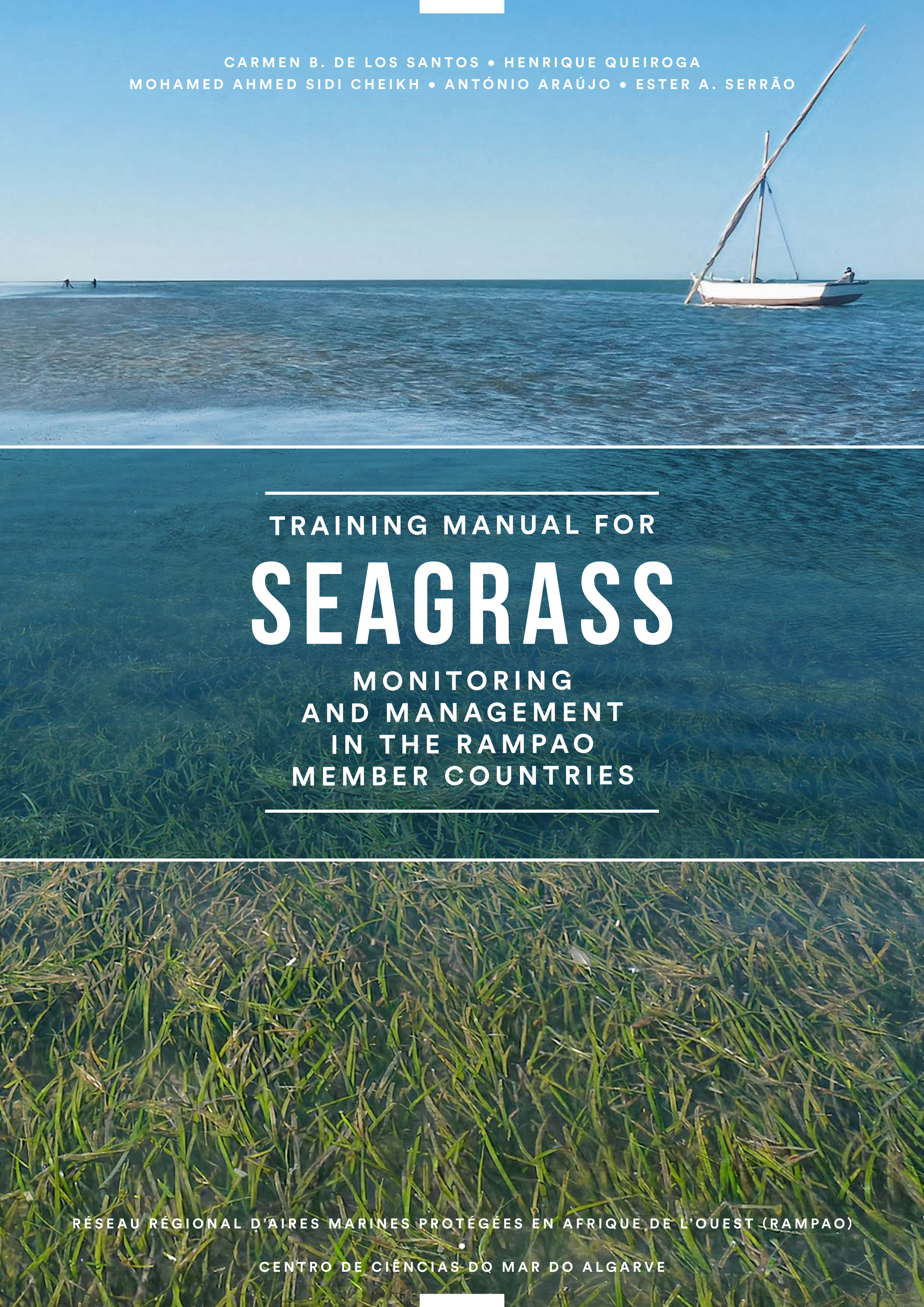

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TRAINING MANUAL FOR SEAGRASS MONITORING AND MANAGEMENT IN THE RAMPAO MEMBER COUNTRIES

RÉSEAU RÉGIONAL D'AIRES MARINES PROTÉGÉES EN AFRIQUE DE L'OUEST (RAMPAO)
•
CENTRO DE CIÊNCIAS DO MAR DO ALGARVE

TRAINING MANUAL FOR SEAGRASS MONITORING AND MANAGEMENT IN THE RAMPAO MEMBER COUNTRIES

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Cover picture: Ester A. Serrão, meadow of *Cymodocea nodosa* in Banc d'Arguin, Mauritania.

