove forests in Africa as well as in the Western Indian Ocean. The greatest pattern of species zonation is found between Beira and the Save (or Sabi) River, where mangroves extend up to 50 km inland with canopies reaching up to 30 m in height (Spalding et al., 1997). The mangrove vegetation in Mozambique is composed of nine species of mangroves, including *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Pemphis acidula*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum* (Bosire et al., 2016).

Besides the function as an important blue carbon habitat, important ecosystem services provided by mangroves include coastal protection, provision of timber for construction and firewood, fish for consumption, and critical fish spawning and nursery habitat for commercially important fish species (ASCLME/SWIOFP, 2012). Molluscs, crustaceans (e.g. shrimps, mangrove crabs, portunid crabs) and gastropods (e.g. mud creepers) collected from mangroves are important sources of protein for human populations in Mozambique, for example at Inhaca Island (Taylor et al., 2003). Reported uses of mangrove wood in Mozambique also include charcoal production, tannins, fencing, fish traps and medicinal uses (Taylor et al., 2003). Specific examples include the use of *Rhizophora mucronata* bark to dye fishing nets, and *Avicennia marina* wood to make dugout canoes and beehives.

2.3.2. Seagrass meadows

In Tanzania, the most extensive seagrass meadows occur in back-reef lagoons, between the beaches or cliffs and the adjacent fringing reefs (Figure 2). For instance, Chwaka Bay, a large semi-enclosed tidal embayment on the east coast of Zanzibar Island, comprises widespread monospecific and mixed seagrass meadows, with up to eleven seagrass species spread across tidal and subtidal areas of this seagrass-dominated bay (Gullström et al., 2006). In Mozambique, seagrass meadows are most extensive in the sandy (south) and limestone (north) areas of the coastline (Figure 3). Extensive seagrass habitats are found in Sofala Bay and the extensive estuary of the Pungwe and Buzi Rivers, Bazaruto Archipelago and around Inhaca Island. The highest seagrass biomass (*Thalassodendron ciliatum*) in the WIO region has been recorded at Inhaca Island (Gullström et al., 2002), which is home to nine of the 12 seagrass species occurring in Mozambique (and c. 16% of the world's seagrass species) (Bandeira, 2002; Bandeira and Gell, 2003). The seagrass meadows in the Bazaruto Archipelago in Mozambique support one of the remaining viable dugong populations in the WIO (Findlay et al., 2011). Protection of this valuable habitat is critical for the survival of the species.

Generally, seagrasses are extensively distributed throughout the WIO region and build meadows across the coast, from the intertidal zone down to about 40 m (sometimes even deeper) depending on water clarity (Bandeira and Gell, 2003). Out of about 60 seagrass species described in the world (Green and Short, 2003), 14 species have been recognized in the WIO region (Gullström et al., 2002; Duarte et al., 2012), with Kenya, Tanzania and Mozambique supporting the highest diversity of seagrass species (Green and Short, 2003). Seagrasses in the region occur either as monospecific stands or as multispecies meadows. In the mixed meadows, a set of seagrass species commonly intermingle with different seaweed species, including also calcareous macroalgae (e.g. *Halimeda* spp.) (Gullström et al., 2006).

The bottom substrate of seagrass habitats varies depending on exposure level and tidal regime; seagrass plants are hence found in all samples from intertidal mud flats to subtidal sand banks and areas dominated by rocky limestone (Gullström et al., 2002). In subtidal areas, habitat engineers or climax species, such as *Enhalus acoroides*, *Thalassodendron ciliatum* and *Thalassia hemprichii*, are the dominant seagrass species, whereas tiny, fast-growing pioneer species like *Halophila ovalis* and *Halodule uninervis* are commonly found in the intertidal areas. Through efficient trapping of sediment, seagrass meadows stabilise the bottom and thereby play an important role in protecting coastal areas from erosion.

Across the region, seagrass meadows often occur in close proximity with coral reefs and mangroves (Lugendo, 2016), where they support the provision of numerous important ecosystem services, benefitting e.g. food security, coastal protection and climate change mitigation (Gell, 1999; de la Torre-Castro and Rönnbäck, 2004; Unsworth and Cullen, 2010; Gullström et al., 2018; Nordlund et al., 2018), as well as functioning as an important link between land, different shallow-water habitats and offshore environments (e.g. Gullström et al., 2008; Berkström et al., 2012; 2013).

2.3.3. Salt marshes

In the WIO region, outside the South African sub-tropical region, the distribution of salt marshes is poorly known and studied. Anecdotal information indicates that they occur in several places between mangroves and marshland or terrestrial vegetation as observed in parts of Maputo Bay (Mozambique). Furthermore, coastal geomorphology may favour the occurrence of some salt marsh species in southern Mozambique, where there are numerous coastal lakes, almost all to some extent saline or brackish. Further investigation is required to determine if salt marshes are a key blue carbon habitat in Mozambique and Tanzania, and elsewhere in the WIO region.

2.4 Threats to coastal blue carbon habitats

Mangrove and seagrass area coverage in many WIO countries is on the decline (e.g. Gullström et al., 2006; Kirui et al., 2013; Jones et al., 2016; Obura et al., 2019). Overharvesting of wood to be used as timber, charcoal and firewood is the most common threat to mangroves in the region, particularly within and close to urban areas (Lugendo, 2016). Other threats include clearing and conversion to alternative land uses such as agriculture (e.g. rice), aquaculture (e.g. shrimp), urban development, tourism and salt production; pollution; sedimentation and changes in river flow; natural factors such as pest infestation and El Niño events; as well as climate change-associated factors such as sea level rise, excessive flooding and increased sedimentation (Lugendo, 2016).

2.4.1. Mangroves in Tanzania

A mangrove management plan was initiated for Tanzania in 1988 and has been responsible for improved mangrove protection and reduced illegal harvesting. However, threats to mangroves in Tanzania still exist (with e.g. reported losses of 5-10% from 1980 to 2005-2010; Lugendo, 2016) primarily due to overexploitation (timber and animals), deforestation for development, and increasing water pollution (ASCLME/SWIOFP, 2012; Bosire et al., 2016). The overexploitation of resources has also been attributed to poverty and the country's dependence on fuelwood for energy. Major threats include slash and burn practices and land clearing for rice farming. For instance, rice cultivation in northern areas of the Rufiji Delta has led to major losses of mangroves (Taylor et al., 2003; Nindi et al. 2014). A lack of government licensing and enforcement capacity has also been identified as an important factor to mangrove loss. It is estimated that a substantial part of the mangrove habitat use in Tanzania is illegal.

2.4.2. Seagrass meadows in Tanzania

Threats to seagrass habitats in Tanzania include semi-industrial, small-scale commercial and industrial trawling for inshore crustaceans, illegal trawling for fish and crustaceans during the closed season, invertebrate gleaning, waste disposal, unsuitable farming practices and coastal development (Green and Short, 2003; WIOFish, 2011; ASCLME/SWIOFP, 2012). Seagrass areas are lost also due to eutrophication, sedimentation, tourism, destructive fishing and aquaculture (where seagrass meadows are being converted to algae farms) (Hedberg et al., 2018). Accurate estimates of seagrass loss are not known on a national level. However, local losses have sporadically been reported. For instance, in Chwaka Bay, Zanzibar, there was a loss of 11.7 % between 1986 and 2003 (Gullström et al. 2006).

2.4.3. Mangroves in Mozambique

The mangrove cover in Mozambique has been reduced at a rate of 18.2 km^2 per year over the past few decades largely due to urbanisation, tourism and industrial development (ASCLME/SWIOFP, 2012). Mangrove loss has been especially severe in the provinces of Sofala, Zambezia and Nampula, with Zambezia showing the largest decline (almost half of its mangroves since 1990) (Lugendo, 2016). Specific threats to mangroves in Mozambique include pollution from several oil spills in Maputo Bay and from heavy shipping traffic in the Mozambique Channel (Taylor et al., 2003; Lugendo, 2016). Other threats include overharvesting of mangrove timber, conversion of mangroves to rice paddies and salt-pans, and construction of dams (potentially reducing the water flow in river systems) (Taylor et al., 2003; Lugendo, 2016). Mangrove forests in Mozambique have also been converted into alternative land uses that generate higher returns, such as real estate and even garbage dumps (ASCLME/SWIOFP, 2012). Considering the current pressure on coastal resources due to population growth, and the dependence on coastal productivity and the prevailing occupational patterns by coastal inhabitants, it seems likely that the actual annual degradation and removal of mangrove areas is much larger.

2.4.4. Seagrass meadows in Mozambique

In Mozambique, destructive fishing practices that damage seagrass habitats occur and include both semi-industrial shrimp trawlers and artisanal beach-seine netting. For examples, seagrass meadows in the Bazaruto Archipelago are heavily fished from the use of beach-seine netting, and even despite being largely covered by established marine protected areas (with both permanent and seasonal closures) (D'Agata, 2016). Other threats include oyster and sea cucumber fisheries at the Bazaruto Archipelago; trampling, fishing and tourism activities at Inhaca Island, where large areas of *Zostera capensis* have disappeared from the front of Inhaca's main village (i.e. at the Maputo Bay side); and gleaning of bivalves at Bairro dos Pescadores near Maputo, where the seagrass cover has decreased from 60% to 10% in a ten-year period (WIOFish, 2011; Nordlund and Gullström, 2013). Such activities may destroy seagrass habitats, in turn threatening local food security (Green and Short, 2003).

3. Marine protected areas (MPAs) and terrestrial nature conservation

3.1 General information about nature protection and MPAs

For centuries, there has been a desire to protect our nature and special places around the world. Nevertheless, long-term protection according to law did not show up until we observed how human impacts could, in fact, seriously affect the health of the planet, by rapidly modifying natural environments and biodiversity. The main reason for establishing protected areas is to preserve and safeguard fundamental natural and cultural heritage for future generations.

The first definitions of protected areas were provided as early as in the 1930s, although it was not until the most recent decades where any broad definitions focusing on the understanding and role of protected areas were declared. In 2008, IUCN stated a definition of protected areas, i.e. “a protected area is a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values”.

Today, the establishment of protected areas (national parks, nature reserves, management areas and other protected areas) by governments and through different global and regional programmes (e.g. world heritage programmes) is more intense than ever before in history. In addition to their essential role to global biodiversity conservation, protected areas benefit e.g. people’s livelihoods, ecosystem services (food, clean water supply, medicines, protection from natural disaster impacts and mitigation to climate change through e.g. carbon sequestration), tourism and cultural values.

In the marine and coastal environment, marine protected areas (MPAs) function as a key tool to conserve biodiversity and to mitigate degradation of coastal and ocean-based ecosystems. This will promote sustainable use of marine resources and sensitive environments, and contribute to maintenance and enhancement of multiple essential ecosystem goods and services. All over the world, we are protecting more than ever in history. In 2017, 23 million km² (or 6.35%) of the ocean were covered by MPAs. This represents a ten-fold increase since 2000, when the area covered by MPAs was approximately 2 million km² (or 0.7%) of the ocean.

3.2 Protection of key blue carbon habitats in Tanzania and Mozambique

The establishment of MPAs in Eastern Africa developed during the 1990s, with major initiations made by WWF and other nature conservation organizations. Mafia Island in Tanzania and Quirimbas in Mozambique are two major examples of successful MPAs.

In this report, spatial information data for the location, type and outline of protected areas were obtained from the World Database on Protected Areas (WDPA). The dataset includes protected areas that meet the IUCN definition of protected areas (see above). The WDPA dataset does not, however, include all types of coastal and marine management areas, e.g. Locally Managed Marine Areas (LMMAs).

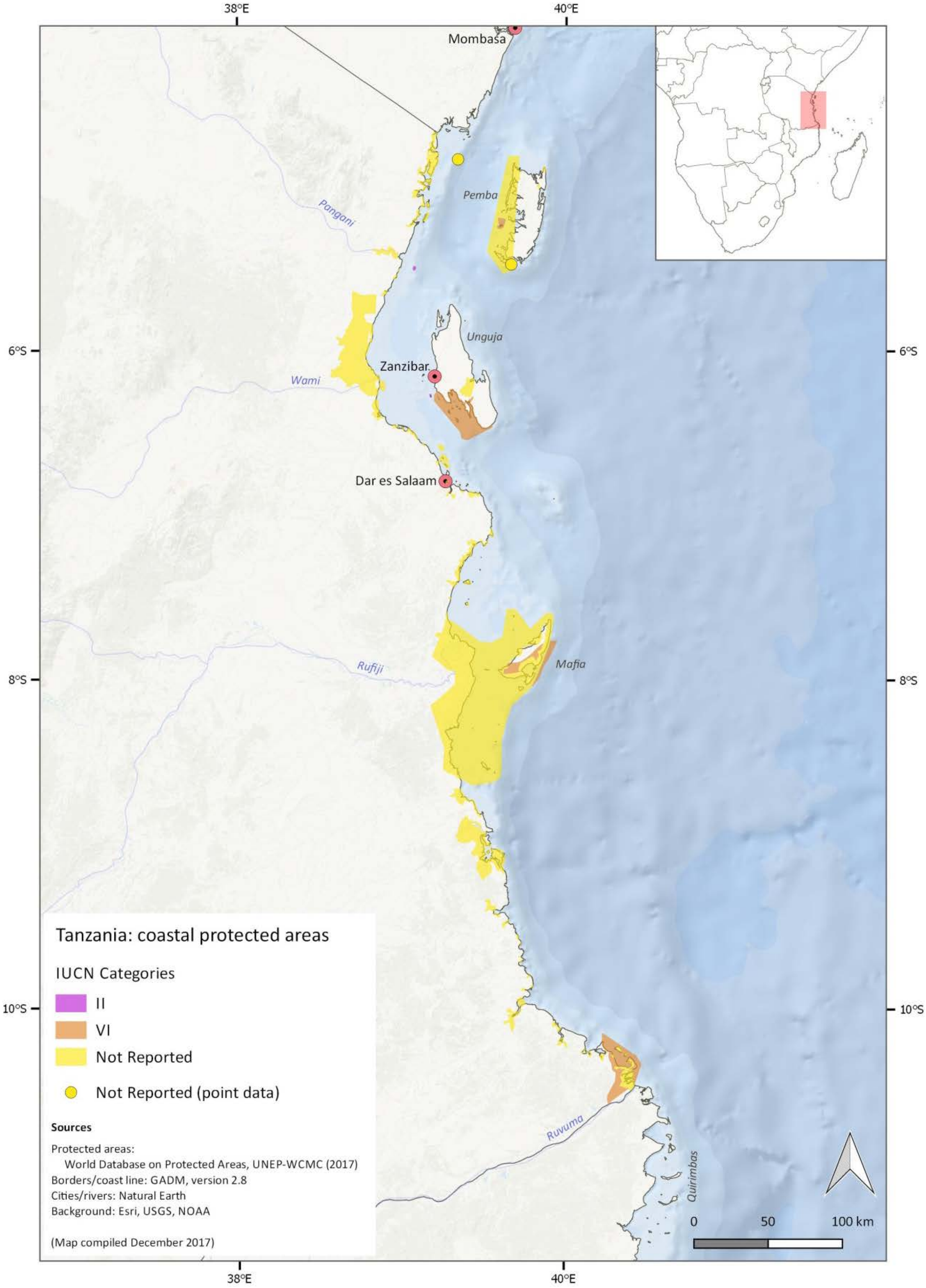


Figure 4. Overview of coastal and marine protected areas in Tanzania. Most mangrove forests are included in Forest Reserves.

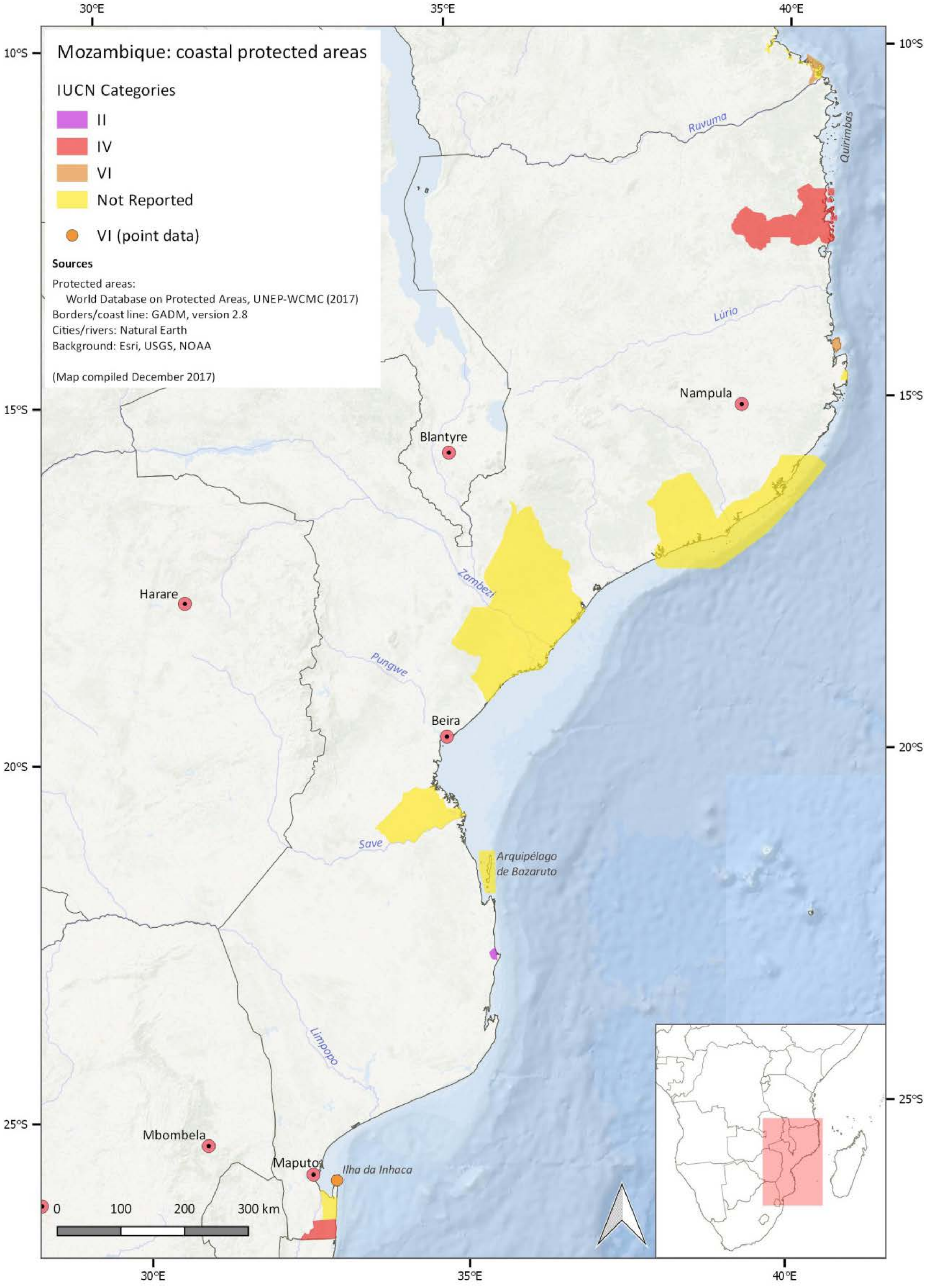


Figure 5. Overview of coastal and marine protected areas in Mozambique.

Some regional information was obtained from a review by Rocliffe et al. (2014) on protected areas in the WIO region, although their article primarily focuses on coral reef habitats. Rocliffe et al. (2014) classified a number of sites into four categories, depending on the extent to which resource management is shared between government and user groups, where levels 1 and 2 are managed by the government or partner organisations, level 3 is governed by local communities and governments or non-state actors that cooperate, and level 4 is locally managed.

Following this classification, Rocliffe et al. (2014) identified MPAs (levels 1 and 2) and LMMAs (levels 3 and 4) in the WIO (Figures 4 and 5). The mean LMMA size across the WIO region was estimated to 183 km^2, with a quarter of sites smaller than about two km^2. Most of these LMMAs have been established after the year 2000, with the passing of legislation to decentralise marine resource management in Kenya, Tanzania, Mozambique and Madagascar (Rocliffe et al., 2014). LMMAs are prevalent in Tanzania with a combined area of 4,096.5 km^2, equivalent to 3.5 times the area of MPAs (Rocliffe et al., 2014). Further research is needed to assess the number and extent of different types of management areas and the habitats they contain.

In Tanzania, the major coastal and marine protected areas (Figure 4) include:

- Mafia Island Marine Park
- Rufiji-Mafia-Kilwa (RMK) Ramsar Site
- Dar es Salaam Marine Reserve
- Kiweni LLMA
- Misali Island Conservation Area
- Pemba Channel Conservation Area
- Menai Bay Conservation Area
- Tanga Collaborative Management Areas

All mangroves in Tanzania are located in Forest Reserves and under management of the Tanzania Forest Services (TFS). Seagrasses, however, rarely fall within the boundaries of MPAs, but may be part of conservation areas (e.g. in Menai Bay Conservation Area, southern Zanzibar Island).

In Mozambique, the major coastal and marine protected areas (Figure 5) include:

- Zambezi River Delta Ramsar Site
- Quirimbas National Park
- Primeiras and Segundas, Marine Reserve and Environmental Protection Area
- Bazaruto National Park
- Ponta do Ouro Partial Marine Reserve

Mangrove forests are also found in some forest reserves and game reserves, and large stretches of the coast fall outside of any protection area. The design of MPAs, likely geared around coral reef, does not appear to consider seagrass distributions. There are, however, examples where seagrass is part of major protection zones (e.g. Ponta do Ouro Partial Marine Reserve encompassing all seagrass around Inhaca Island).

4. Compilation of data, field methods and laboratory processing

4.1 Compilation of available spatial data

This section outlines the results of a compilation of publicly available spatial datasets on marine and coastal habitats in Tanzania and Mozambique, including protected areas. Selected maps are shown in Figures 2-5, and a detailed list of spatial datasets is provided in Annex 1, including sources, production date, methodology and accuracy (when provided). Compiled spatial data are saved as shapefiles (for use in GIS). The spatial data compilation exercise focussed on the same habitats prioritised during the literature review.