Halodule wrightii,
Banc d'Arguin, Mauritania.

Zostera noltei

FOREWORD

Seagrass beds are known and recognised in almost all RAMPAO countries as a key habitat for mitigating the impacts of climate change and reinforcing the resilience of coastal communities.

The presence of these seagrass beds in the MPAs of the network, which have very high biological and ecological value and provide numerous ecosystem goods and services, make them subjects of research par excellence, in order to improve knowledge and better reinforce their protection status.

Through this manual, produced within the framework of the ResilienSea Project, financed by the MAVA Foundation, RAMPAO aims to inform, raise awareness, and train professionals, stakeholders and managers of MPAs in monitoring and management practices. For the first time ever, a major review of essential information relevant and specific to the West African region is compiled by seagrass experts.

This manual, by transcending languages and borders, provides the knowledge base for joint integrated seagrass management and monitoring practices. This should ultimately contribute to the sustainability of these habitats on which so many iconic species depend for feeding and breeding.

It is my hope that this manual will strengthen the networking and mutual learning between the members of RAMPAO, to unite their efforts for the conservation of seagrass beds in the West African region.

Marie Suzanne Traore
Secretary General RAMPAO

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MODULE 1:
INTRODUCTION TO THE BIOLOGY AND ECOLOGY OF SEAGRASSES

Carmen B. de los Santos, Carolina de la Hoz Schilling, Mohamed Ahmed Sidi Cheikh, Duarte Frade, Iça Barri, António Araújo, Ester A. Serrão.

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Introduction to the biology and ecology of seagrasses

1.1. BIOLOGY AND ECOLOGY OF SEAGRASSES

Seagrasses are angiosperms (flowering plants) that are unique in that they are the only plants that have specialised in marine environments (Figure 1.1). Other plants can tolerate seawater (mangroves and salt marshes) but are not strictly marine plants. The evolutionary pathway of seagrasses is linked to aquatic ancestors from freshwater environments that had originated from terrestrial plants. They have successfully colonised all continents, except for the Antarctic [1] (Figure 1.2). Taxonomically, seagrass species belong to the major subdivision of monocotyledons, plants with the presence of a single cotyledon, fibrous roots, scattered vascular bundles, long narrow leaves with parallel veins and floral parts in multiples of three. Recent phylogenetic classification ascribes an estimated 70 species to 13 genera and 5 families that are all comprised within the order Alismatales [2]. However, only 4 families are exclusively adapted to marine life (Posidoniaceae, Zosteraceae, Hydrocharitaceae and Cymodoceaceae). Some species of the family Ruppiaceae are also adapted to marine environments but the classification of *Ruppia spp.* (e.g., *Ruppia maritima*) as true seagrasses is not consensual, as they may complete their life cycle outside of a marine environment and occur in brackish, saline, or hypersaline waters, in saltpans, lagoons and salt lakes, usually near the coast but sometimes also inland. However, the International Union for Conservation of Nature (IUCN) classifies the genus *Ruppia* as a seagrass. Considering all five families, existing seagrasses add up to less than two percent of all flowering species.

Biogeographically, seagrasses are divided into six global bioregions [3] (Figure 1.2). RAMPAO member countries (Mauritania, Cabo Verde, Senegal, The Gambia, Guinea-Bissau, Guinea, and Sierra Leone) belongs to the Tropical Atlantic bioregion, which hosts herbivore megafauna that grazes on seagrasses, such as the African manatee (*Trichechus senegalensis*) and the green turtle (*Chelonia mydas*). Four species of seagrass from three different families are known to occur in the region: *Cymodocea nodosa* (Cymodoceaceae), *Zostera noltei* (Zosteraceae), *Halodule wrightii* (Cymodoceaceae); and *Ruppia maritima* (Ruppiaceae) [1]. Despite low species diversity, seagrass abundance in one of the marine protected areas of West Africa, the National Park of the Banc d'Arguin (PNBA) in Mauritania, is ranked among the sites with the highest seagrass abundance within global designated UNESCO marine World Heritage sites, and it extends beyond the site borders [4]. Thus, seagrasses form ecologically relevant coastal habitats in this region.