Several datasets of mangrove distribution were found for the study area (Annex 1) with some discrepancies among datasets, potentially due to differing methodologies and source date. There are sustained efforts in the region to improve and update mangrove spatial datasets. The Global Mangrove Watch initiative has ongoing monitoring based on high-resolution SAR satellite data (PALSAR/PALSAR2) to assess changes from a baseline for the nominal year 2010. Furthermore, research by the USDA Forest Service involves remote sensing assessments of mangrove biomass and carbon stock estimates in key locations, including the Zambezi River Delta in Mozambique and the Rufiji River Delta in Tanzania. Work currently underway in the Rufiji Delta is also focusing on trying to develop estimates of carbon uptake rates within the mangroves as well as loss (e.g., emission) from disturbance and conversion.

There are discrepancies aamong spatial datasets and uncertainties with remote sensing analyses of seagrass. One dataset identified one grouped category for seagrass together with underwater vegetation such as macroalgae.

4.2 Field methods for sedimentary carbon sampling

This section presents a proposed methodology for field assessments of carbon stored in coastal sediments.

Sediment cores are sampled using conventional push-core technique, preferably no less than three cores per site. The core size is preferably at least 50 cm long to catch the entire root-rhizome biomass zone and get a representative core length for long-term storage of carbon. The selected diameter of the core (commonly about 4 to 10 cm) should be decided by the characteristics of the sediment (e.g. coarse or muddy sediment type) and is a trade-off between the effect of sediment compaction and the possibility of pushing the core into the expected sediment depth (where a smaller diameter will increase the compaction, while a sediment core with a larger diameter will be more difficult to sample).

The sediment cores will be divided (by slicing) into different depth sections and the size of the depth sections should be standardised based on local sediment conditions. The shallow surface layers should be sliced with higher size resolution (e.g. 2.5 cm depth sections) because the carbon content variation is normally higher in the surface layers, while below the root-rhizome biomass zone the intervals could be larger since the carbon content is more stable. The sediment from the different depth sections should be stored in a freezer, if not directly dried or freeze-dried.

To prepare for the carbon content analysis in the laboratory, the sediment should be weighted and homogenized, and plant parts and animals removed, before being dried at 60 °C until the weight has stabilized. A subsample of sediment (about 20 g) will be ground and further homogenized into a fine powder with a mixing mill or using a mortar. Subsequently, two smaller subsamples, one treated with 1M HCl (either through direct addition or via fuming depending on the inorganic carbon content of the sediment sample) to remove inorganic carbon and one without the HCl treatment, will be analysed for carbon. To derive the inorganic carbon content, the sample with organic carbon will be reduced from the one with total carbon. After the pre-processes of the sediment, the carbon levels are suggested to be provided using either direct carbon measurements (method 1 below) or by indirect carbon estimations (method 2 below), and additionally, carbon accumulation rates in sediment may also be assessed (method 3 below).

Method 1 (direct carbon measurements): An organic elemental analyser is used to determine organic and inorganic carbon in the sediment. This method is widely used in the blue carbon literature and gives a direct measure on the carbon content (in percent). An additional advantage of using an organic elemental analyser is that the nitrogen content of the sediment is obtained. The nitrogen can be useful to get a value on nutrient availability and C:N ratio estimations, which in turn can be used as an indication of the quality and decomposition phase of the organic matter (Christensen, 1992). The relationship between carbon and nitrogen can be used to estimate the stability of the organic matter, and if the C:N ratio does not change over time (or by depths given that there is no mixing of the sediment), this can be an indication of stable recalcitrance carbon (Mateo et al., 2006), more commonly referred to refractory carbon. This method was used in this report.

Sediment core sampling in a Tanzanian mangrove forest. Photo by Sara Forsberg.

Method 2 (indirect carbon estimations): A common method used to measure organic matter is the Loss On Ignition (LOI) technique. In contrast to the organic elemental analyser method, LOI gives an indirect measurement of organic carbon as it measures the organic matter content. To calculate the carbon content of the organic matter, the organic matter needs to be converted using e.g. an equation based on Fourqurean et al. (2012) or by calculating a conversion factor based on own data by analyzing some of the samples using a CN elemental analyzer. Detailed calculations about the LOI conversion to get organic carbon estimations are found in Howard et al. (2014).

In addition to the carbon assessments, there are also many associated variables that should be measured in a proper blue carbon stock survey. For instance, sedimentary carbon density can be calculated from measurements of the sediment bulk density. Sediment density is derived from dividing the dry weight of the sediment by the volume of the sample. Combined with sediment carbon sampling, seagrass meadow characteristics should be assessed. Such seagrass-related measures, including biometrics of the seagrass (canopy height, shoot density and seagrass coverage) as well as seagrass biomass, can be used to quantify the carbon content of the living seagrass standing stock and to relate sedimentary carbon stocks to seagrass structural complexity.

Method 3 (assessments of accumulation rates of carbon): The established method for estimating the accumulation of carbon in coastal sediment is the use of age-depth chronology based on radioactive isotope analysis. In order to determine the age of the sediment, the radioactive isotopes ^{210}Pb (for sediment less than 150 years old) and ^{14}C (for older material) are generally used (Serrano et al., 2016). The radiocarbon dating (^{14}C) requires seagrass sheath- or rhizome material from different sediment depth intervals. Combining these dating techniques with the depth of the sediment collected and the carbon content, one can estimate the carbon accumulation rate over time.

5. Blue carbon stock assessments in the WIO region

5.1 A summary of previous studies

This section provides an overview on what is known about sedimentary carbon stocks in mangroves and seagrass meadows in the WIO region (Table 1). Compared to many other regions across the world, especially Australia, Europe and the US, the WIO is virtually unexplored in terms blue carbon stock assessments. The scarce number of published studies are from a few particular localities, including Gazi Bay in Kenya, Zanzibar Island (Unguja), some sites on the Tanzanian mainland and Inhaca Island, Mozambique, for seagrass meadows, and some sites in Tanzania (Geza and Mtimbwani) and Mozambique (Zambezi Delta and Sofola Bay) for mangroves (Table 1).

5.2 Carbon stock distribution in coastal habitats of Tanzania and southern Mozambique

This report presents new data based on a comprehensive field effort conducted in 148 sampling sites (based on 532 sediment cores, n = 3-6 cores per site) across Tanzania and southern Mozambique. The coastline of Northern Mozambique was not surveyed due to the area not being easily accessible at the time of the field sampling effort. However, reported literature data show coverage of seagrass and mangroves, which likely host carbon stocks; further studies in the northern area are hence needed to fully quantify the carbon storage potential of Mozambique. Overall, the findings show that sedimentary organic and inorganic carbon stocks in blue forest ecosystems (mangroves and seagrass meadows) vary with e.g. latitude, regional variations and landscape configuration. The mean sedimentary organic carbon stock levels in the tropical region were clearly highest in mangroves (n = 29 sites), followed by seagrass meadows (n = 59) and unvegetated areas (n = 27) (Figure 6A). In the subtropical region, the mean sedimentary organic carbon stock levels were slightly higher in mangroves (n = 8) compared to seagrass meadows (n = 16), whereas the unvegetated areas (n = 9) showed much lower organic carbon content in the sediment than the vegetated habitats (Figure 6A). In terms of sedimentary inorganic carbon, the stock levels in the tropical zone were considerably higher seagrass- (n = 58) and unvegetated habitats (n = 26) compared to the levels in mangroves (n = 26) (Figure 6B). In the subtropical zone, seagrass meadows (n = 16) showed significantly higher inorganic carbon levels than both mangroves (n = 8) and unvegetated areas (n = 9) (Figure 6B), which were themselves similar with only slightly (but not significantly) lower inorganic carbon levels in mangroves compared to unvegetated areas (Figure 6B).

A comparison of carbon stock levels among seagrass meadows dominated by each of the four sampled seagrass species showed some patterns of variability (Figure 7), although no significant differences were found. In the tropical region, the sedimentary organic carbon stock levels were very similar in the four different seagrass habitats, with the highest levels in meadows dominated by *Enhalus acoroides*, followed by those dominated by *Thalassodendron ciliatum*, *Cymodocea* spp. and *Thalassia hemprichii* (Figure 7A). Also in the subtropical region, very similar organic carbon stock levels were found in the different

Table 1. Summary of sedimentary carbon stocks in seagrass- and mangrove habitats in the Western Indian Ocean region. The sediment carbon stocks are calculated as mean (± standard deviation) down to 50 cm sediment depth, if not otherwise noted. C_{org} = organic carbon, C_{carb} = inorganic carbon as carbonate

Location	Species		C_{org} (% C)	C_{org} (gCm^{-2})	C_{carb} (% C)	C_{carb} (gCm^{-2})	Reference
Seagrass							
Gazi Bay, Kenya	*T. hemprichii*		0.76 (0.39)	11689 (4298)			Githaiga et al. (2017)
	E. acoroides		0.96 (0.74)	14787 (6217)			
	T. ciliatum		0.93 (0.53)	12605 (5407)			
	S. isoetifolium		0.85 (0.38)	8231 (4059)			
Zanzibar, Tanzania	*E. acoroides*		0.92 (0.15)	6562 (740)	9.8 (1.57)	70319 (9258)	Gullström et al. (2018)
	T. hemprichii		0.83 (0.46)	5996 (2864)	10.0 (3.04)	74271 (7338)	
	Cymodocea spp.		0.54 (0.09)	4891 (844)	3.3 (0.25)	29723 (2654)	
	T. ciliatum		0.83 (0.46)	5996 (2846)	10.0 (0.96)	74271 (7338)	
Mainland, Tanzania	*E. acoroides*		0.39 (0.15)	3274 (966)	2.1 (1.01)	16947 (7041)	
	T. hemprichii		0.28 (0.08)	2513 (749)	0.9 (0.56)	8258 (5113)	
	Cymodocea spp.		0.34 (0.09)	2953 (689)	0.9 (0.63)	8223 (5373)	
	T. ciliatum		0.44 (0.44)	3589 (3398)	2.0 (0.97)	16790 (7693)	
Inhaca, Mozambique	*T. hemprichii*		0.32 (0.05)	2740 (393)	0.5 (0.19)	4322 (1815)	
	Cymodocea spp.		0.23 (0.05)	2079 (433)	0.4 (0.08)	3635 (723)	
	T. ciliatum		0.36 (0.19)	3036 (1625)	1.4 (0.53)	11691 (3847)	
Zanzibar, Tanzania	*C. serrulata*			3546 (941)			Belshe et al. (2018)[1]
	T. ciliatum			3219 (788)			
	Mixed species			3374 (835)			
Zanzibar, Tanzania	*T. hemprichii*	Control	1.38 (0.23)		11.0 (0.1)		Dahl et al. (2016)[2]
	T. hemprichii	Disturbed (low shading)	1.46 (0.33)		11.0 (0.2)		
	T. hemprichii	Disturbed (high shading)	1.40 (0.20)		11.0 (0.1)		
	T. hemprichii	Disturbed (low clipping)	1.32 (0.15)		11.1 (0.1)		
	T. hemprichii	Disturbed (high clipping)	1.30 (0.25)		11.3 (0.2)		
Mangrove							
Geza, Tanzania	Mixed species			17581			Alavaisha and Mangora (2016)
Mtimbwani, Tanzania	Mixed species			26049			
Zambezi River Delta, Mozambique	Mixed species		1.83 (0.16)	7117 (227)			Stringer (2015)
Sofola Bay, Mozambique	Mixed species		1.48 (0.08)	8257			Sitoe et al. (2014)

[1] Sediment depth was 0-100 cm
[2] Sediment depth was 0-30 cm

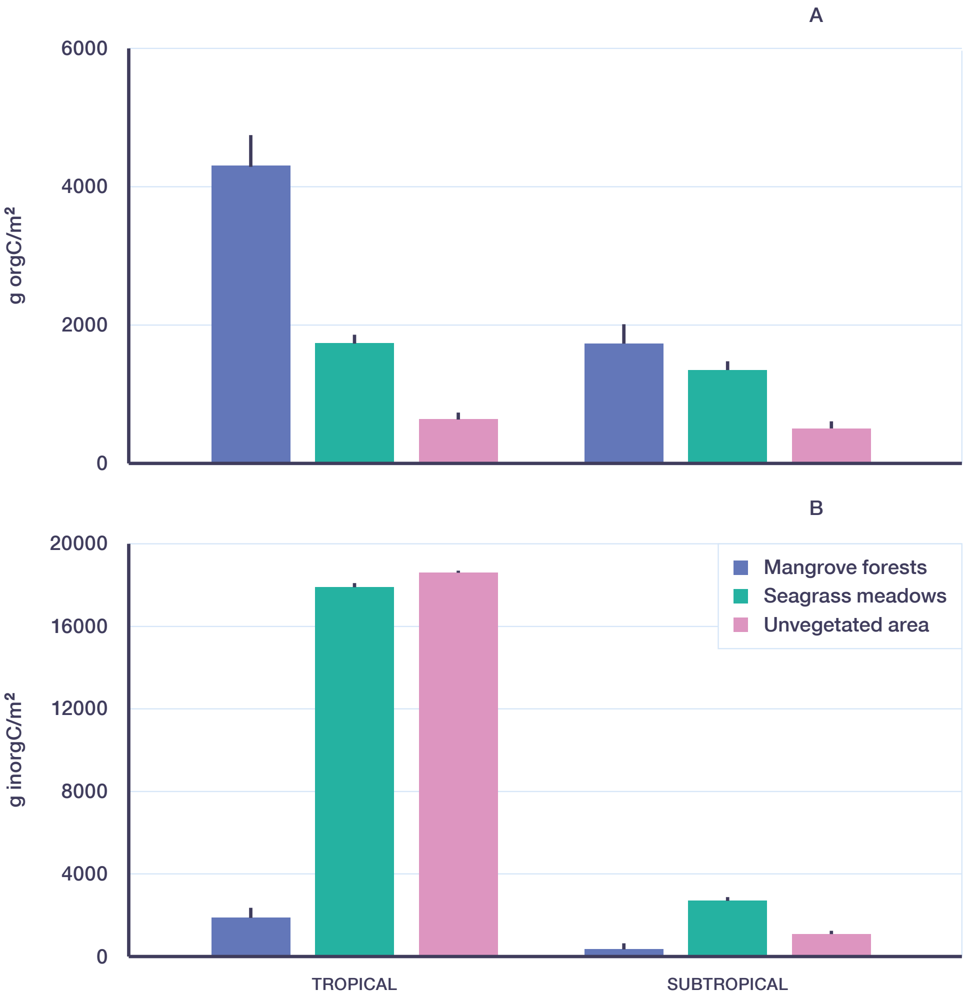


Figure 6. Mean (±SE) organic (orgC) (A) and inorganic (inorgC) (B) carbon stocks (g C per m^2, 0-25 cm sediment depth) in mangroves, seagrass meadows and unvegetated areas. All sampling sites were in tropical (Tanzania) or subtropical (southern Mozambique) regions. Note that the range of the y-axes differs between the two graphs.

seagrass habitats, with meadows dominated by *T. hemprichii* showing slightly higher levels than those dominated by *T. ciliatum* and *Cymodocea* spp. (Figure 7A). Regarding the inorganic carbon stock levels in the tropical region, these were highest in *T. ciliatum* followed by *T. hemprichii*, *E. acoroides* and *Cymodocea* spp. (Figure 7B). In the subtropical region, the inorganic carbon stock levels were generally low, with meadows dominated by *T. ciliatum* showing marginally higher levels than meadows dominated by *E. acoroides* and *Cymodocea* spp. (Figure 7B).

In terms of latitudinal influences on carbon stocks, the findings show that sedimentary organic and inorganic carbon stocks in mangroves were substantially higher in the tropical region (Tanzania) compared to the subtropical region (Mozambique) (Figure 6A and 8). In seagrass meadows and unvegetated areas, however, the organic carbon stock levels were generally quite similar in the two climate zones, while there was a remarkably higher amount of inorganic carbon in the tropical seagrass- and unvegetated habitats compared to those in the subtropical region (Figures 6B and 9). Apart from the general patterns, there was a high spatial variability in carbon stock levels of the three studied habitats across the different geographical regions (or provinces) (Figures 8 and 9, Annex 2). We found that the organic carbon stock levels in mangroves were particularly high in Zanzibar Island and Lindi at the tropical mainland coast, while also most of the other tropical regions (Mafia Island, Pwani and Mtwara) showed relatively high organic carbon stock levels (Figure 8).

For seagrass meadows, Zanzibar Island showed slightly higher carbon stock levels compared to any of the other regions, although there was a high similarity observed when comparing the

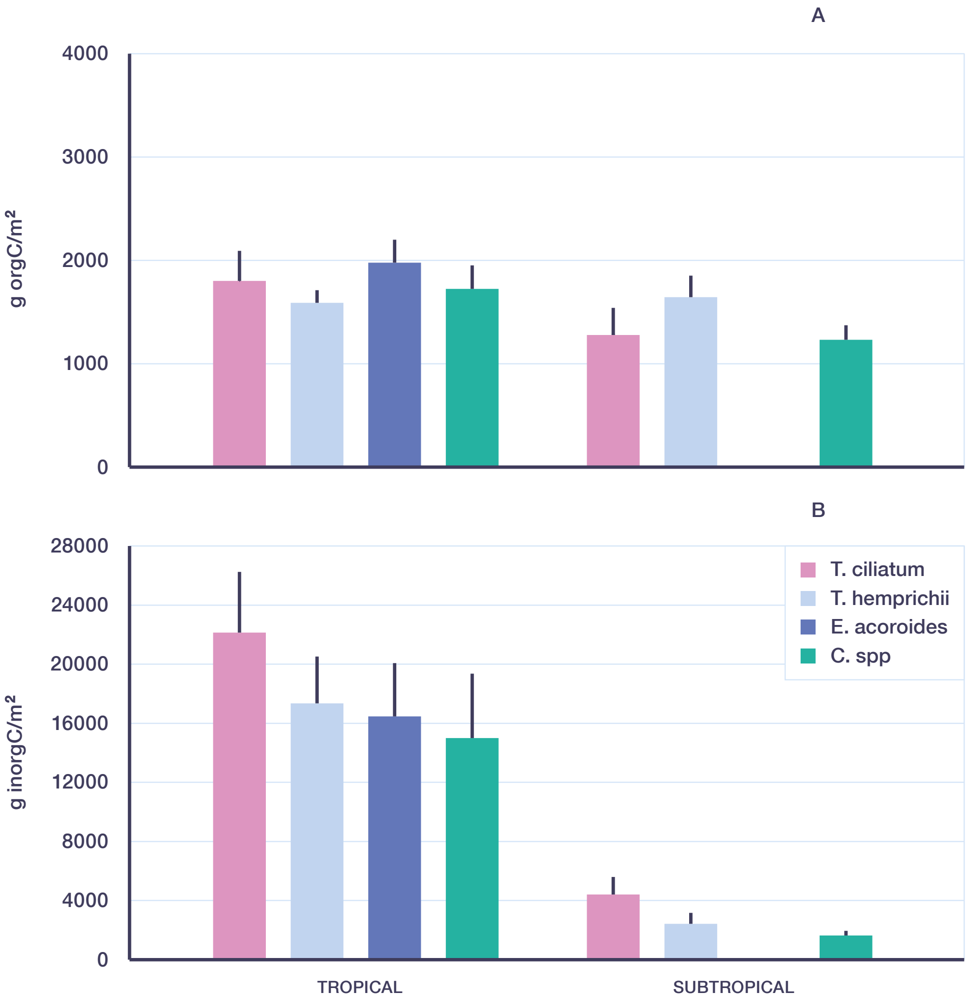


Figure 7. Mean (±SE) organic (orgC) and inorganic (inorgC) carbon stocks (g C per m^2, 0-25 cm sediment depth) in seagrass meadows dominated by either of the following seagrass species: *Thalassodendron ciliatum*, *Thalassia hemprichii*, *Enhalus acoroides* and *Cymodocea* spp. All sampling sites were in tropical (Tanzania) or subtropical (southern Mozambique) regions. Note that the range of the y-axes differs between the two graphs.

different regions across both climate zones (Figure 8). Compared to the two vegetated blue carbon habitats, unvegetated areas showed considerably lower sedimentary organic carbon stock levels in all regions of both climate zones (Figure 8). In contrast to the variability in organic stock levels, the inorganic carbon stocks were very low in mangroves in all regions, except in Mtwara and to some extent in Mafia Island (Figure 9). Seagrass meadows and unvegetated areas showed remarkably high levels of sedimentary inorganic carbon in Zanzibar Island, but also high levels in three of the other tropical regions (i.e. Dar es Salaam, Mafia Island and Mtwara) (Figure 9). The inorganic carbon stocks were generally low in the central Tanzanian mainland regions (Pwani and Lindi) as well as in the regions of the subtropical climate zone (Figure 9).