FIGURE 1.1. Pictures of seagrasses of the world: A) *Halodule uninervis* (Wakatobi, Indonesia), B) *Syringodium filiforme* and *Thalassia testudinum* (Quintana Roo, Mexico), C) *Phyllospadix sp.* (Bamfield, Canada), D) *Posidonia oceanica* (Sicily, Italy), E) *Thalassia testudinum* (Santa Marta, Colombia), F) *Zostera marina* (Troia, Portugal). **Photos by:** B. Jones / Ocean Image Bank (A,B); C.B. de los Santos (C,E), P. Wirtz (D), E.A. Serrão (F).

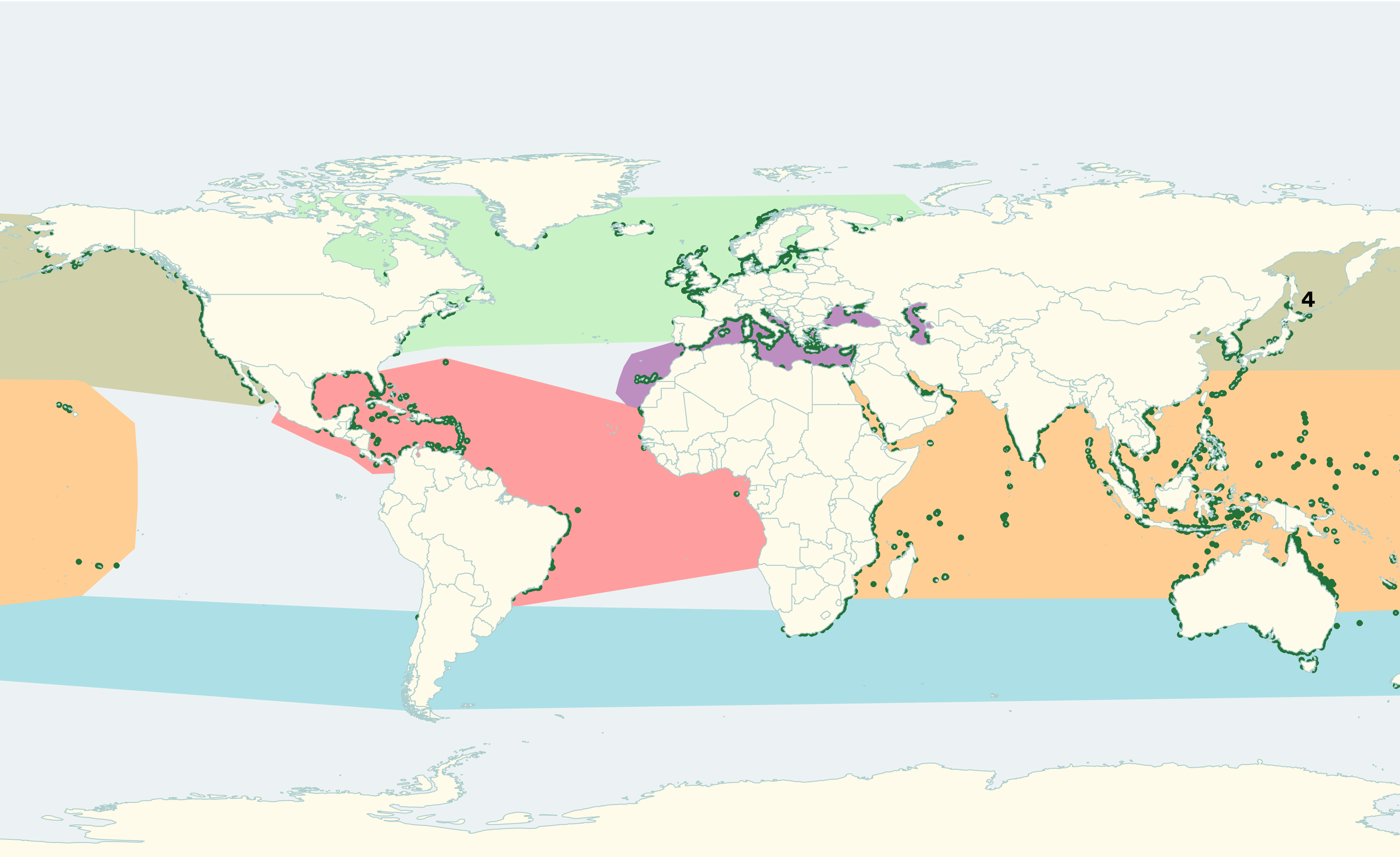


FIGURE 2. World seagrass bioregions. Adapted from [3,5].