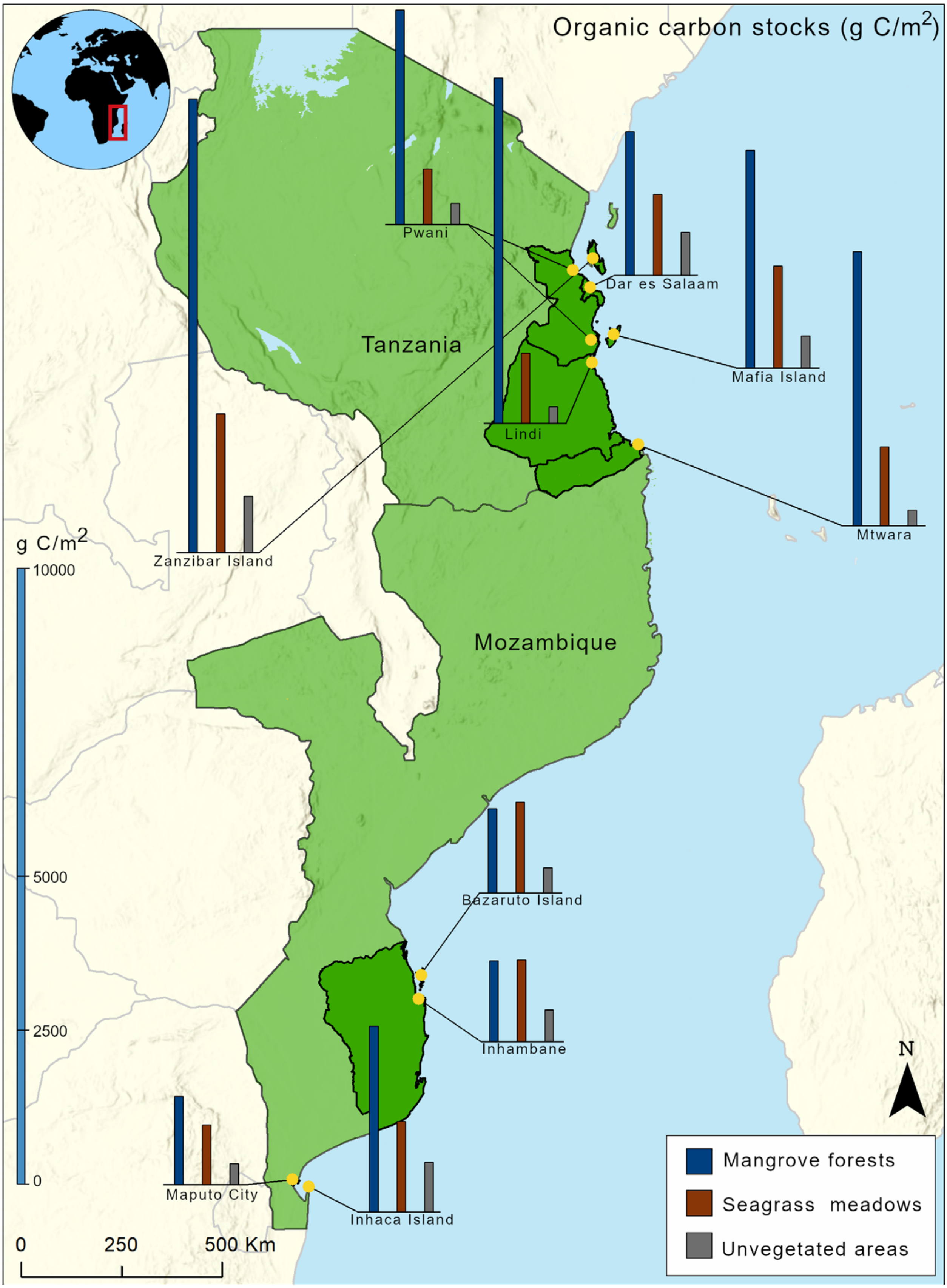


Figure 8. Overview of sedimentary organic carbon stocks in mangrove forests, seagrass meadows and unvegetated areas in all sampling sites across tropical Tanzania and subtropical southern Mozambique. The bars are based on mean values (g C per m²) down to 25 cm sediment depth. Source of background map: Esri, USGS, NOAA.

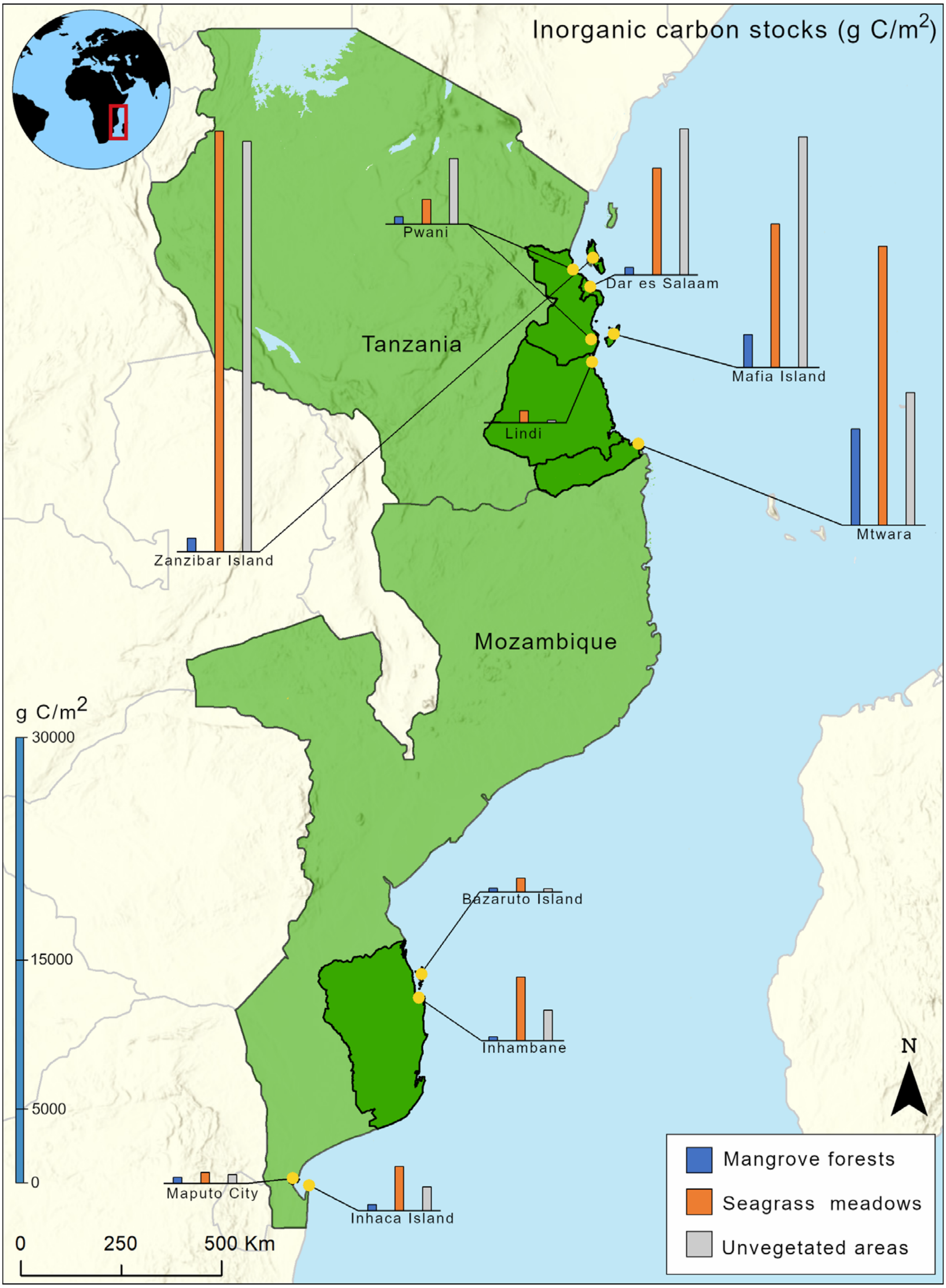


Figure 9. Overview of sedimentary inorganic carbon stocks in mangrove forests, seagrass meadows and unvegetated areas in all sampling sites across tropical Tanzania and subtropical southern Mozambique. The bars are based on mean values (g C per m²) down to 25 cm sediment depth. Source of background map: Esri, USGS, NOAA.

5.3 Influence of marine protection on carbon stocks in Tanzania and southern Mozambique

A major focus in this report is to understand to what degree marine protected areas influence sedimentary carbon stocks in blue forest ecosystems (mangroves and seagrass meadows). In terms of comparisons between protected- and unprotected areas, the outcome showed few clear distinguished patterns of variability. Sedimentary organic and inorganic carbon stock levels in mangroves did not differ between protected- and unprotected areas in either of the two climate zones (Figure 10). The same was found for seagrass meadows and unvegetated areas regarding organic carbon stock levels, which did not differ between protected- and unprotected areas (Figure 10A). In contrast, the inorganic carbon stock levels were slightly higher in protected areas compared to unprotected areas in both seagrass meadows and unvegetated areas of the tropical climate zone, whereas unprotected areas showed higher inorganic carbon stock levels compared to the protected areas in the subtropical climate zone (Figure 10B).

The influence of protection on carbon stocks in different seagrass meadows (i.e. meadows dominated by different seagrass species) was generally of minor nature, although some dissimilarities between

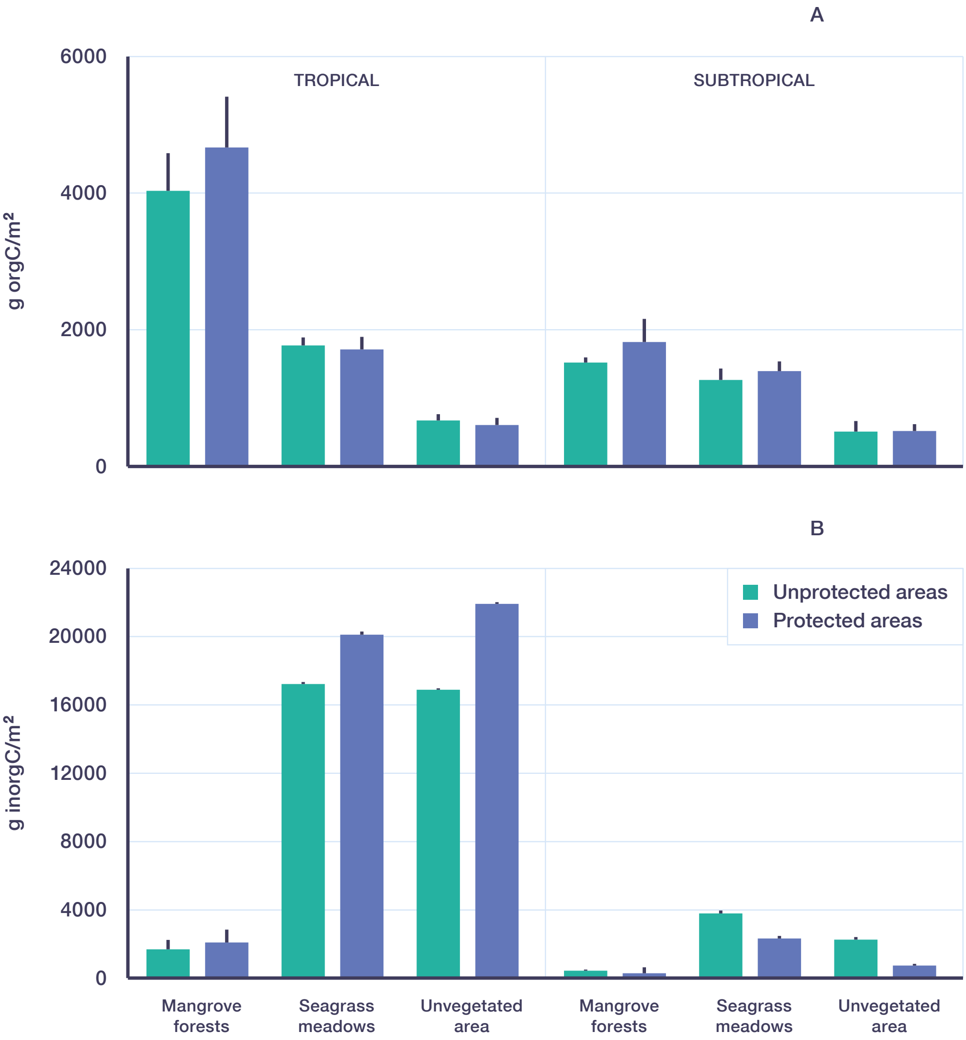


Figure 10. Mean (±SE) organic (orgC) and inorganic (inorgC) carbon stocks (g C per m^2, 0-25 cm sediment depth) in mangroves, seagrass meadows and unvegetated areas within protected- and unprotected areas. All sampling sites were in tropical (Tanzania) or subtropical (southern Mozambique) regions.

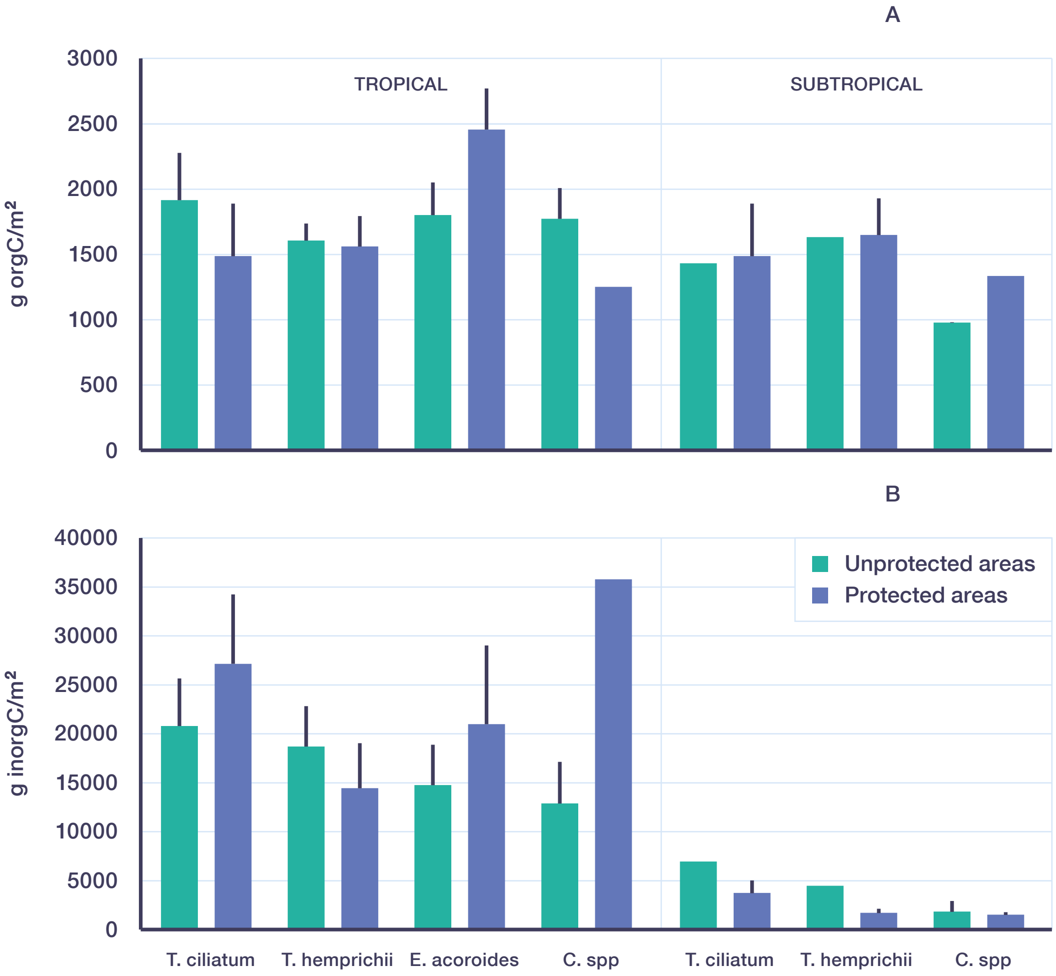


Figure 11. Mean (±SE) organic (orgC) and inorganic (inorgC) carbon stocks (g C per m^2, 0-25 cm sediment depth) in seagrass meadows dominated by either *Thalassodendron ciliatum*, *Thalassia hemprichii*, *Enhalus acoroides* or *Cymodocea* spp. within protected- and unprotected areas. All sampling sites were in tropical (Tanzania) or subtropical (southern Mozambique) regions.

protected- and unprotected areas could be discerned (Figure 11). The sedimentary organic carbon stock levels were slightly higher in protected meadows dominated by *E. acoroides*, and slightly lower in protected meadows dominated by *Cymodocea* spp., compared to unprotected areas (Figure 11A), whereas all other comparisons between protected- and unprotected areas focusing on organic carbon stocks in seagrass meadows showed no significant differences (Figure 11A). The inorganic carbon stock levels in the tropical region were clearly higher in protected meadows dominated by *Cymodocea* spp., and slightly higher in meadows dominated by *T. ciliatum* or *E. acoroides*, compared to unprotected areas (Figure 11B). In contrast, meadows dominated by *T. ciliatum*, and meadows dominated by *T. hemprichii* in the subtropical climate zone, had lower inorganic carbon stock levels in protected areas compared to unprotected areas (Figure 11B).

Zanzibar Island

Zanzibar Island, or Unguja, is one of the two islands comprising the Zanzibar archipelago (the other one is Pemba Island). The island consists of a broad distribution of blue carbon habitats in terms of some major mangrove forests and a high diversity of seagrass meadows (up to 11 seagrass species have been recognised; Gullström et al., 2006) (Figure 2). Three major protected areas were sampled during the fieldwork, including Jozani–Chwaka Bay National Park on the east coast of the island, Menai Bay Conservation Area in the southwest and Chumbe Island on the west coast. The sedimentary organic carbon stock levels in mangroves were very high (in the north as well as on the east coast, i.e. in Chwaka Bay) or high (north of Zanzibar Town), whereas seagrass meadows ranged from low to high organic carbon stock levels at different places around the island (Figures 12-15). Unvegetated sediment showed low or very low organic carbon content (Figures 12-15).

In the Jozani–Chwaka Bay National Park, very high organic carbon stock levels were found in mangroves, while in the unprotected seagrass meadows (in Chwaka Bay, i.e. adjacent to the national park) the organic carbon stock levels ranged from low to very high (Figure 13). With regard to the inorganic carbon stocks in protected habitats, the levels were particularly high in the sampled seagrass meadows of Menai Bay Conservation Area (Figure 14) and Chumbe Island (Figure 15), and low in mangroves of the national park of Jozani-Chwaka Bay (Figure 15).

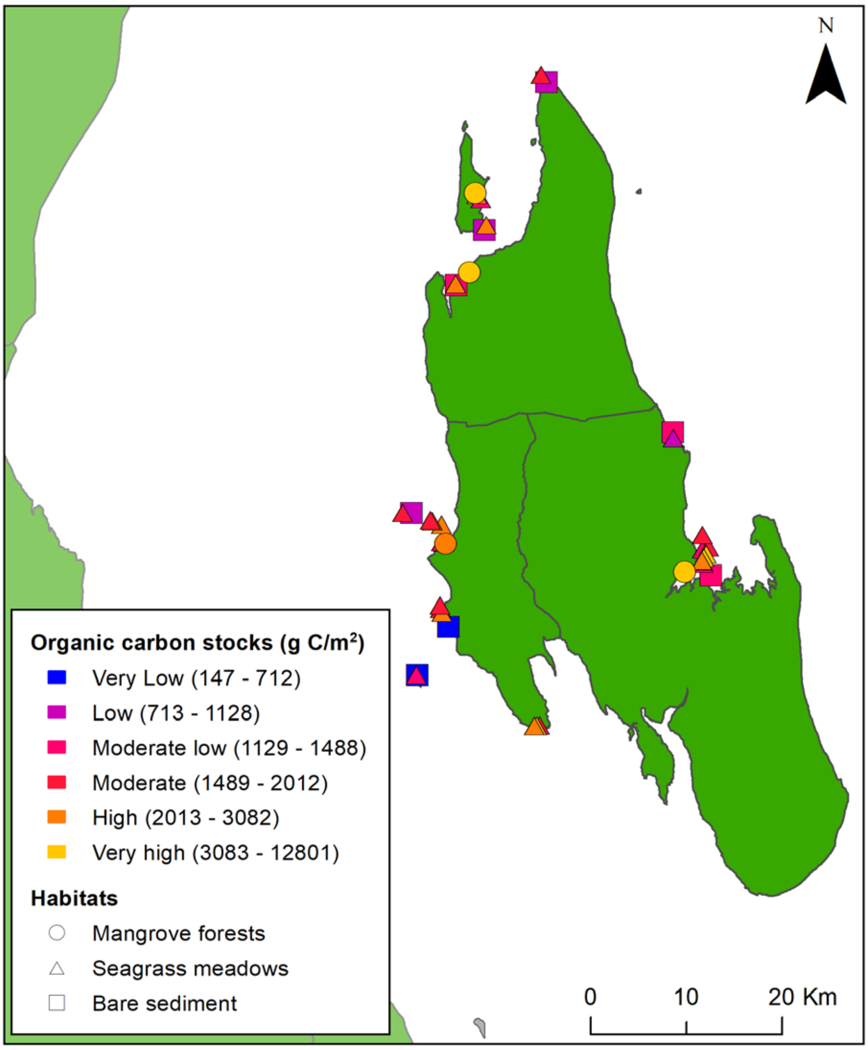
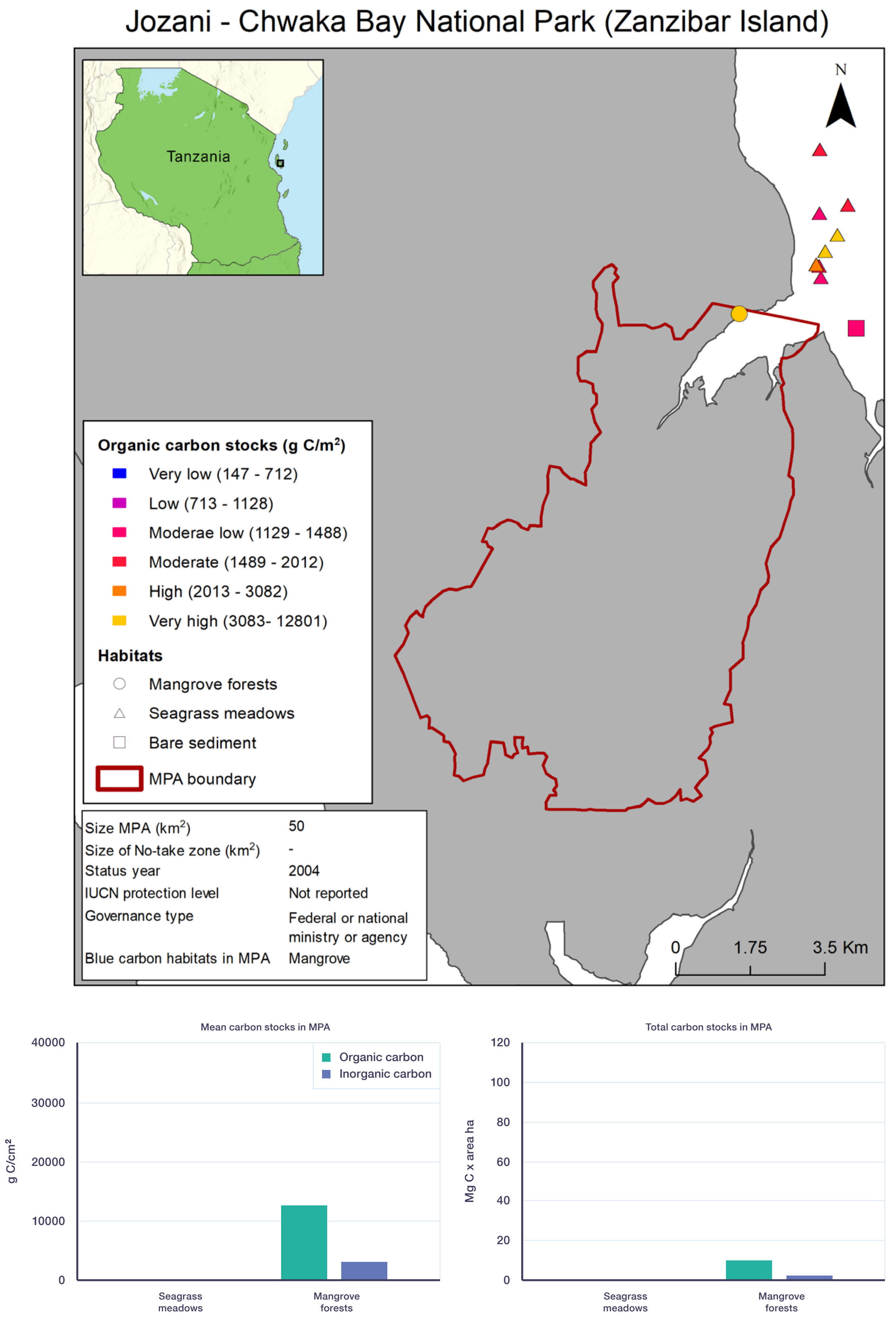
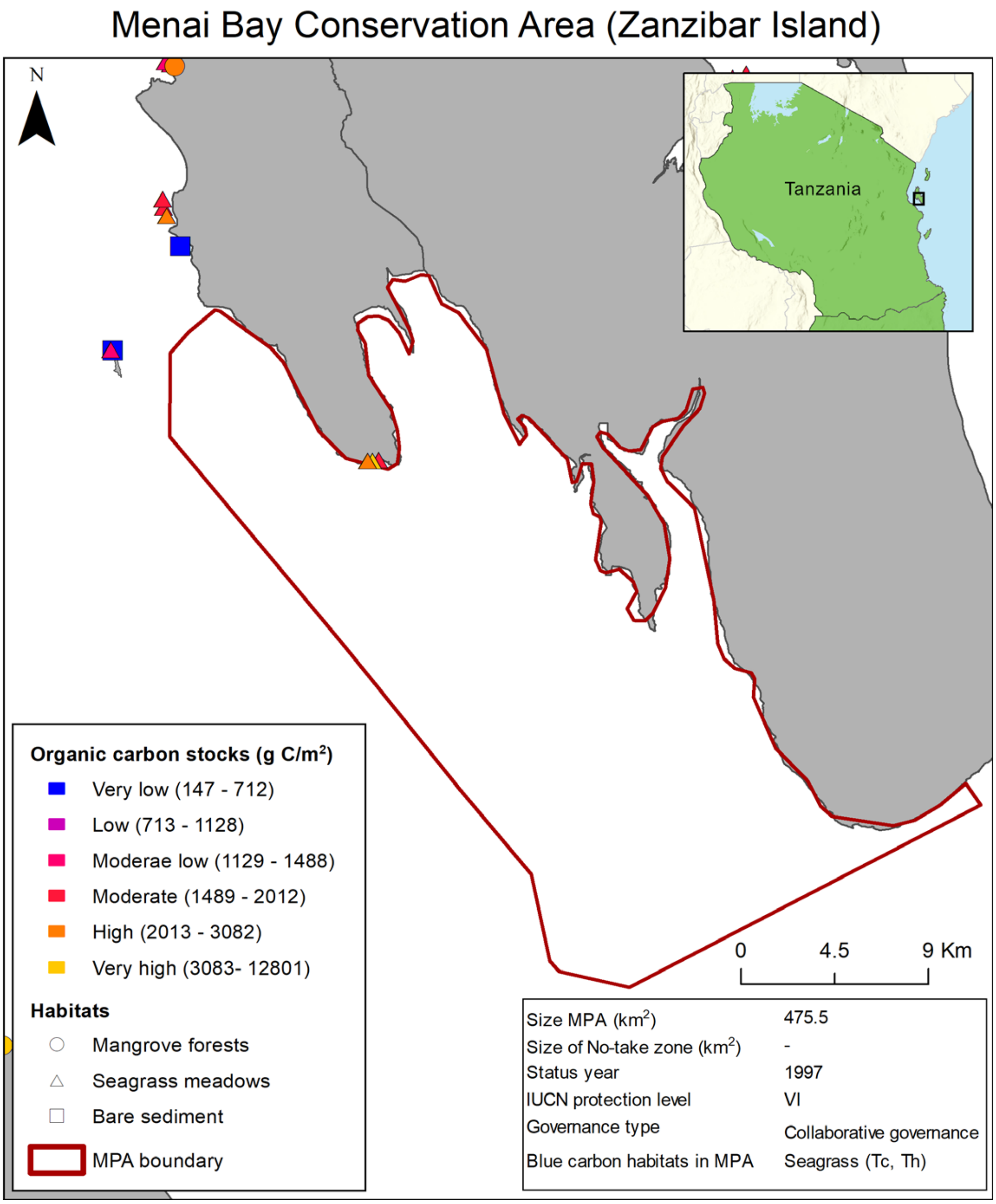


Figure 12. Region: Zanzibar Island. Source of background map: Esri, USGS, NOAA.

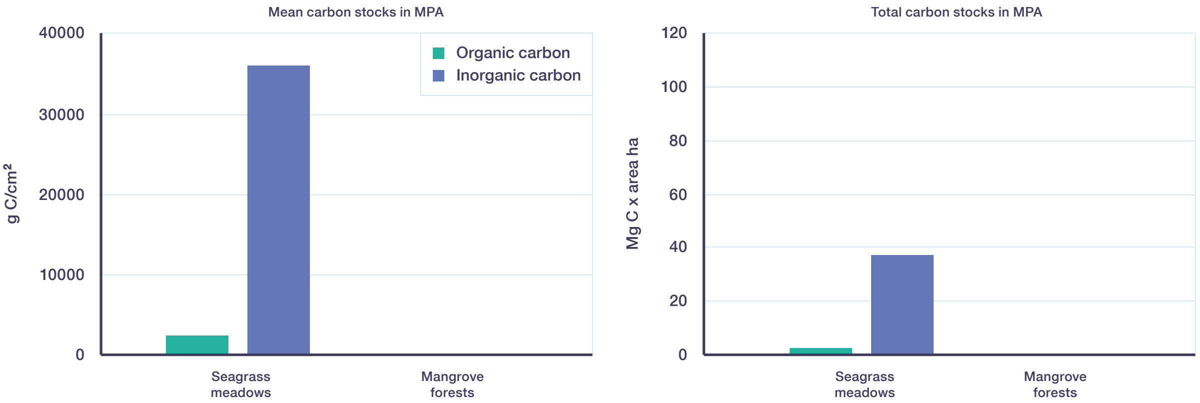


Size MPA (km^2)	50
Size of No-take zone (km^2)	-
Status year	2004
IUCN protection level	Not reported
Governance type	Federal or national ministry or agency
Blue carbon habitats in MPA	Mangrove

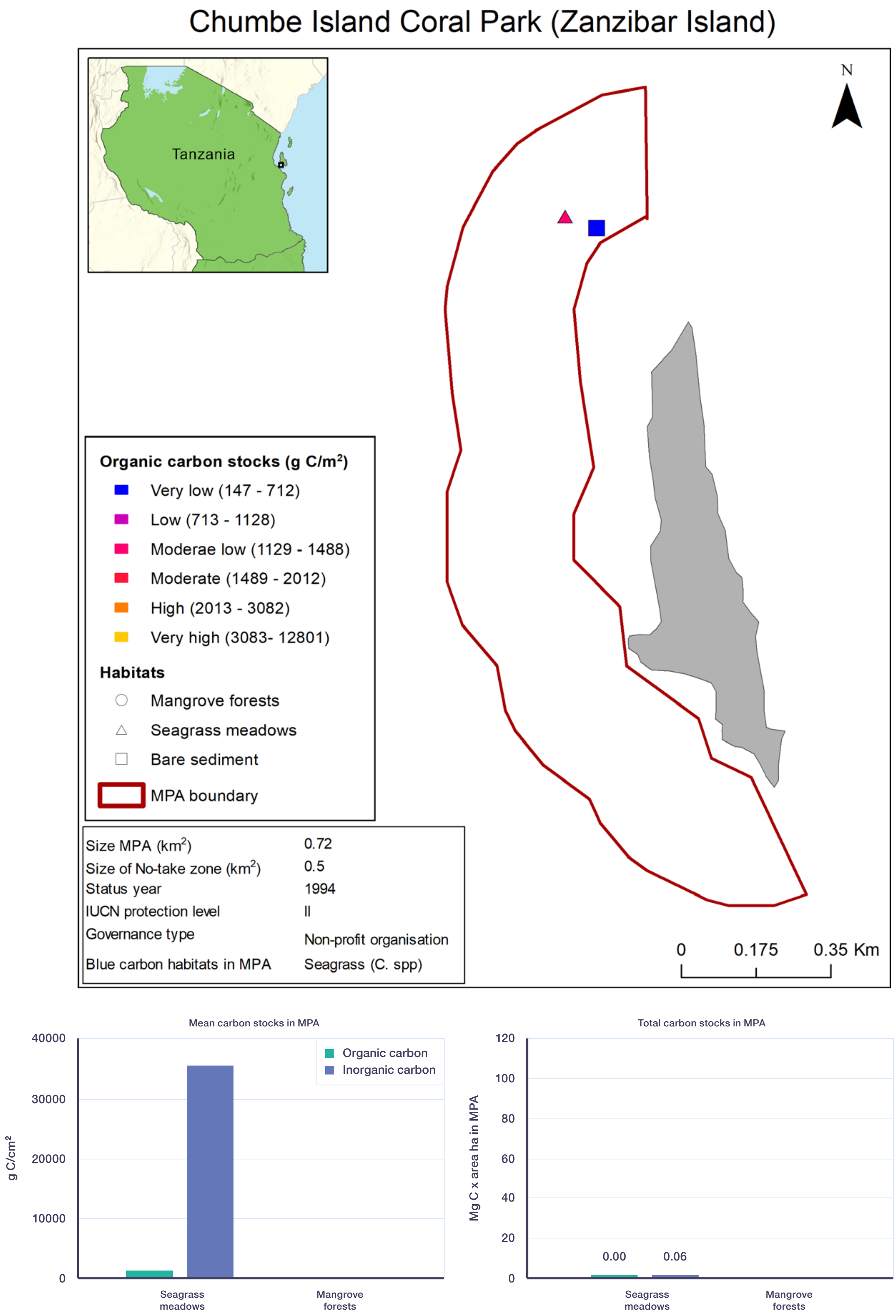
Figures 13. Protected area Jozani–Chwaka Bay National Park. Source background map: ESR, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m^2) inside MPA.



Size MPA (km²)	475.5
Size of No-take zone (km²)	-
Status year	1997
IUCN protection level	VI
Governance type	Collaborative governance
Blue carbon habitats in MPA	Seagrass (Tc, Th)



Figures 14. Protected area Menai Bay Conservation Area. Source background map: ESR, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.



Size MPA (km²)	0.72
Size of No-take zone (km²)	0.5
Status year	1994
IUCN protection level	II
Governance type	Non-profit organisation
Blue carbon habitats in MPA	Seagrass (C. spp)

Figures 15. Protected area Chumbe Island Coral Park. Source background map: ESR, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Dar es Salaam

The Dar es Salaam region comprises a highly populated area since it covers the central and surrounding areas of Dar es Salaam, i.e. the largest city in Tanzania. The region is composed of scattered areas of mangroves and seagrass meadows that stretch along the coastline (Figure 2). The sedimentary organic carbon stock levels were generally moderate to very high in mangroves and very low to very high in seagrass meadows (Figures 16 and 17), while the unvegetated areas showed very low or low organic carbon stock levels (Figures 16 and 17). Within the Dar es Salaam Marine Reserve, seagrass meadows dominated by *T. ciliatum* and unvegetated areas showed low or very low organic carbon stock levels (Figure 17). The inorganic carbon stock levels were high in the sampled seagrass meadows within the marine reserve zone (Figure 17).

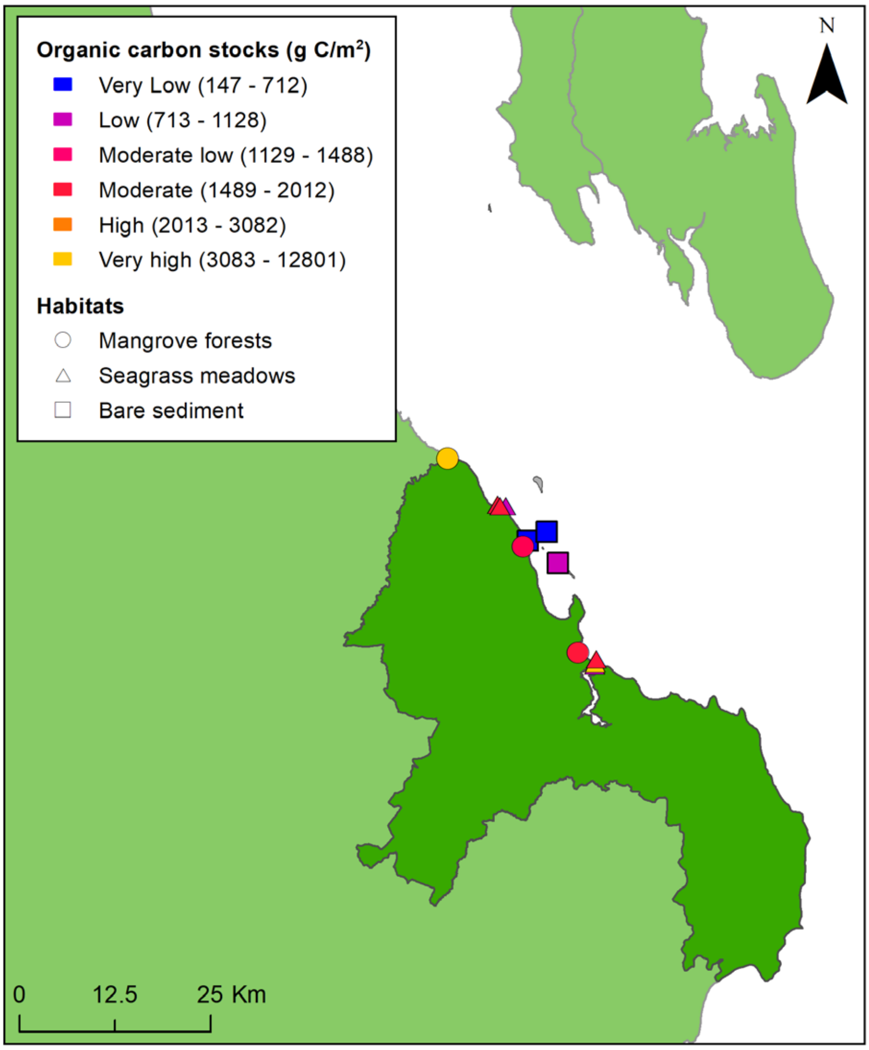
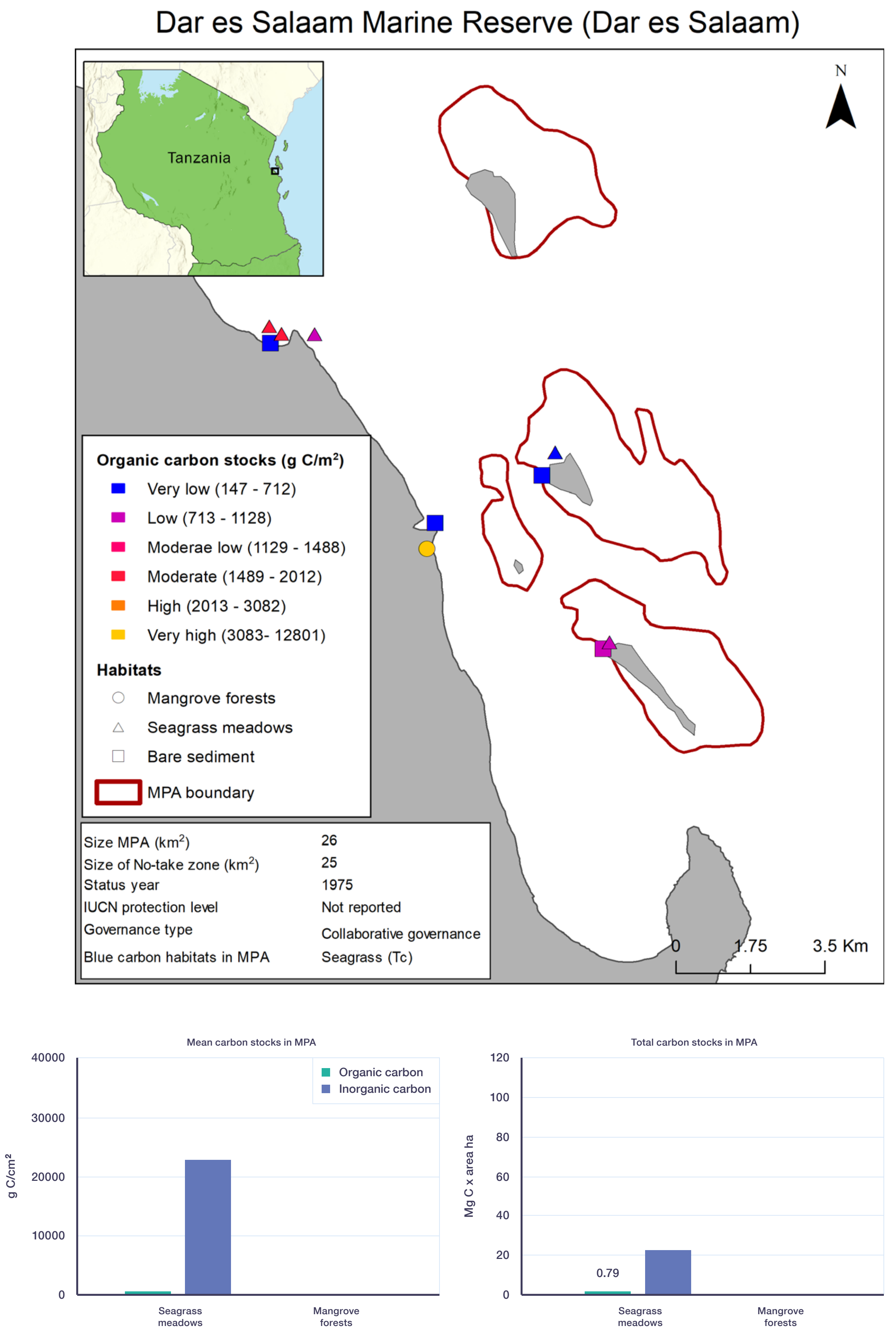


Figure 16. Region: Dar es Salaam. Source of background map: Esri, USGS, NOAA.



Size MPA (km²)	26
Size of No-take zone (km²)	25
Status year	1975
IUCN protection level	Not reported
Governance type	Collaborative governance
Blue carbon habitats in MPA	Seagrass (Tc)

Figure 17. Protected area: Dar es Salaam Marine Reserve. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Pwani

Pwani is a region with mangroves mostly covering continuous areas of the coastline, and especially in the southern part of the region, where the state-owned Rufiji delta mangrove forest is extensively distributed (Figure 2). Seagrass meadows are distributed in a scattered manner along the coastal zone (Figure 2). The sedimentary organic carbon stock levels were moderate, high or very high in mangroves, low in seagrass (including only one site of *Cymodocea* spp.) and very low in unvegetated areas (Figure 18). Within the Mikindani Forest Reserve, a very high organic carbon stock level was found in the mangrove habitat, while the unvegetated sediment showed a very low organic carbon stock level (Figure 19). The inorganic carbon stock level was very low in the protected mangrove habitat (Figure 19).