Temperate North Atlantic
Tropical Atlantic
Mediterranean
Global Distribution
Temperate North Pacific
Tropical Indo-Pacific
Temperate Southern Oceans

Seagrasses are closely related to terrestrial plants and therefore share some of their characteristic traits [6]. Contrary to seaweeds, seagrasses are vascular plants with tissues that produce flowers, fruits, and seeds (Box 1.1). Seagrasses are composed of ramets, a unit capable of independent life, which includes a rhizome portion connected to leaves (grouped in shoots) and roots. Each shoot contains several leaves that normally have a strap-like shape (Figure 1.3). Leaves present two distinct parts, the blade and the sheath, which display features that help in species identification (Box 1.2). Shoots arise from rhizomes, stems that can be vertical or horizontal and are divided into segments called internodes, which are the sections between two consecutive nodes (Figure 1.3). A node is the point at which the shoot joints to the rhizome or where old leaves were attached (Figure 1.3). Roots are important both for anchorage and nutrient uptake, whilst the rhizome network serves as anchorage and provides a system of communication and nutrient transportation to sustain plant and rhizome growth [7]. Through this pattern of growth, seagrasses often form sparse to dense meadows, well-adapted to withstand strong tidal currents and wave action.

Depending on the species, seagrass meadows occur in the intertidal zone, which is the area exposed to air at low tide and submerged at high tide, or in the subtidal zone, which is the area that is always submersed even at the lowest tide (Figure 1.4). Seagrasses commonly occur in shallow areas, yet they can be found at greater depths (up to 60 m) in some regions where the water

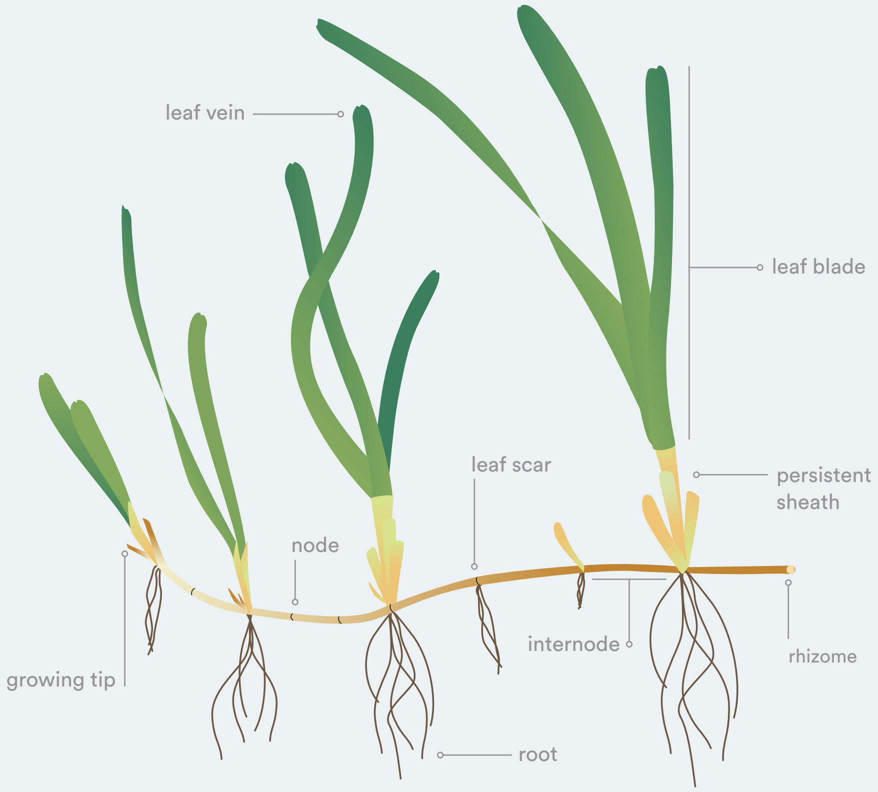
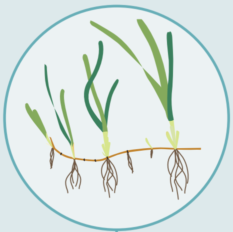


FIGURE 1.3. Common morphology of seagrasses.

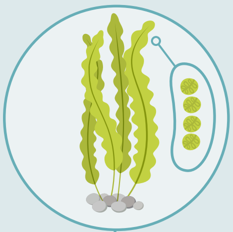
Image adapted from: Integration and Application Network (ian.umces.edu/media-library).