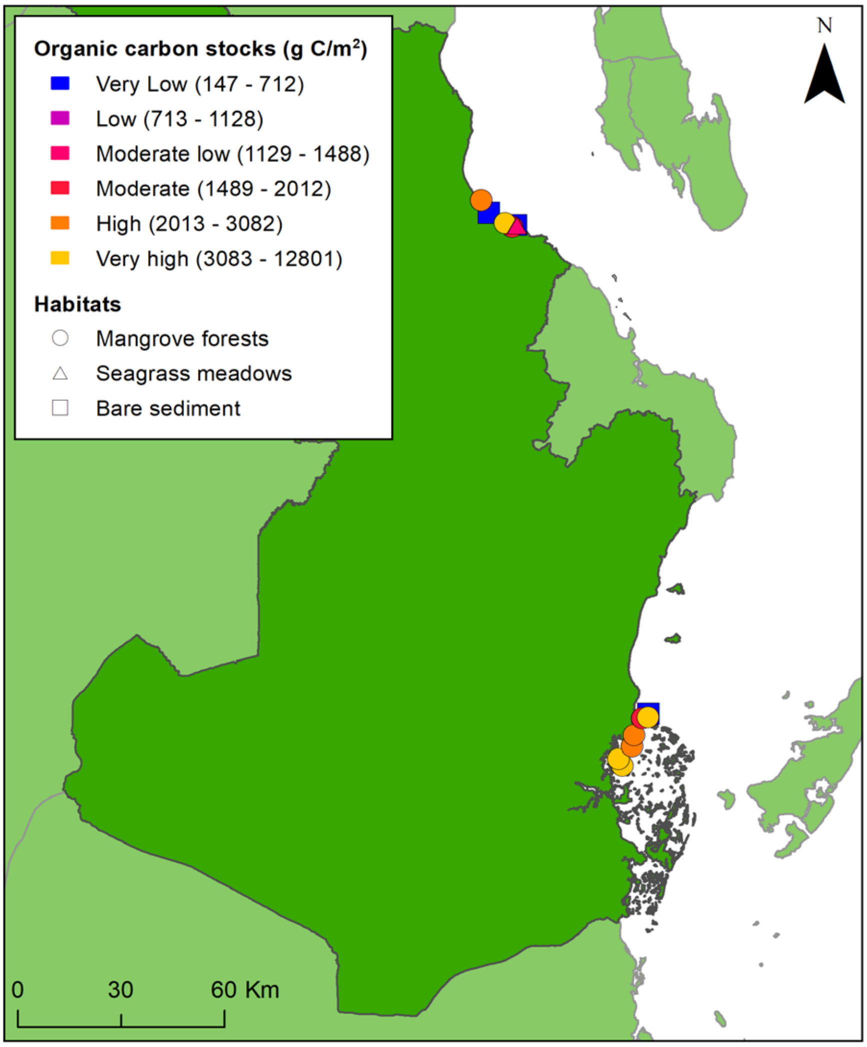
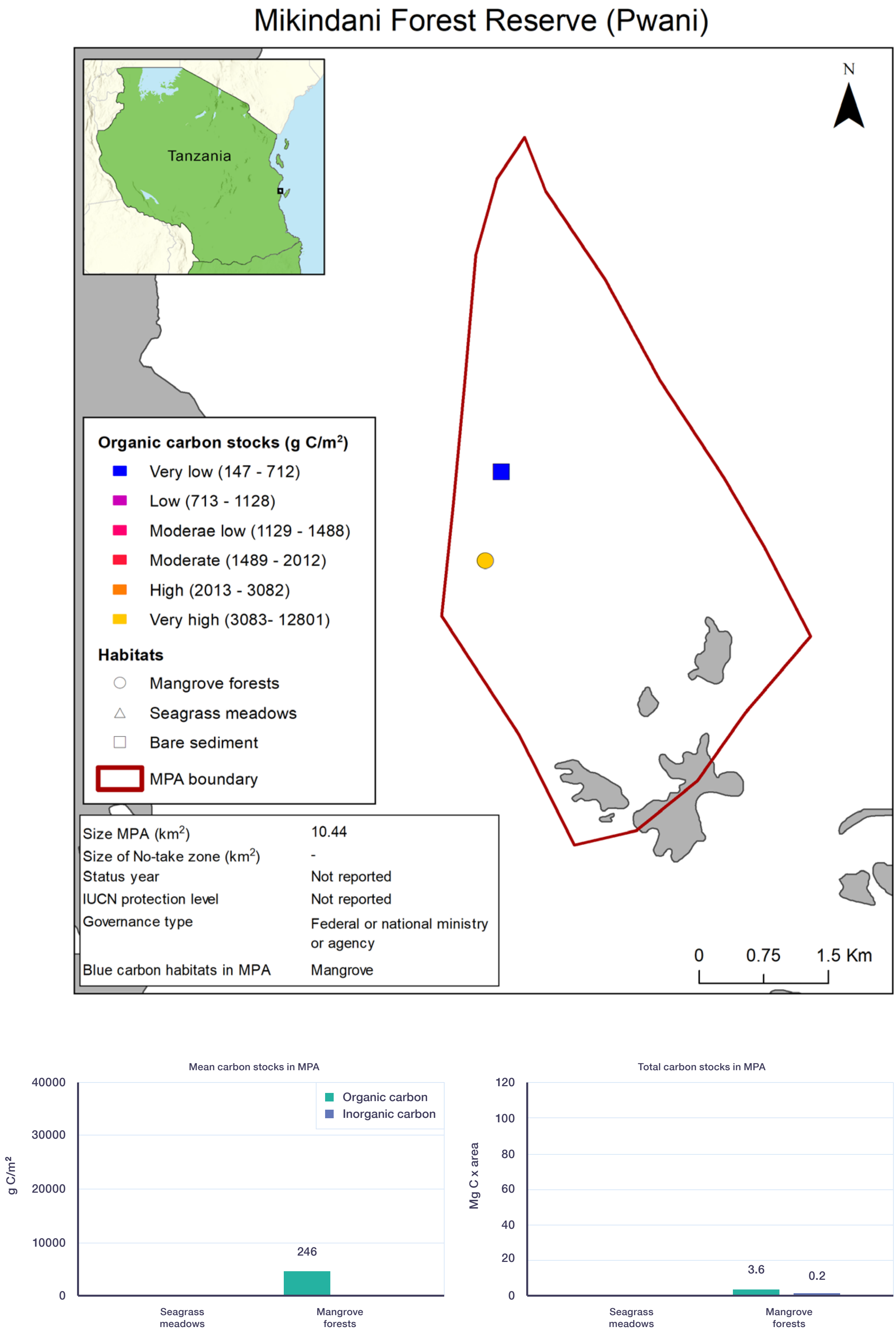


Figure 18. Region: Pwani. Source of background map: Esri, USGS, NOAA.



Size MPA (km²)	10.44
Size of No-take zone (km²)	-
Status year	Not reported
IUCN protection level	Not reported
Governance type	Federal or national ministry or agency
Blue carbon habitats in MPA	Mangrove

Figure 19. Protected area: Mikindani Forest Reserve. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Mafia Island

About half of Mafia Island is composed of the Mafia Island Marine Park. The island is composed of large areas of blue carbon habitats in terms of mangroves and seagrass meadows (Figure 2). Mangroves showed high or mostly very high levels of sedimentary organic carbon stocks, while seagrass meadows ranged from low to high organic carbon stock levels (Figure 20). Unvegetated areas showed very low or low sedimentary organic carbon stock levels (Figure 20). In general, the organic carbon stocks were at similar levels in the protected park zone as in the unprotected areas, which were confirmed by pairwise comparisons for each of the three studied habitats (i.e. mangroves, seagrass meadows and unvegetated areas) (Figure 21). The inorganic carbon stocks were at moderate levels in seagrass meadows and very low in the mangrove sites (Figure 21).

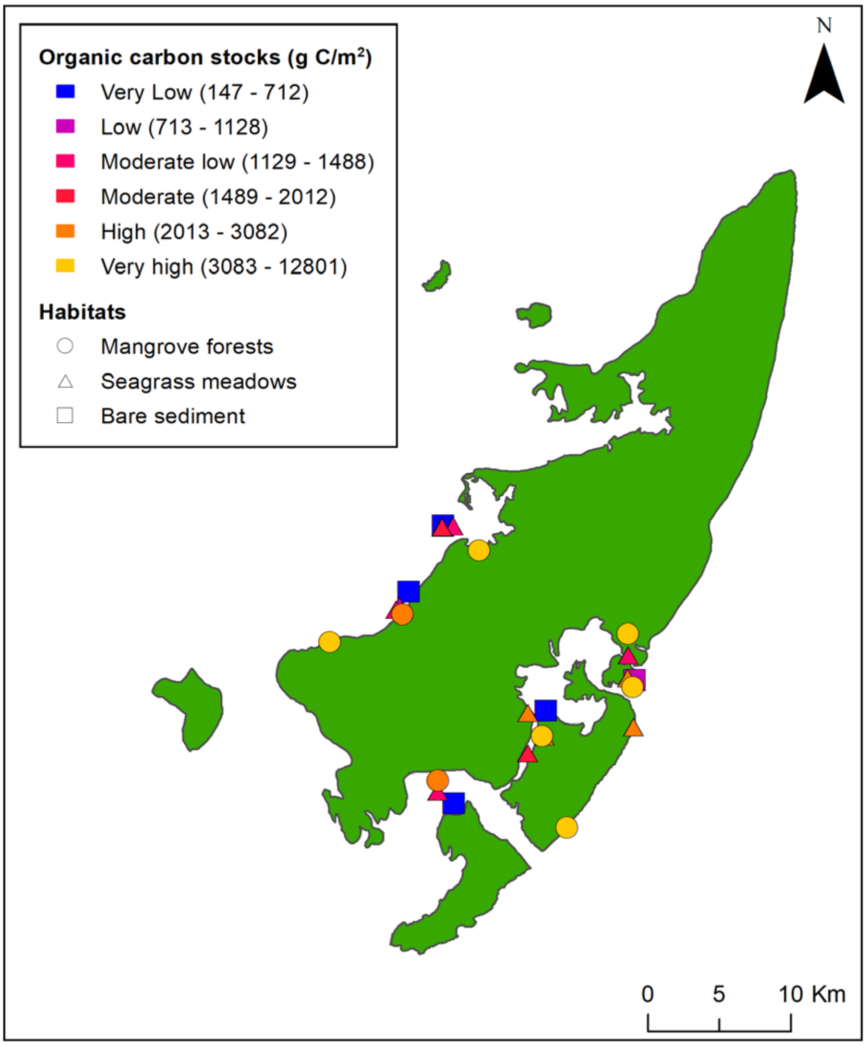
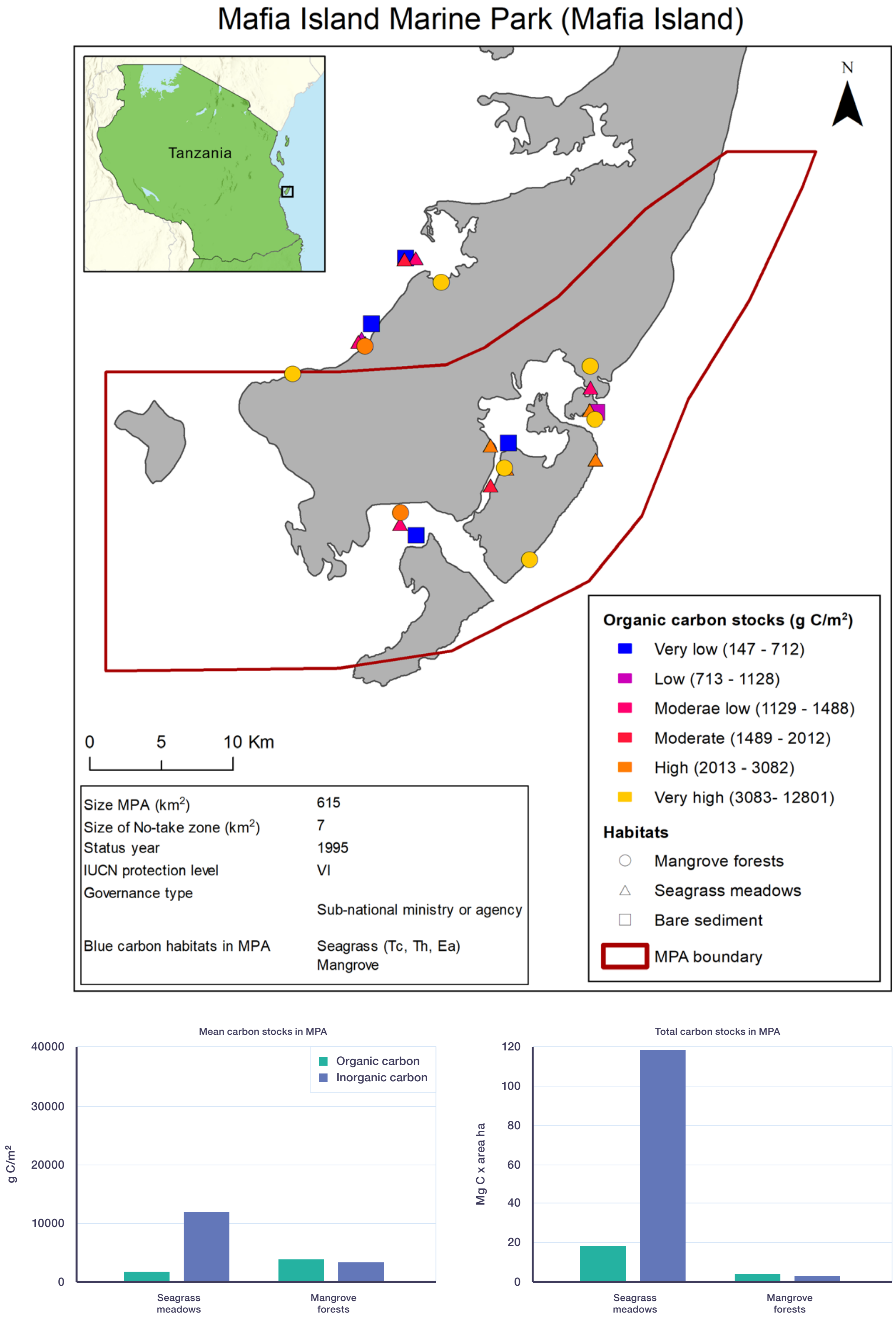


Figure 20. Region: Mafia Island. Source of background map: Esri, USGS, NOAA.



Size MPA (km^2)	615
Size of No-take zone (km^2)	7
Status year	1995
IUCN protection level	VI
Governance type	Sub-national ministry or agency
Blue carbon habitats in MPA	Seagrass (Tc, Th, Ea) Mangrove

Figure 21. Protected area: Mafia Island Marine Park. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Lindi

The Lindi region consists of some extensive mangroves, while seagrass meadows are scattered in different areas along the coastline (Figure 2). The region has no reported protected areas (Figure 4). The sedimentary organic carbon stock levels were very high in mangroves, low to moderate in seagrass meadows and very low in unvegetated areas (Figure 22).

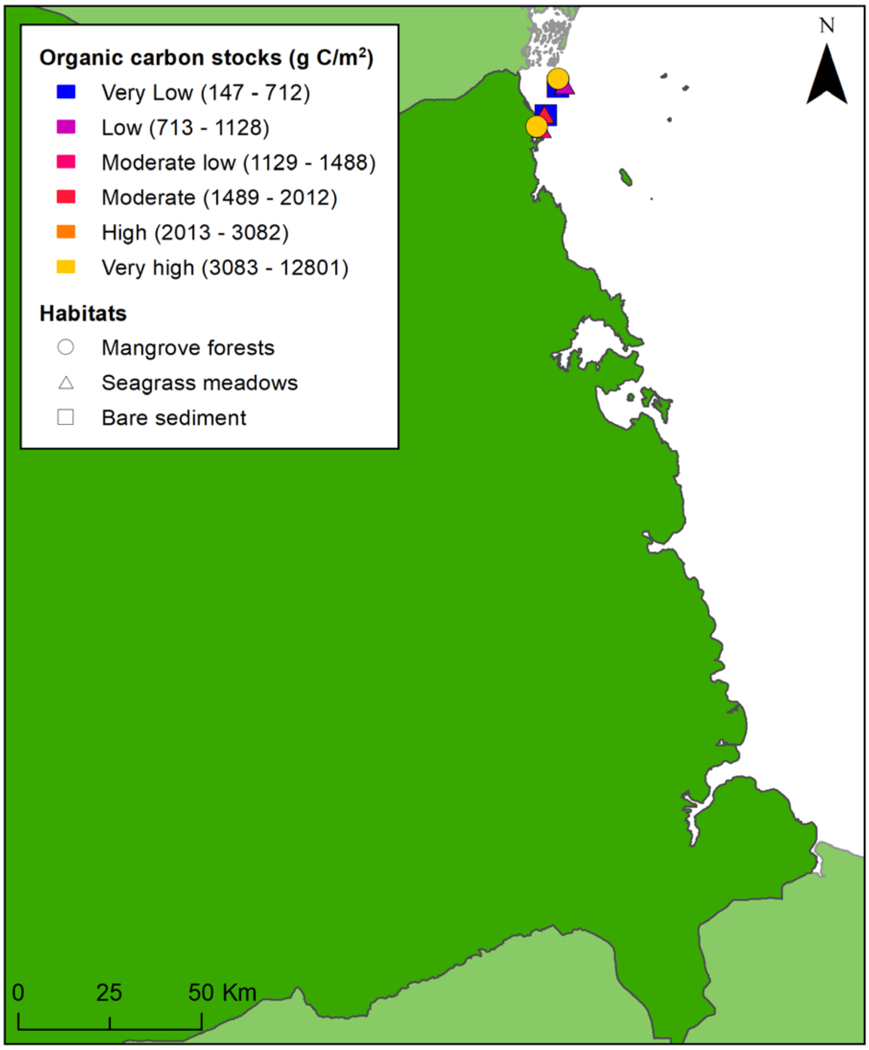


Figure 22. Region: Lindi. Source of background map: Esri, USGS, NOAA.

Mtwara

Mtwara is the most southern region of those sampled in the tropical climate zone (Figure 8). The Mnazi Bay-Ruvuma Estuary Marine Park covers coastal areas a bit north of the border to Mozambique (Figure 4). The Mtwara region in general (Figure 23), as well as the park area specifically (Figure 24), showed very high organic carbon stock levels in mangroves, very low to high levels in seagrass meadows and very low levels in unvegetated areas (Figure 23). In the marine park, the inorganic carbon stock levels were low in seagrass meadows and negligible in mangroves (Figure 24).

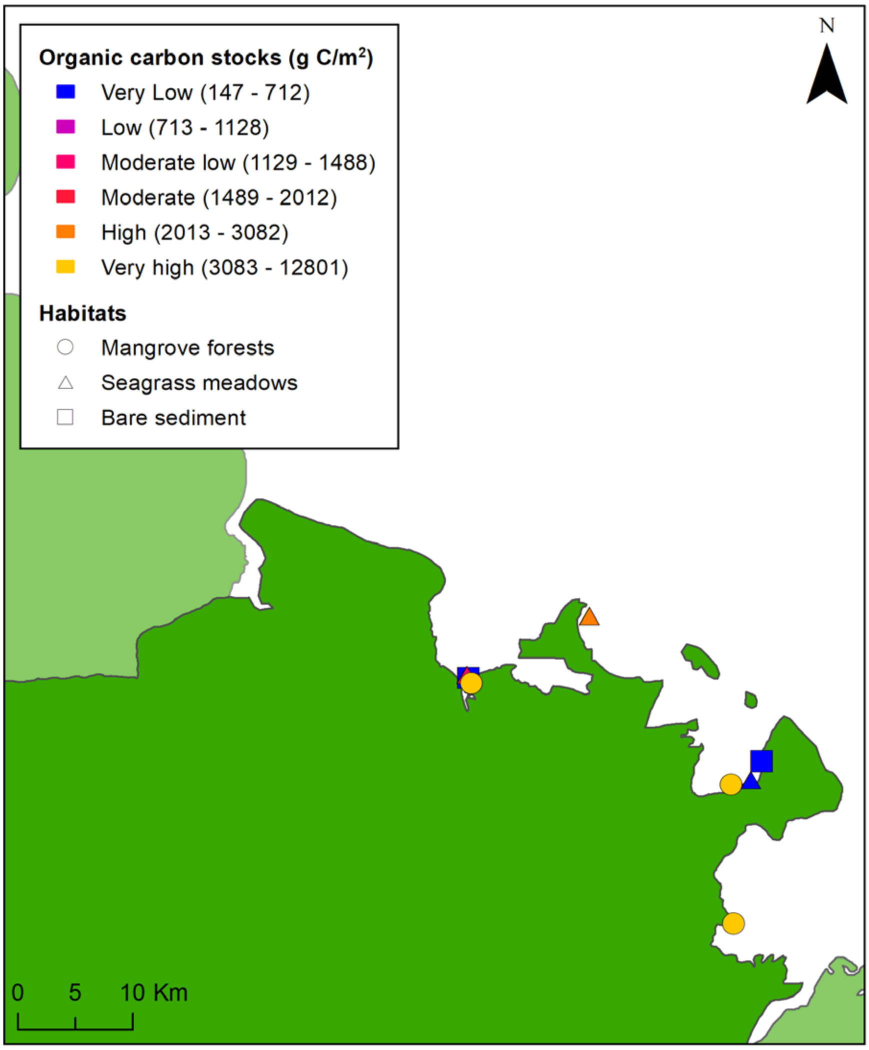
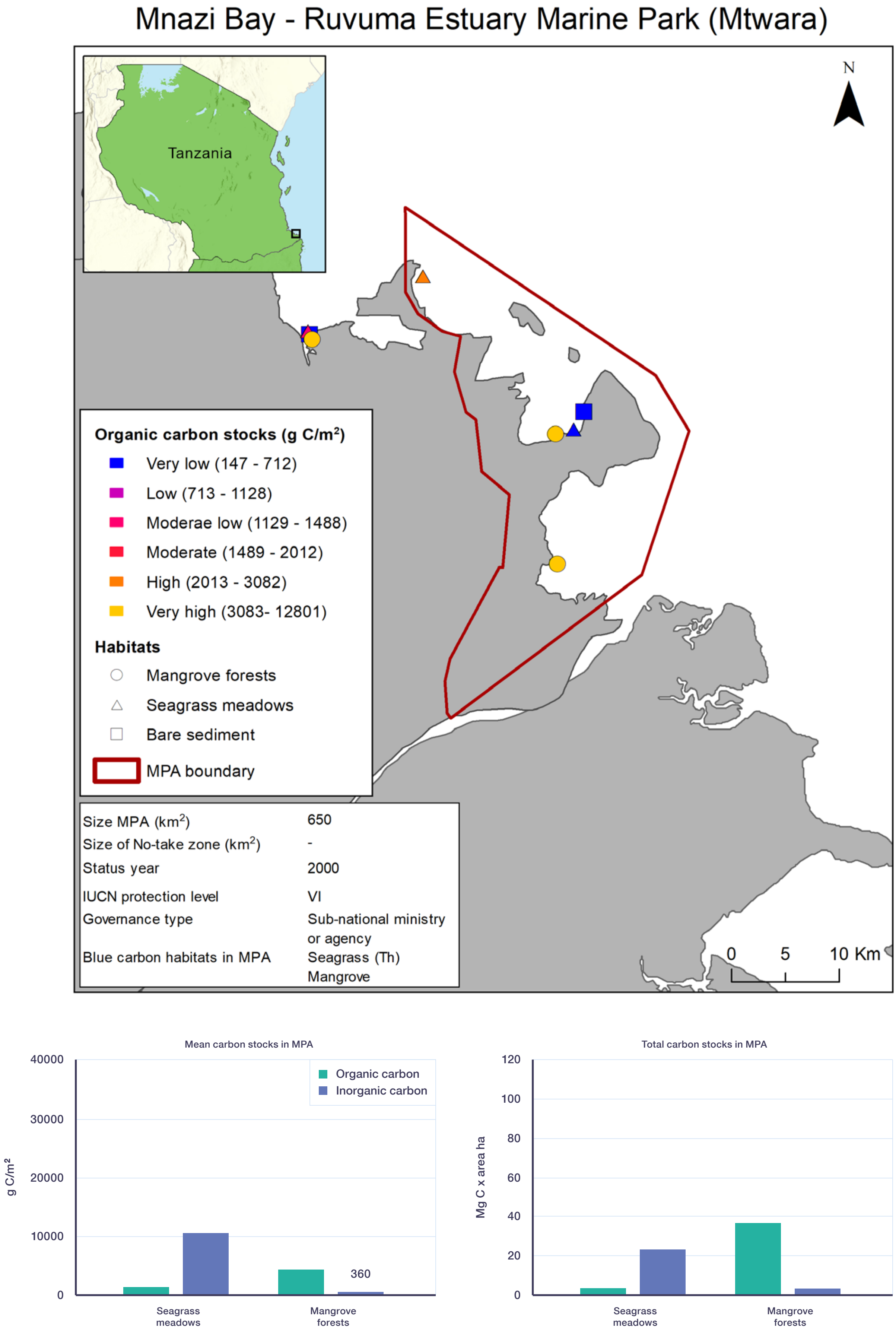


Figure 23. Region: Mtwara. Source of background map: Esri, USGS, NOAA.



Mnazi Bay - Ruvuma Estuary Marine Park (Mtwara)

Size MPA (km²)	650
Size of No-take zone (km²)	-
Status year	2000
IUCN protection level	VI
Governance type	Sub-national ministry or agency
Blue carbon habitats in MPA	Seagrass (Th) Mangrove

Figure 24. Protected area: Mnazi Bay-Ruvuma Estuary Marine Park. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Bazaruto Island

The entire region encompassing Bazaruto Island is protected in the form of Bazaruto Archipelago National Park (Figure 5). The island comprises mangrove- and seagrass habitats scattered at the island (Figure 3). The levels of sedimentary organic carbon stocks were generally moderately low in mangroves and low to high in seagrass meadows, whereas unvegetated sediment showed very low or low levels (Figures 25 and 26). The inorganic carbon stock levels were very low in both seagrass meadows and mangroves (Figure 26).

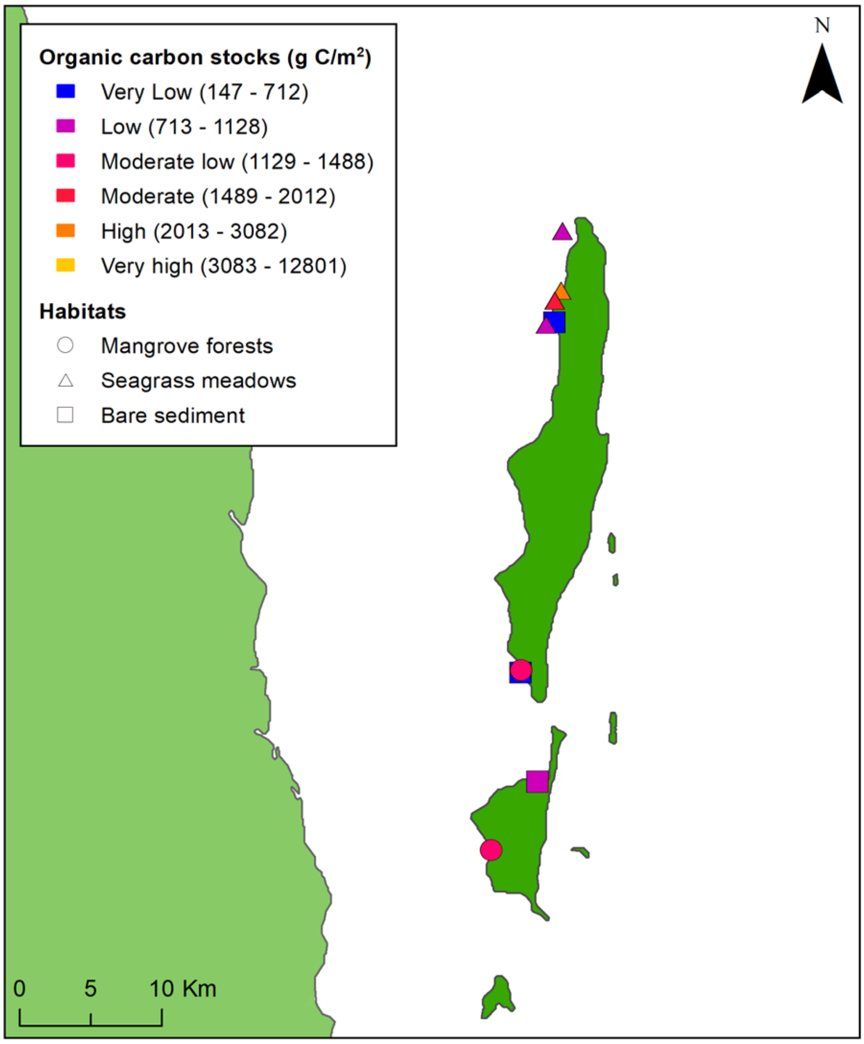
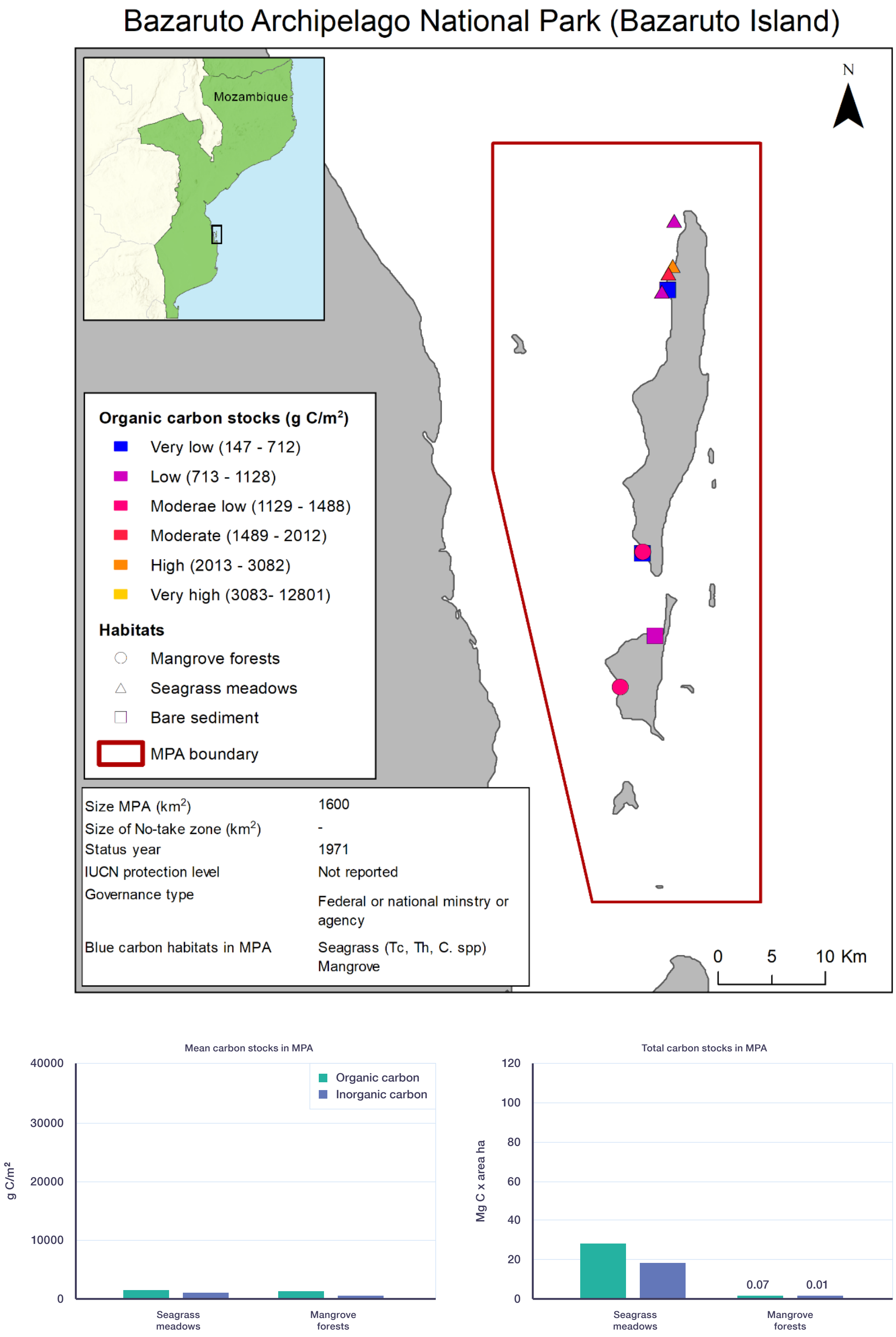


Figure 25. Region: Bazaruto Island. Source of background map: Esri, USGS, NOAA.



Size MPA (km²)	1600
Size of No-take zone (km²)	-
Status year	1971
IUCN protection level	Not reported
Governance type	Federal or national minstry or agency
Blue carbon habitats in MPA	Seagrass (Tc, Th, C. spp) Mangrove

Figure 26. Protected area: Bazaruto Archipelago National Park. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Inhambane

The Inhambane region shows small, scattered areas of blue carbon habitats, i.e. mangroves and seagrass meadows (Figure 3). All sampling sites in this region were located at the mainland coast, south or southwest of the Bazaruto Archipelago National Park (Figure 27). Seagrass meadows showed low to moderate levels of sedimentary organic carbon stocks (Figure 27), while the mangroves ranged from low to moderate levels (Figures 27 and 28). There were very low levels of organic carbon in the unvegetated sediment (Figure 27). The San Sebastian Coastal Reserve – The Sanctuary is a reserve within the Inhambane region and located straight south of the Bazaruto Island. Both the mangrove- and unvegetated sediment within the protected reserve had low organic and inorganic carbon stock levels (Figure 28).

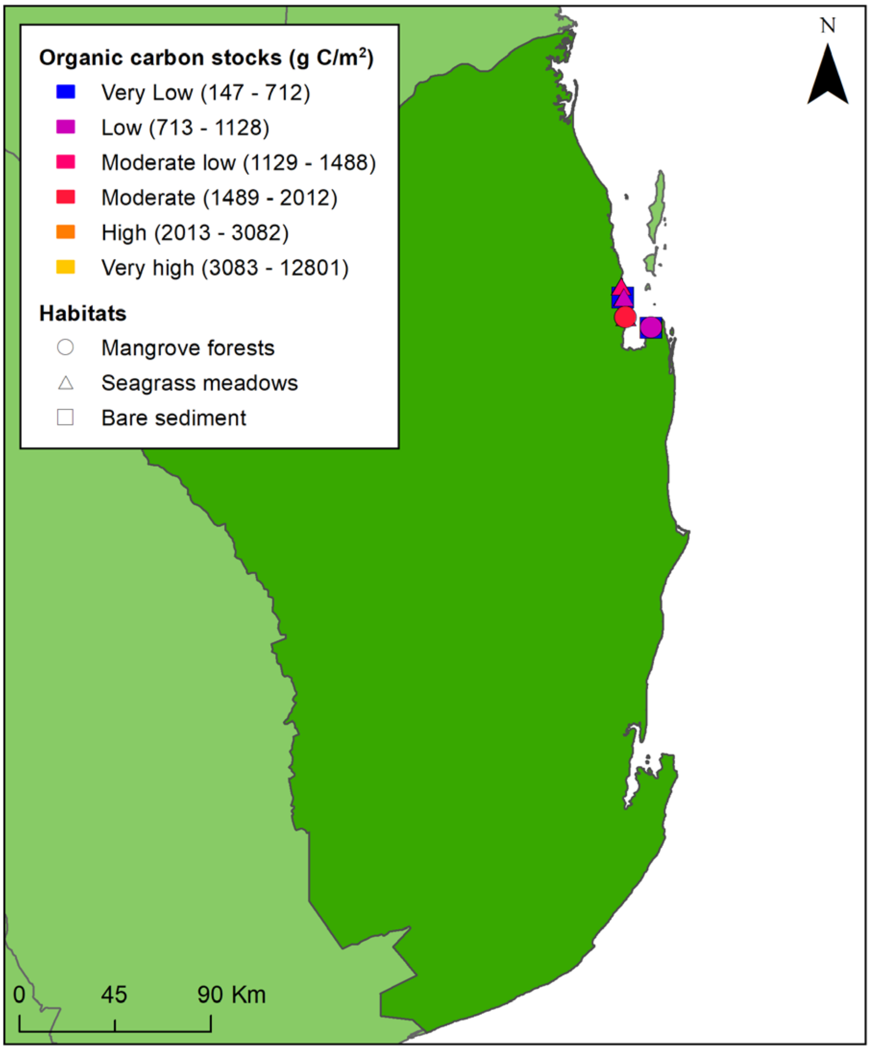
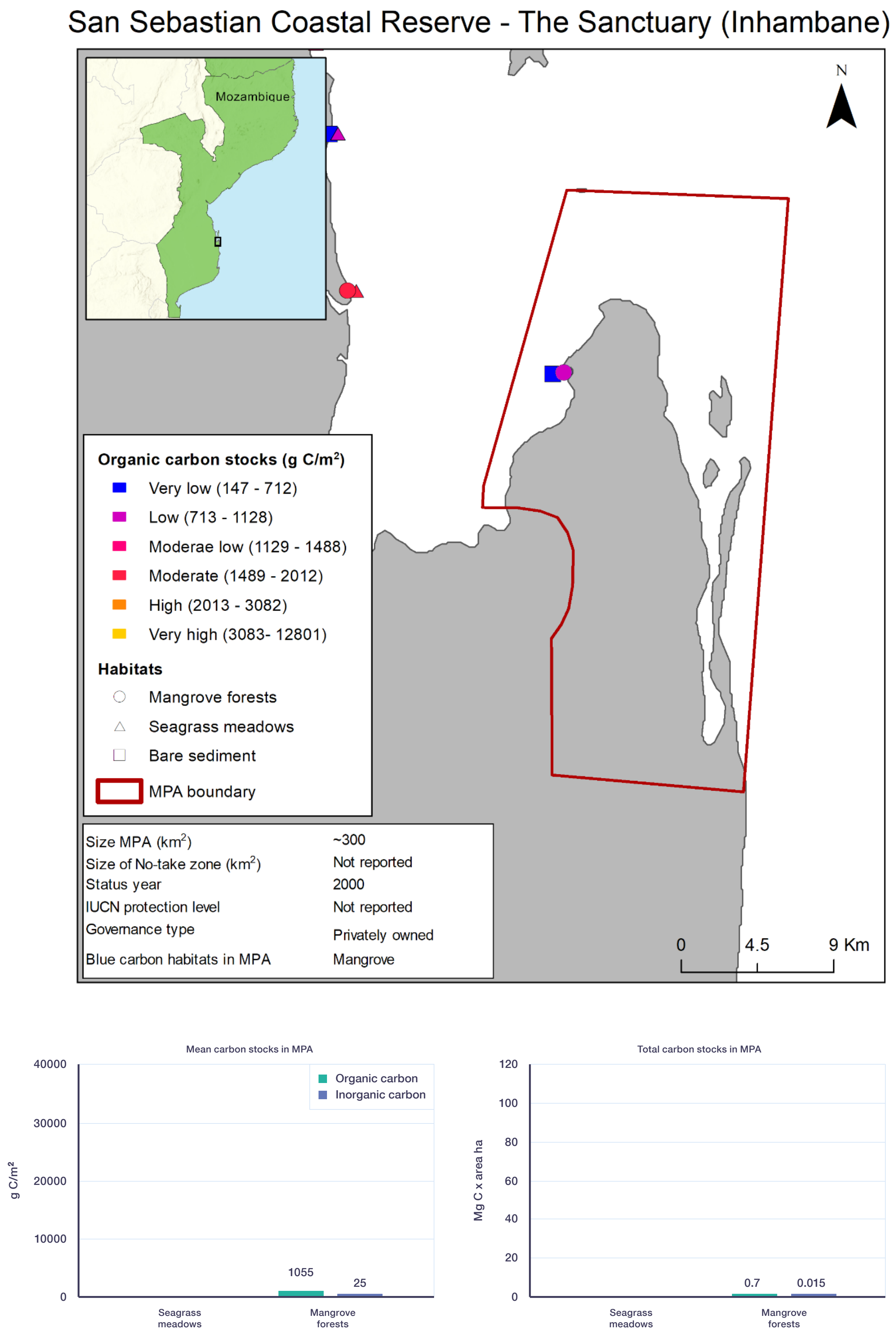


Figure 27. Region: Inhambane. Source of background map: Esri, USGS, NOAA.



Size MPA (km^2)	~300
Size of No-take zone (km^2)	Not reported
Status year	2000
IUCN protection level	Not reported
Governance type	Privately owned
Blue carbon habitats in MPA	Mangrove

Figure 28. Protected area: San Sebastian Coastal Reserve – The Sanctuary. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

Maputo City

The region of Maputo City comprises some mangrove- and seagrass habitats (Figure 3; Bandeira et al., 2014; Paula et al., 2014), but no reported protected areas (Figure 4). The sedimentary organic carbon stock levels were moderately low in mangroves, low in seagrass meadows and very low in unvegetated areas (Figure 29).

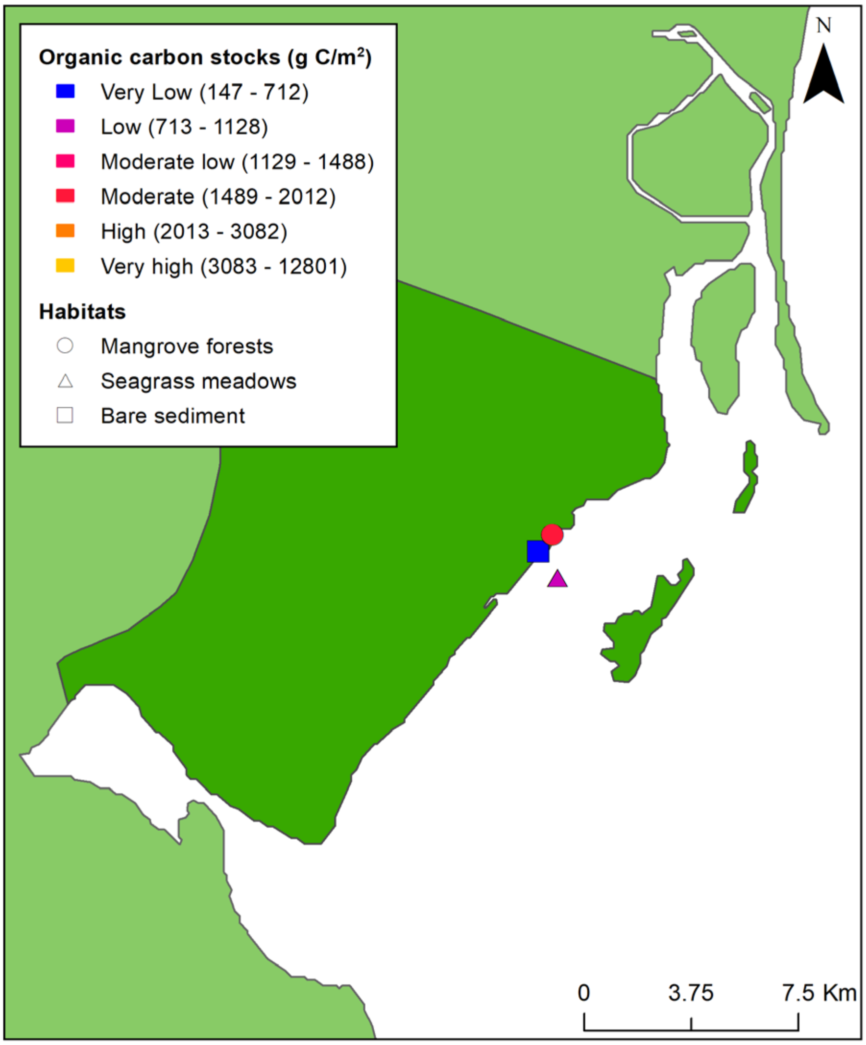


Figure 29. Region: Maputo City. Source of background map: Esri, USGS, NOAA.

Inhaca Island

Inhaca Island is a small island in southern Mozambique, which encompasses large mangroves (Paula et al., 2014) and a high diversity of seagrass meadows (Bandeira et al., 2014). All sampling sites at Inhaca Island were situated within the Ponto do Ouro Partial Marine Reserve (Figures 30 and 31). The sedimentary organic carbon stocks ranged from moderate to very high levels in mangroves and from low to high levels in seagrass meadows (Figure 30 and 31). The unvegetated areas showed low or very low organic carbon stock levels (Figure 30 and 31). The few unprotected sites (at the Maputo coastline) showed similar organic carbon stock levels as in the marine reserve (Figure 31). The inorganic carbon stock levels were very low in both mangroves and seagrass meadows (Figure 31).