BOX 1.

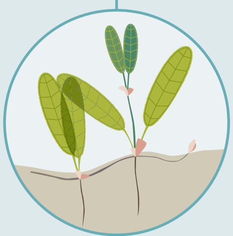
SEAGRASSES VERSUS SEAWEEDS



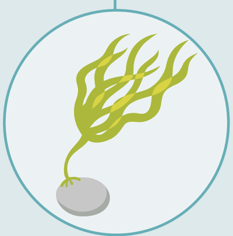
- Seagrasses are plants
- Seagrasses produce flowers, seeds and fruits



- Macroalgae are eukaryotes of different groups
- Macroalgae produce different types of spores and naked gametes



- Seagrasses have an underground root system
- Seagrasses leaves are usually grass-like, blade shaped
- Uses roots and leaves to extract nutrients from soil and water



- Macroalgae have holdfasts that secure them to rocks and other solid structures, and some like *Caulerpa* have rhizoids to hold them in place in soft sediment but are not roots
- Macroalgae have no leaves, just a thallus that can have a variety of shapes and sizes

- Seagrasses are about 70 species worldwide

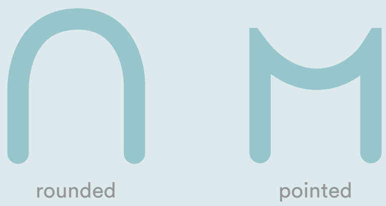
- Macroalgae have > 8000 species worldwide

Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

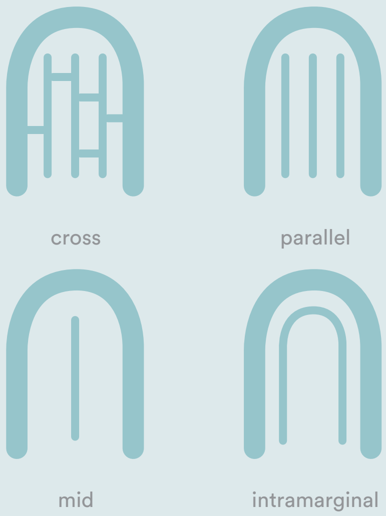
BOX 2.

FEATURES OF SEAGRASS LEAVES

Seagrass leaves are very specialized organs that withstand the water motion and carry on the photosynthesis. Several of their features help in the identification of the species.

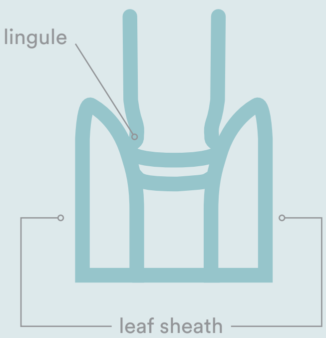


LEAF TIP. The upper part of the leaf is normally damaged due to herbivory or strong currents, so young leaves are better to observe. Seagrass leaf tips are normally rounded or pointed.



LEAF VEINS. The veins are the vascular tissue of the leaf used for the transportation of water, nutrients and photosynthetic products. The pattern of the veins is called venation, and it is normally parallel (i.e., along the length of the leaf) in seagrasses. Some species also present cross-veins, i.e. perpendicular to the length of the leaf, or a mid-vein, i.e. a distinct central vein.

LEAF EDGE. Seagrass leaves can have either serrated, smooth or rolled edges.



LEAF SHEATH. The sheath is at the base of the leaf and protects the new leaves that are being developed. The sheath can be continuous, if it surrounds the whole shoot, or non-continuous, if the shoot is only partially surrounded by it. Old leaf sheaths can remain attached to the rhizome after the leaf blades are shed.

Adapted from [9].

is clear and transparent, and they can obtain enough light. Their depth range is strongly controlled by their desiccation tolerance (i.e., how long they can be out of the water) at the shallow depth limit of the shore and by their minimum light requirements for performing photosynthesis at the deeper lower depth limit [8]. Light availability is particularly important because it is diminished in aquatic environments due to rapid absorption by water and light scattering by suspended particles.

As opposed to terrestrial plants, seagrasses live fully (subtidal species) or partially (intertidal species) submersed and display various genetic and morphological adaptations to life under water [6]. These include the ability to absorb nutrients through two organs, roots and leaves, as well as having cell with cell walls that allow gas exchange without the presence of stomata, and a salt tolerance that allows them to colonise marine environments [10].