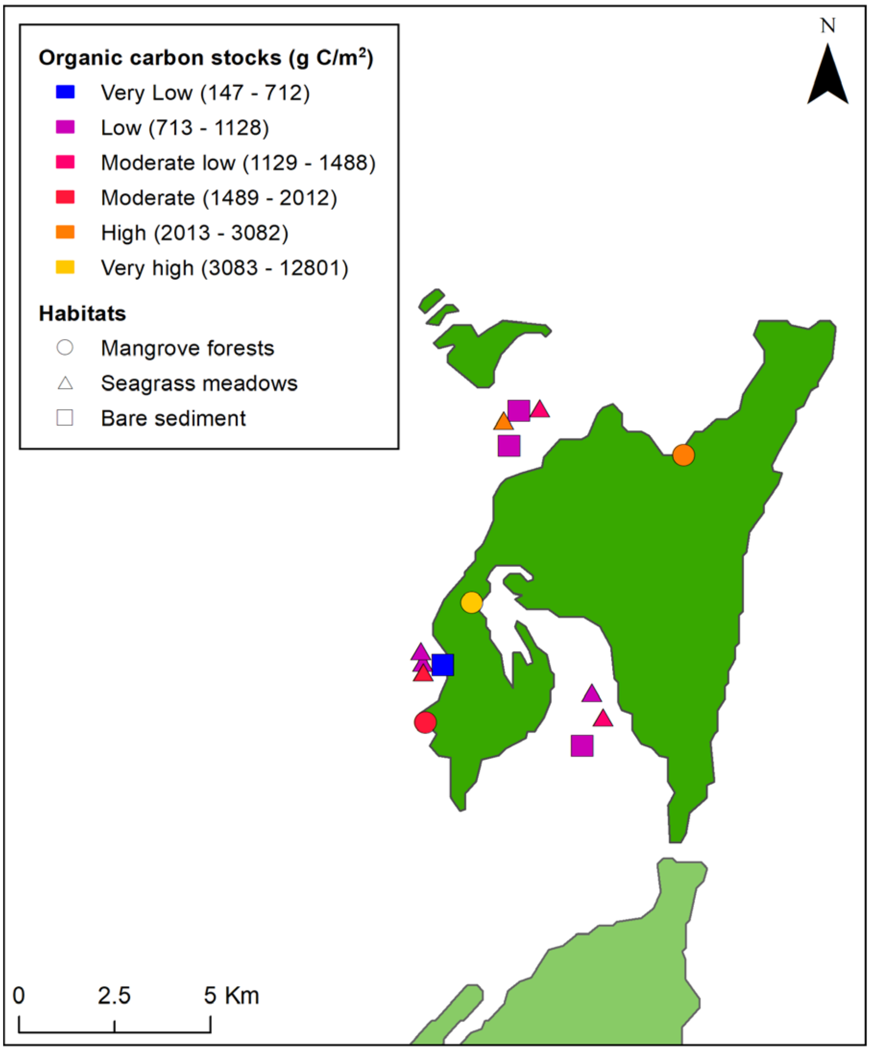
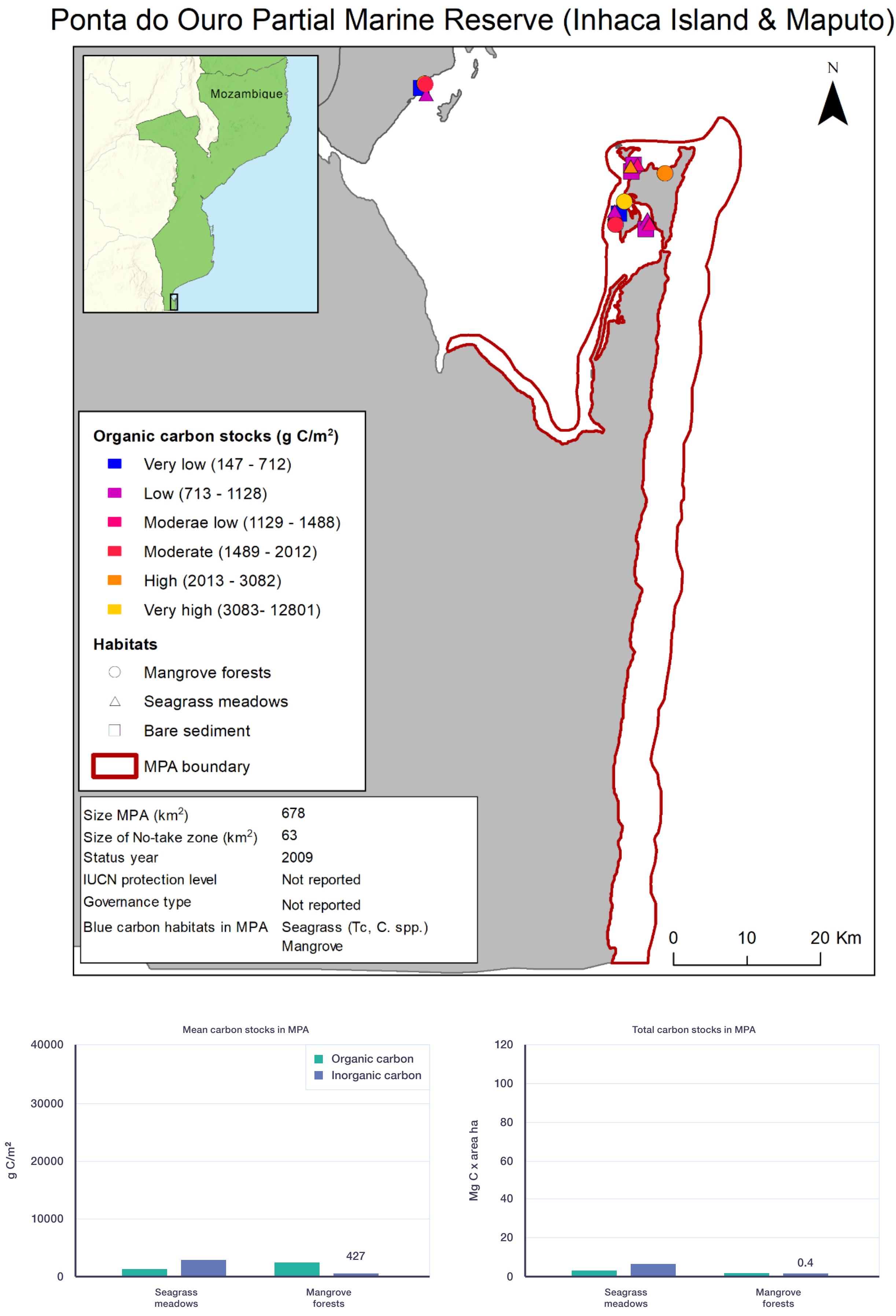


Figure 30. Region: Inhaca Island. Source of background map: Esri, USGS, NOAA.

Ponta do Ouro Partial Marine Reserve (Inhaca Island & Maputo)



Size MPA (km^2)	678
Size of No-take zone (km^2)	63
Status year	2009
IUCN protection level	Not reported
Governance type	Not reported
Blue carbon habitats in MPA	Seagrass (Tc, C. spp.) Mangrove

Figure 31. Protected area: Ponto do Ouro Partial Marine Reserve. Source of background map: Esri, USGS, NOAA. Plots show average (left) and total (right) carbon stocks (gC/m²) inside MPA.

6. Concluding remarks, management and policy recommendations

6.1 Coastal carbon stocks in Tanzania and southern Mozambique

Blue carbon sequestration and storage in coastal sediment generally vary across climate zones or latitudes (Lavery et al., 2013; Kauffman and Bhomia, 2017; Gullström et al., 2018), among habitats (Mcleod et al., 2011) and with regard to the settings of the surrounding environment and seascape configuration (Ricart et al., 2017; Gullström et al., 2018; Huxham et al., 2018; Twilley et al., 2018). The influence of landscape context on coastal sedimentary carbon stocks depends on multiple processes (climatic conditions, hydrodynamics, land catchment area, etc.) that drive movement and exchange of carbon (Bouillon and Connolly, 2009; Hyndes et al., 2014; Ricart et al., 2015; Watanabe and Kuwae, 2015; Samper-Villarreal et al., 2016). These large-scale effects of environmental settings operate in concert with multiple interrelated biogeochemical and physical factors (Watanabe and Kuwae, 2015; Samper-Villarreal et al., 2016), where the local plant-sediment properties have a fundamental role (e.g. Lavery et al., 2013; Dahl et al., 2016; Trevathan-Tackett et al., 2015; Röhr et al., 2018; Gullström et al., 2018; see also section 2.2.).

The findings from the current blue carbon survey showed considerably higher organic carbon stock levels in mangroves of the tropical areas (Tanzania) compared to the subtropical areas (southern Mozambique), whereas organic carbon stock levels in the sediment of seagrass meadows and unvegetated areas did not show such clear differences between the two climate zones (Figures 6-32; Table 2). In general, the sedimentary organic carbon stock levels were clearly higher in the two blue forest ecosystems (~6 and 3 times in mangroves and seagrass meadows, respectively) compared to unvegetated areas (Table 2). Within the tropical climate zone, mangroves showed higher (~2.5 times) mean carbon stocks than seagrass meadows, while in the subtropical areas the mean carbon stocks were only slightly higher in the mangroves compared to seagrass meadows (Table 2). Habitats dominated by different seagrass species, on the other hand, showed high resemblance to each other. A comparison among the different regions (or provinces) showed patterns of variability across the tropical-subtropical coastline studied. The outcome suggests that the carbon stock levels in the tropical coastal habitats on the Tanzanian mainland and nearby islands (Zanzibar and Mafia Islands) are high and well in range with, or above, the levels from what other studies have shown globally for tropical mangroves (Donato et al., 2011; Kauffman and Bhomia, 2017; Atwood et al., 2017) and seagrass meadows (e.g. Lavery et al., 2013).

In the subtropical region (i.e. southern Mozambique), the organic carbon stock levels were at relatively high levels in both mangrove- and seagrass habitats compared to elsewhere around subtropical latitudes (e.g. Fourqurean et al., 2012; Lavery et al., 2013; Atwood et al., 2018). In comparison with previous studies conducted in tropical and subtropical areas of the WIO (summarised in Table 1), the sedimentary organic carbon stocks in the present survey were found to be similar or slightly higher (Figures 6 and 7) than other regional studies have shown in mangroves (Sitoe et al., 2014; Stringer, 2015; Alavaisha and Mangora, 2016) and seagrass meadows (Githaiga et al., 2017; Belshe et al., 2018; Gullström et al., 2018; Table 1). A comparison with the estimated global average of carbon stocks in terrestrial habitats reveals that tropical mangrove forests in Tanzania had higher organic carbon stock levels compared to both tropical savannas/grasslands and tropical forests (Figure 33). All habitats in this report were, however, clearly lower than the estimated global average for wetlands (Figure 33).

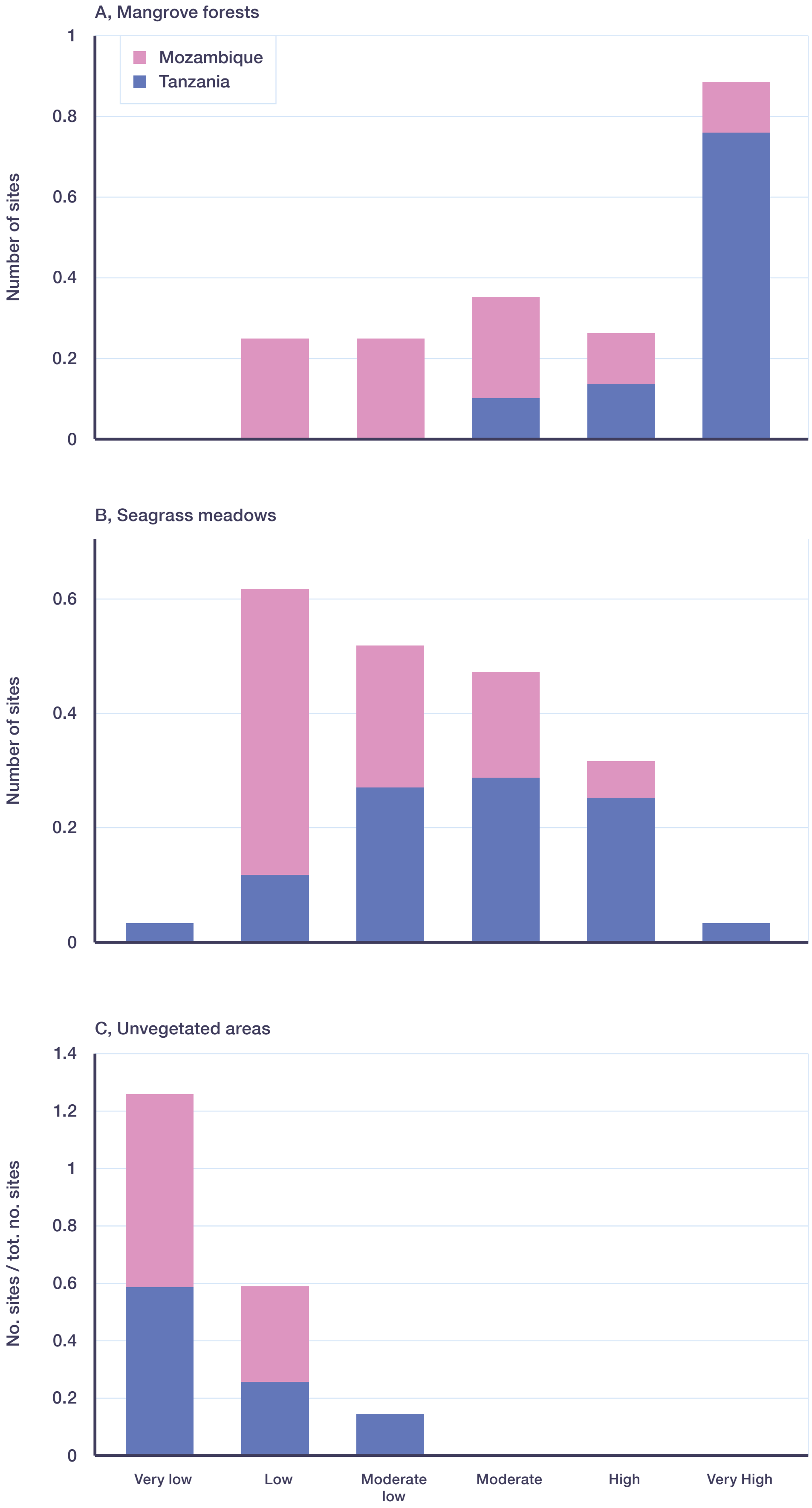


Figure 32. Number of sites in proportion to the total number of sites in each country and for each organic carbon stock category (see Figures 12-31 for classifications) of the different habitats.

Table 2. Organic carbon stocks in sediment (Mg C ha^{-1} down to 25 cm sediment depth) of tropical and subtropical habitats and their equivalent CO_2 values (Mg CO_2) in brackets.

	Mangrove forests		Seagrass meadows		Unvegetated areas	
	Organic carbon stocks	Range	Organic carbon stocks	Range	Organic carbon stocks	Range
Tropical (Tanzania)	43 (158)	19-128 (70-469)	17 (62)	5-49 (18-180)	6 (22)	1-13 (4-48)
Subtropical (southern Mozambique)	17 (62)	11-33 (40-121)	14 (51)	8-22 (29-81)	5 (18)	2-8 (7-29)
Average tropical and subtropical	37 (136)	11-128 (40-469)	17 (62)	5-49 (18-180)	6 (22)	1-13 (4-48)

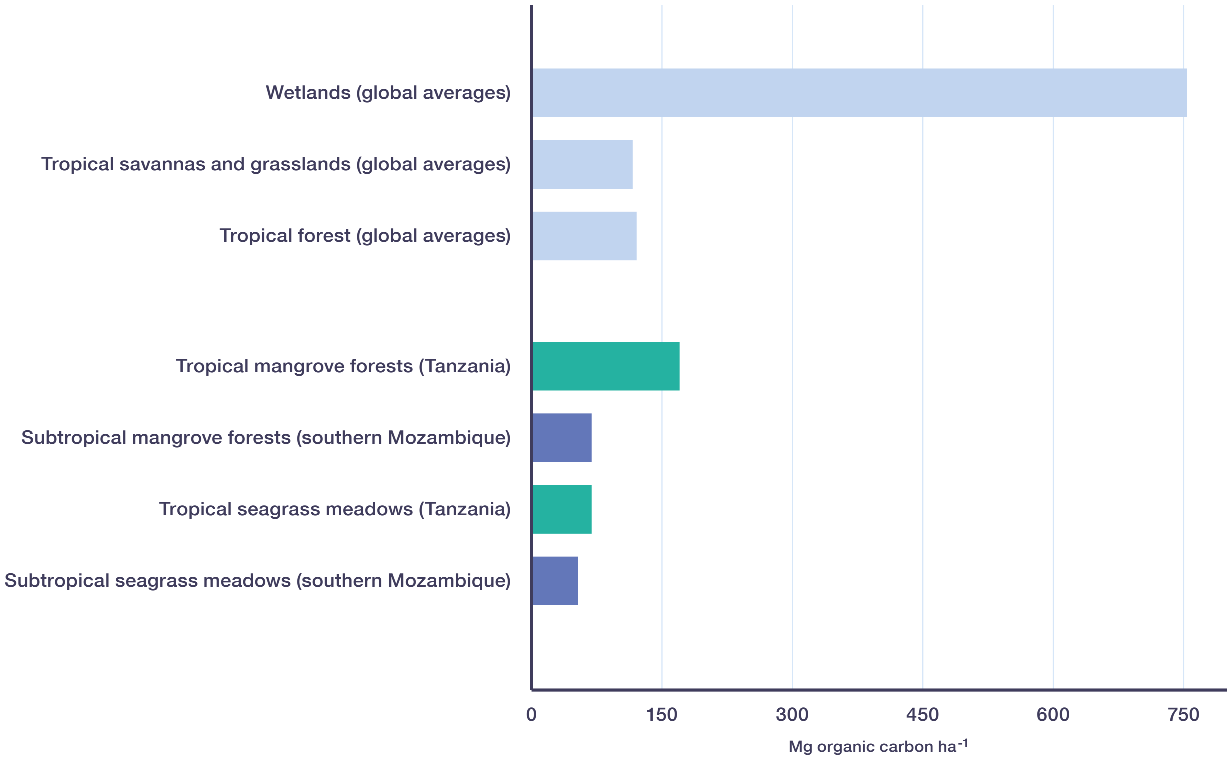


Figure 33. Comparisons of sedimentary organic carbon stocks (Mg C ha^{-1} down to 1 m sediment depth) in tropical- and subtropical mangrove forests and seagrass meadows with global averages of terrestrial habitats. The global estimates of terrestrial habitats were obtained from Laffoley and Grimsditch (2009).

6.2 Carbon sink hotspots in relation to current placement of protected areas

Marine protected areas (MPAs), or other relevant terrestrial- or marine reserves, are considered important tools to support the protection of blue forest ecosystems. Besides the variability in blue carbon stocks presented above (section 6.1.), the spatial patterns of variability of carbon stock levels were also analysed regarding the influence of existing MPAs. The findings show that MPAs had no or very little role in protecting blue carbon stocks, most probably because the carbon stock function was not considered when these MPAs were designated. MPAs, or other types of terrestrial or marine reserves, are found in a wide variety environments and sizes, where indeed the objectives for the implementation are clearly distinguished. In addition, the time and contemporary circumstances for implementation matters, and in the case of the protected areas in Tanzania and Mozambique, it is possible that they were designed in order to fulfil the provision of ecosystem services (e.g. sustain biodiversity, enhance fisheries productivity, protect the coastline from erosion, and so on) that did not consider mitigating climate change by protecting natural blue carbon sinks as a priority at the time of the park/reserve designation. Moreover, traditionally, MPAs have been designated for biodiversity conservation, fisheries sustainability, tourism, critical habitat for target species, cultural or spiritual values, research, and education (Salm et al., 2000). However, in the last decade or so (but after the designation of most protected areas in Tanzania and Mozambique), their potential to support carbon sequestration has been acknowledged (Barbier et al., 2011; Liquete et al., 2013).

Based on the new data reported, coastal blue carbon hotspots were not specifically found within protected areas. A qualitative analysis of the spatial assessments (Figures 12-31) of the hotspot areas, with high levels of blue carbon stored in the sediment of mangrove- and seagrass habitats in Tanzania and southern Mozambique, suggests that contemporary environment settings, landscape/seascape configuration and the size of continuous or integrated blue carbon habitats may play important roles. Hotspot blue carbon locations were primarily recognized within areas of large, continuous and relatively sheltered blue carbon habitats. The reason for the potentially major influence of environmental settings and landscape configuration on sedimentary carbon levels is the high variation of allochthonous input (which can be very high in some areas) in comparison, or as a complement, to the high production of autochthonous carbon (Figure 1). From the findings of the survey, potential blue carbon hotspots were recognized e.g. in Chwaka Bay on Zanzibar Island (sheltered mangroves and large continuous seagrass meadows) and at Mafia Island (mangroves and seagrass meadows mostly located in sheltered areas).

6.3 Blue carbon management strategies

This report contributes to the growing body of evidence that coastal blue carbon habitats in the WIO region have a high capacity in capturing CO_2 for long-term storage of sedimentary organic carbon. In general, the wide distribution of mangroves and seagrass meadows, and to some degree tidal salt marshes, across the productive coastal seascapes of this region (Lugendo, 2016) emphasizes that extensive carbon sequestration and storage may have a high potential for mitigating the impact of climate change. The climate-related service provided by the long-term binding of carbon into blue forest ecosystems is together with the provision of other essential ecosystem services in coastal environments (e.g. sustainable fisheries, biodiversity conservation and coastal protection) incitement for solid, solution-oriented resource management. All these high-benefitting values, together with major anthropogenic pressures from e.g. sedimentation, pollution, resource overexploitation and conversion of habitats, doubtlessly call for well-functioning seascape management approaches to restore and conserve blue carbon stocks in vegetated coastal habitats. Measures to enhance blue carbon stocks through restoration and conservation can be undertaken at the regional, national and local levels and for specific habitats or hotspot areas.

6.3.1. Mangrove governance and jurisdiction

Current efforts to conserve mangroves in eastern Africa include specific legislation, MPAs, national and regional mangrove strategies and action plans, public outreach, restoration activities, and the incorporation of mangroves into REDD+ activities (The Blue Carbon Initiative, 2015). In Kenya, while the 2017-2027 Mangrove Ecosystem Management Plan supports zoning for specific activities, coordination between government institutions is still weak, although environmental impact assessments and strategic environment assessments represent under-utilised tools to improve conservation (Slobodian et al., 2019). In contrast, in Mozambique, mangroves have proven their role in protecting coastlines from floods and cyclones, but remain at risk as governments continue to issue concessions and licenses for oil and gas exploration in areas with mangroves (Slobodian et al., 2019).

According to a global review of tenure and governance arrangements of mangroves led by the Centre for International Forestry Research (CIFOR), mangroves are often under the jurisdiction of multiple ministries and agencies, creating a maze of overlapping and vague responsibilities that deliver little protection on the ground in many countries. The review included a case study in the Rufiji delta of Tanzania, which has one of the two most extensive mangrove areas in East Africa. At this site, scientists analysed national-level legal and policy frameworks, coordination across government agencies, and institutional arrangements at the local level.

In Tanzania, all mangrove forests are owned by the state and managed under strict protection, with restricted use by local communities. Yet, threats to mangrove systems remain unabated. Concluding remarks from the Rufiji delta case study in Tanzania suggest that expansion and strengthening of the tenure rights of local communities to mangroves should be a central component of their sustainable management and conservation in the country. The key is to strike a balance between forest use and conservation, and to involve communities in mangrove management by devolving rights to tenure. This goes in line with the growing recognition in Tanzania regarding the weakness of top-down mangrove protection approaches and the importance to promote more community-led management processes. The research of this case study also reveals that women rarely have a seat at the table when it comes to mangrove management, even though they are often keen to engage in paid employment for raising mangrove seedlings in nurseries, planting mangroves, or setting up enterprises to prepare products from mangroves, such as honey, syrups or natural dyes.

Several partners and initiatives exist to support mangrove conservation, while less attention has been placed on seagrass conservation. The “Save Our Mangroves Now!” Initiative of WWF and IUCN supported by the German Federal Ministry for Economic Cooperation and Development (BMZ), has assessed mangrove governance for conservation and sustainable use in different countries, including Mozambique and Tanzania (Slobodian et al 2019). The associated report identifies detailed recommendations, easily adapted to be of relevance to blue carbon conservation (see Annex 3).

6.4 Integrating blue carbon into MPA management

Most MPAs have been designated to protect significant marine ecosystems and species. This focus on biodiversity conservation overlaps but is not always aligned with carbon conservation (as emphasised above). The present survey of carbon stocks in blue forest ecosystems indicates that significant areas for carbon sequestration and storage in Tanzania and southern Mozambique are outside of legally protected marine areas or locally-managed marine areas. Hence, the identification of blue carbon stocks may provide guidance for increasing MPA coverage to conserve hotspots of blue carbon in concert with the protection of other vital ecosystem services. Further, MPA management, understandably, has traditionally focused on the protection of marine biodiversity.

With an increasing recognition of the importance of blue carbon, management plans for MPAs should also include strategies and actions to protect, restore and enhance carbon stocks in the marine environment. Information on blue carbon stocks in Tanzania and Mozambique can also be used to inform on a range of activities supported by the Nationally Determined Contributions (NDCs). These activities include inventory preparation, baseline studies, evaluation and mitigation potential, and linking mitigation to national development priorities.

It is also essential to ensure that MPA management incorporates best practice in community engagement and good governance.

6.5 Budget for carbon stock assessment

To achieve a feasible carbon stock assessment in the WIO region, we have estimated a budget based on the methodology used in the work of this report. Here, we have made an overall estimate of time (Table 3) and costs (Table 4) for a blue carbon stock assessment (1) per site, and (2) for a realistic survey of relevant blue forest habitats within and outside an MPA (10 sites in total). The calculations for the survey of the MPA are based on habitats of relevance (mangrove forests and seagrass meadows) for efficient sequestration and storage of blue carbon and unvegetated sediment used as reference areas. To reflect the natural composition of habitat distribution, we have added three seagrass habitat types, including seagrass meadows dominated by each of three different species, as the seagrasses may show a high variation in carbon storage (and are commonly distributed near each other in relatively limited areas). The estimated costs and time needed for sampling are, however, at similar levels for all different habitats.

Table 3. Estimated time for sampling and analysis of carbon stocks in sediment of blue forest habitats (mangrove forests and seagrass meadows) and unvegetated areas.

	Days[1]/site[2]	Days/MPA[3]
Field sampling[4]	0.33	3.3
Laboratory (internal)[5]		
Step 1 - Remove shells, larger stones and living biomass and dry weighting of sediment	0.4	4
Step 2 - Grinding of dry sediment	0.24	2.4
Step 3 - Weighting of grinded sediment for organic carbon content	0.15	1.5
Step 4 - HCL treatment (1 mol) to remove inorganic carbon	0.15	1.5
Step 5 - Loss-on-ignition analysis		
Step 6 - Weighting of grinded sediment for inorganic carbon content	0.15	1.5
Laboratory (external)[5, 6]		
CN-analysis (at e.g. UC Davis, USA) x 30 samples (repeat steps 3 and 4)	0.3	3
Total	**1.32**	**13.2**

[1] Days calculated as 8 working hours

[2] Each site contains 3 replicates (sliced at 4 depth intervals, which equals 12 slices in total)

[3] Five habitats (mangrove forest, 3 seagrass meadows, unvegetated area)
1 site per habitat in MPA
1 site per habitat outside MPA
In total 30 cores, 120 sediment slices

[4] For three persons

[5] For one person

[6] Using the LOI-method will give a measure on the organic matter content of the sediment and in order to obtain the organic carbon content some samples need to be analysed with a CN elemental analyser. The values from the analysis in the CN elemental analyser are used to estimate the correlation between organic carbon and organic matter content for the samples (see Howard et al., 2014 for more details).

Table 4. Estimated costs (in USD) for sampling and analysis of carbon stocks in sediment of blue forest habitats (mangrove forests and seagrass meadows) and unvegetated areas.

	Costs/site	Costs/MPA[1]
Field sampling		
Initial material[2]	100	100
Running cost	10	100
Laboratory (internal)[2]	0	0
Analysis (external)		
CN-analysis (at e.g. UC Davis, USA) x 30 samples (one-time cost)		300
Silver- and tin capsules x 30		15
HCL treatment (1 mol), 5 ml		5
Total	**110**	**520**
Analysis (external)		
Sediment dating (for carbon accumulation rates)	2000	20000
Total	**2110**	**20520**

[1] Five habitats (mangrove forest, 3 seagrass meadows, unvegetated area)
1 site per habitat in MPA
1 site per habitat outside MPA
In total 30 cores, 120 sediment slices

[2] Initial material:
- Cores x 9
- Rubber hammer
- Slicers
- Ruler
- Plastic bags
- Cooling box

6.6 Key findings and policy recommendations

Today, blue forest ecosystems are perceived as one of the priority sectors in marine management due to their potential in climate change mitigation through their efficiency in accumulating refractory organic carbon in coastal sediment. This report presents the outcome of comprehensive assessments of blue carbon stocks in the coastal zones of tropical Tanzania and subtropical southern Mozambique, which adds important information regarding blue carbon to the understudied Western Indian Ocean region for both mangroves and seagrass meadows. Key findings and policy recommendations are listed below.

Key findings:

- The coastal seascapes of Tanzania and Mozambique have a high potential as contributing components to the mitigation of climate change impacts due to their extensive distribution of carbon-rich blue forest ecosystems, i.e. mangroves and seagrass meadows (and to some degree tidal salt marshes).

- Blue carbon stocks in mangroves and seagrass meadows within existing protected areas of the two countries showed similar values as outside the protected area boundaries.

- Climate mitigation using blue carbon seems not explicitly considered in the implementation phase of existing protected areas on the coastlines of Tanzania and Mozambique.

- Mangroves and seagrass meadows sequester and store substantially higher amounts of sedimentary blue carbon than unvegetated areas.

- Assessed sedimentary organic carbon stocks were considerably higher in mangroves of tropical areas (Tanzania) than in subtropical areas (southern Mozambique), whereas organic carbon stock levels in the sediment of seagrass meadows and unvegetated areas did not show such clear differences between the two climate zones.

- Blue carbon stocks in coastal habitats (mangroves and seagrass meadows) of the WIO region show similar values as in many other tropical and subtropical zones worldwide.

- Locations of hotspots for carbon sequestration and storage were primarily identified within areas of large, continuous and relatively sheltered blue forest ecosystems, a result likely driven by contemporary coastal environmental settings and seascape configuration.

- Potential blue carbon hotspots were identified in Chwaka Bay on Zanzibar Island (sheltered mangroves and large continuous seagrass meadows) and at Mafia Island (mangroves and seagrass meadows mostly located in sheltered areas).

- Assessments of carbon stocks in blue forest ecosystems in Tanzania and Mozambique were found to be relatively cheap to achieve. Carbon accumulation rates, however, are much more expensive.

Policy recommendations:

- Protect blue carbon ecosystems (i.e. mangroves, seagrass meadows and tidal salt marshes) in the western Indian Ocean region for climate change mitigation to maintain these ecosystems' high carbon storage capacity.

- Enhance the number and size of protected areas incorporating blue carbon ecosystems and include hotspot areas with high carbon storage capacity using protected area extensions and buffer zones, where relevant.

- Restore areas where blue carbon ecosystems have been degraded, fragmented or lost to secure and enhance the carbon storage capacity and the mitigation of climate change.

- Prioritise environments with large, continuous and relatively sheltered blue carbon ecosystems when designing and selecting sites for new protected areas.

- Include multiple blue carbon ecosystems (where possible) in MPAs, LMMAs and other area-based conservation measures to enhance connectivity due to the transport of organic carbon and spill-over effects from one blue carbon habitat to another (e.g. from mangroves to seagrass meadows or the vice versa).

- Ensure that MPAs are effectively managed and monitored to safeguard long-term blue carbon storage capacity in the region.

- Identify and engage key stakeholders in coordination of policy actions, conservation planning and management of blue forest ecosystems and other climate change mitigation processes, taking into account the needs of women, indigenous people and local communities.

- Develop Strategic policy frameworks in the region to facilitate policy activities and generate financing incentives as well as to develop priority targets (short- and long-term) related to climate change mitigation and adaptation (with regard to sea level rise, ocean warming, acidification, deoxygenation, stratification, more frequent and intense storms, etc.) through conservation, management, restoration and sustainable use of coastal blue carbon habitats.

- Provide incentives for conservation and restoration of blue carbon ecosystems through payments for ecosystem services, such as trading credits of carbon (carbon offsets).
- Perform carbon stock surveys and incorporate these into established national and/or regional monitoring programmes.
- Assess carbon accumulation rates in carbon hotspot areas of blue forest ecosystems in order to quantify the carbon storage efficiency and ecosystem uptake of CO_2, which could be used to assess Nationally Determined Contributions (NDCs).

Opportunities:

- Explore the range of international processes and mechanisms, which offer opportunities to support policy development, coordination and implementation at the international and regional levels, including Nationally Determined Contributions (NDCs) under the Paris Agreement and National Biodiversity Strategy Action Plans (NBSAPs) under the Convention on Biological Diversity (CBD) and various relevant financial mechanisms and instruments.
- Integrate and coordinate strategies and plans for blue carbon ecosystems with other national planning processes in recognition that blue carbon ecosystems provide multiple benefits as they are also important for biodiversity conservation and ecosystem-based disaster risk reduction (EcoDRR), food security and other ecosystem services.
- Incorporate effective conservation and management of blue carbon ecosystems as critical foundations to creating a resilient Blue Economy due to their role in ocean risk mitigation and adaptation.

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Annex 1. Overview of available spatial datasets for coastal habitats in Tanzania and Mozambique

Data set	Habitat	Coverage	Source	Method	Mapping date	Comment
Habitat distribution: global, regional, national data sets						
World Atlas of Mangroves (2010), (WCMC011_AtlasMangrove2010)	Mangr.	global	http://data.unep-wcmc.org/datasets/5	Opt. RS; Landsat 5/7	MZ: 1999-2002 TZ: 2000	Compilation from many sources;
Global Distribution of Mangroves USGS (2011) (WCMC010_MangrovesUSGS2011_v1_3)	Mangr.	global	http://data.unep-wcmc.org/datasets/4 (Identical layer under: http://maspawio.net/layers/geonode%3Amangroves	Opt. RS; Landsat 5/7	1997-2000	
Global Mangrove Forests Distribution, v1, (2000), (Giri et al. 2011)	Mangr.	global	http://sedac.ciesin.columbia.edu/data/set/lulc-global-mangrove-forests-distribution-2000/data-download	Opt. RS; Landsat 5/7	Ca. 2000	Former version of 'Global Distribution of Mangroves'
Global Distribution of Modelled Mangrove Biomass (2014), (TNC001_MangroveForestBiomass2014	Mangr.	global	http://data.unep-wcmc.org/datasets/39			Same area as World Atlas of Mangroves (2010)
RCMRD-SERVIR Mangrove Cover Tanzania & Mozambique	Mangr.	TZ, MZ, Kenya, Madagascar	http://apps.rcmrd.org/coastaleco/	Opt. RS; Landsat 8	Ca. 2013-2015	Results appear filtered/edited (compare with WCMC010); Overall classification accuracies: Mozambique 86%, Tanzania 77%.
Global Mangrove Watch	Mangr.	global	(Data not available yet)	SAR RS; PALSAR/PALSAR2	Nominal years 2010 & 2015 future updates foreseen	
Global Distribution of Seagrasses (2016),(WCMC_013_014_SeagrassesPy_v4/WCMC_013_014_SeagrassesPt_v4)	Seagr.	global	http://data.unep-wcmc.org/datasets/7	Various	1996-2003	Compilation from many sources; Polygon & Point data; Info on species;
RCMRD-SERVIR Sea Grass Cover Tanzania & Mozambique	Seagr. (part of 'submerged vegetation'); Coral	TZ, MZ, Kenya, Madagascar	http://geoportal.rcmrd.org/layers/?limit=100&offset=0 https://www.servirglobal.net/data-maps/GeoPortalMetaDataViewer?geoPortalID=8&region=0&recordID={8e3f307e-86ac-11e5-aafe-00155da3c410}	Opt. RS; Landsat 8	Ca. 2013-2015	

Data set	Habitat	Coverage	Source	Method	Mapping date	Comment
Global Distribution of Coral Reefs (2010), (WCMC008_CoralReef2010_v1_3)	Coral	global	http://data.unep-wcmc.org/datasets/1 (Identical layer under: http://maspawio.net/layers/geonode%3Awio_coral_reef) http://umr-entropie.ird.nc/index.php/home/ressources/mcrmp	85% of global cover through Opt. RS; Landsat 7 & classification (part of Millennium Coral Reef Mapping Project" Rest: various sources	1954-2009; Millennium Coral Reef Mapping Project: 1999-2002	Compilation from many sources; 99% of areas in MZ/TZ from Millennium Coral Reef Mapping
Global Distribution of Cold-water Corals (2017), (WCMC001_ColdCorals2017_v3)	Coral	global	http://data.unep-wcmc.org/datasets/3	Various	1915-2014	Compilation from many sources ; Polygon & Point data; Info on species;
Global Distribution of Saltmarshes, (WCMC027_Saltmarsh_py_v4/WCMC027_Saltmarsh_pt_v4)	Saltm.	global	http://data.unep-wcmc.org/datasets/43 (Identical layer under: http://maspawio.net/layers/geonode%3Asaltmarsh)	Various (field surveys, aerial imagery, satellite data, etc.)	1973 – 2015	Compilation from many sources ; Polygon & Point data; Only one site in TZ (point); none in MZ.
IMS data sets (TanSEA/Statoil) (tza_mangroves_50k.shp)	Mangr.	TZ	No public access	Digitized from topo maps 1:50k & aerial images	1980s, 1991, 2001(?)	Compilation from several sources; Base data for topo maps not yet known.
IMS data sets (TanSEA/Statoil) (tza_coral_reefs_50k.shp)	Coral	TZ	No public access	?	1997, 2009	
IMS data sets (TanSEA/Statoil) (tza_coastal_land_cover_50k.shp)	Mangr., Seagr., Coral, Saltm.	TZ	No public access	Digitized from topo maps 1:50k	1989 (date of maps)	Base data for topo maps not yet known.
Habitat distribution: local studies/data sets						
Fatoyinbo, L. et al., 2008; 2013; results from various studies related to Carbon Monitoring System (CSM)	Mangr.	Zambezi and Rufiji River Deltas; Sites on Inhaca Island and in Maputo Elephant Reserve	https://carbon.nasa.gov/cgi-bin/inv_pgp.pl?pgid=3132&expprod=495#prodid495	Various: Airborne Lidar, Optical sat (Landsat, WV-1), SAR sat (Alos PALSAR, TanDEM-X plus Pol-InSAR), field measurements.	1990-2015	Mangrove forest extent maps; Mangrove Canopy Characteristics and Land Cover Change; Mangrove Canopy Height; Aboveground Biomass;
Bandeira S.O., 2002: "Diversity and distribution of seagrasses around Inhaca Island, southern Mozambique"	Seagr.	Inhaca Island (MZ)	No public access	Field survey	Ca. 2000	
Gullström M. et al., 2006: "Assessment of changes in the seagrass-dominated submerged vegetation of tropical Chwaka Bay (Zanzibar) using satellite remote sensing"	Seagr.	Chwaka Bay, Zanzibar, Tz.	No public access	Opt. RS; Landsat 5/7; classification; change detection; fieldwork	1987 & 2003	
Knudby A. and L. Nordlund, 2010: "Remote sensing of seagrasses in a patchy multi-species environment"	Seagr.	Chumbe Island, Tz.	No public access	Opt. RS; Ikonos (4m); classification; fieldwork	2007	

Data set	Habitat	Coverage	Source	Method	Mapping date	Comment
Knudby A. et al., 2010: "Simple and effective monitoring of historic changes in nearshore environments using the free archive of Landsat imagery"	Seagr., Coral, Algae	Bawe and Chumbe islands, Tz.	No public access	Opt. RS; Landsat 5/7; classification; change detection; fieldwork	1984 to 2009	
Knudby A. et al., 2014: "Using multiple Landsat scenes in an ensemble classifier reduces classification error in a stable nearshore environment"	Mangr., Seagr., Coral, Algae	Zanzibar, Tz.	No public access	Opt. RS; Landsat 5/7; classification; fieldwork	2011/2012	
Teixeira L. et al., 2015: "Benthic habitat mapping and biodiversity analysis in the Primeiras and Segundas Archipelago Reserve"	Seagr., Coral, Brown macro-algae	Primeiras and Segundas Archipelago Reserve, MZ	No public access	Opt. RS; Ikonos, Quickbird and WorldView-2; classification (object-based); fieldwork	2009 to 2013	
Protected areas						
World Database on Protected Areas (WCMC-WDPA Protected Areas)		Global	https://protectedplanet.net/		Download Dec. 2017	Polygon & Point data
Boundaries of Ponta do Ouro Partial Marine Reserve		Park area	http://www.mpatlas.org/mpa/sites/68808358/ http://www.peaceparks.org/gis.php?pid=100&mid=39 http://new-ppfmaps.opendata.arcgis.com/datasets/d9e080e21c49405ebbb1d5d5bb610cca_0			Comparison onmpatlas.org showed only this area as missing in WDPA in MZ/TZ
IMS data sets (TanSEA/Statoil) (tza_marine_protected_areas_xx.shp)		TZ	No public access		Status?	

Annex 2. Summary table of sedimentary carbon stocks (mean ±SE, 0-25 cm depth) in the different regions of Tanzania and southern Mozambique

Region	Organic carbon stocks	Inorganic carbon stocks
Zanzibar		
Mangrove	7412 ± 2573	1116 ± 1016
Seagrass	2095 ± 158	27858 ± 2335
Unveg	907 ± 99	28505 ± 5187
Dar es salaam		
Mangrove	3035 ± 107	532 ± 164
Seagrass	1415 ± 198	9063 ± 2447
Unveg	724 ±170	16077 ± 8702
Pwani		
Mangrove	3511 ± 511	618 ± 227
Seagrass	905	1749
Unveg	340 ± 92	4668 ± 3669
Mafia Island		
Mangrove	3670 ± 306	2595 ± 1806
Seagrass	1660 ± 136	10206 ± 2028
Unveg	517 ± 137	16152 ± 5092
Lindi		
Mangrove	5645 ± 45	11 ± 0.03
Seagrass	1140 ± 181	825 ± 93
Unveg	267 ± 37	140
Mtwara		
Mangrove	4584 ± 528	6876 ± 6517
Seagrass	1292 ± 450	19950 ± 10642
Unveg	284 ± 137	17896 ± 16958
Bazaruto		
Mangrove	1373 ± 52	240 ± 198
Seagrass	1481 ± 296	970 ± 110
Unveg	412 ± 162	204 ± 25

Region	Organic carbon stocks	Inorganic carbon stocks
Inhambane		
Mangrove	1318 ± 264	243 ± 218
Seagrass	1350 ± 192	4809 ± 1168
Unveg	520 ± 133	2152 ± 1731
Maputo City		
Mangrove	1437	411
Seagrass	973	765
Unveg	343	621
Inhaca		
Mangrove	2347 ± 516	427 ± 87
Seagrass	1333 ± 164	3012 ± 653
Unveg	645 ± 165	1400 ± 811

Annex 3. Recommendations relevant to blue carbon conservation

Recommendations adapted from Slobodian, L. N., Badoz, L., eds. (2019). Tangled roots and changing tides: mangrove governance for conservation and sustainable use. WWF Germany, Berlin, Germany and IUCN, Gland, Switzerland. xii+280pp.

Recommendation 1. Adopt a dedicated mangrove, seagrass and salt marsh policy or plan that specifically incorporates blue carbon

Recommendation 2. Fully use existing legal frameworks to conserve mangrove, seagrass and salt marsh ecosystems

Recommendation 2.1. Implement international obligations through national regimes

Recommendation 2.2. Ground mangrove, **seagrass and salt marsh ecosystem** conservation and sustainable use in constitutional norms

Recommendation 2.3. Integrate mangrove, **seagrass and salt marsh ecosystem** conservation in sectoral legal frameworks

Recommendation 2.4. Designate mangrove, **seagrass and salt marsh ecosystem** areas as protected areas

Recommendation 3. Promote inter-agency and cross-sectoral coordination

Recommendation 3.1. Harmonize responsibilities of government agencies to avoid conflict and overlap

Recommendation 3.2. Mainstream mangrove, **seagrass and salt marsh ecosystem/blue carbon** considerations across government institutions

Recommendation 3.4. Create procedures for communication and information sharing, joint implementation and coordination among agencies

Recommendation 3.5. Designate an institutional body for coordination at national or local level

Recommendation 4. Strengthen institutional capacity at all levels

Recommendation 4.1. Ensure suffcient allocation of financial resources

Recommendation 4.2. Raise awareness among government institutions and policymakers of the importance of mangrove, **seagrass and salt marsh ecosystem/blue carbon** management and sustainable use

Recommendation 4.3. Empower local and municipal authorities

Recommendation 4.4. Strengthen multidisciplinary capacity within competent institutions

Recommendation 5. Monitor and promote implementation and compliance

Recommendation 5.1. Monitor implementation and compliance through regular progress reports

Recommendation 5.2. Develop a compliance plan to address non-compliance

Recommendation 6. Adopt measures to ensure accountability, transparency, participation and access to justice

Recommendation 6.1. Require Strategic Environmental Assessment (SEA) for plans or programmes potentially affecting mangroves, **seagrass and salt marsh ecosystems/blue carbon**

Recommendation 6.2. Ensure private sector accountability through Environmental Impact Assessments and information-sharing obligations

Recommendation 6.3. Ensure public consultation in development of laws and policies

Recommendation 6.4. Develop and/or strengthen environmental tribunals

Recommendation 6.5. Protect mangrove, **seagrass and salt marsh ecosystems/blue carbon** advocates and defenders

Recommendation 7. Collect and share scientific information

Recommendation 7.1. Set up and keep updated a national mangrove, **seagrass and salt marsh ecosystem/blue carbon** inventory

Recommendation 7.2. Ensure availability of scientific information

Recommendation 8. Engage communities, the private sector and the public

Recommendation 8.1. Create a legal basis for community co-management of mangrove, **seagrass and salt marsh ecosystem/blue carbon** areas

Recommendation 8.2. Engage the private sector in mangrove, **seagrass and salt marsh ecosystem/blue carbon** conservation and restoration

Recommendation 8.3. Promote meaningful public engagement in decision-making

Recommendation 9. Align incentives for conservation and sustainable use

Recommendation 9.1. Ensure clarity on land and resource rights and tenure

Recommendation 9.2. Create financial incentives for mangrove, **seagrass and salt marsh ecosystem/blue carbon** conservation

Recommendation 10. Consider indirect and underlying drivers of mangrove, seagrass and salt marsh ecosystem/blue carbon loss at national and transnational levels

Recommendation 10.1. Realize rights of women and girls

Recommendation 10.2. Promote alternative livelihoods and economic models

Recommendation 10.3. Encourage development and use of alternative energy sources and products to reduce pressure on mangrove, **seagrass and salt marsh ecosystems/blue carbon**

Recommendation 10.4. Evaluate and improve supply chain sustainability

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