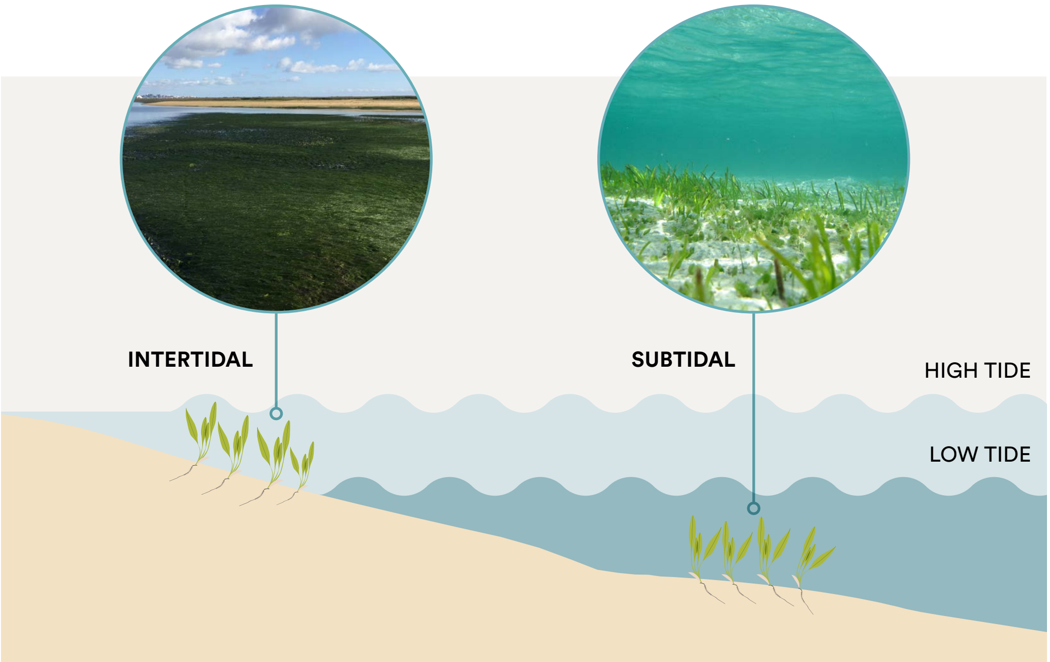


FIGURE 1.4. Seagrass position in the coastal area relative to the tide, showing examples of intertidal and subtidal seagrass meadows. **Photos by:** C.B. de los Santos. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

Seagrasses thrive mostly in muddy or sandy bottoms in various environmental conditions ranging from sheltered areas such as lagoons or estuaries to habitats exposed to strong water movement. Some species (e.g., *Phyllospadix spp.*) represent notable exceptions as they attach to rocky substrates. Nitrogen and phosphorus may act as agents limiting growth both individually or combined. However, compared to other primary producers, seagrasses can thrive on lower levels of nutrients and have adapted to nutrient-poor environments by developing the additional ability of nutrient uptake through the leaves and the redistribution of nutrients within the interconnected rhizome network.

Due to the generally anoxic or hypoxic soil conditions in muddy, organic matter rich sediments, roots are oxygenated through an internal network of channels for gas redistribution that is based on oxygen concentrations within and outside the plant. Seagrass tissue contains little pockets of air called lacunae that help keep the leaves buoyant, but also help exchange oxygen and carbon dioxide throughout the plant. During daytime, roots are unilaterally supplied with oxygen produced from the leaves through photosynthesis. In the absence of light, oxygen diffuses into the leaves from the water column and is subsequently transported to the root system following a decreasing oxygen gradient. Carbon dioxide produced by root respiration may follow the reverse pathway and be transported to leaves for photosynthesis. Seagrasses are adapted to hypersaline environments, however, different species have varying salinity tolerance levels.

Seagrasses have two reproductive strategies, sexually (seeds) and asexually (vegetative growth, also called clonal propagation). Gene flow within a population is mediated through pollination and seed dispersal as part of sexual reproduction. Most seagrass genera, 9 out of 13, include dioecious species, where individuals are either female or male, producing only female flowers or only male flowers. When using an asexual reproductive strategy, seagrasses propagate by clonal growth. The relative proportion of clonal (vegetative growth) versus sexual (flower production) propagation can be very variable between populations of the same species, and in the same population over time, depending on environmental conditions. Many populations allocate few resources to sexual reproduction and only a small amount of the shoots produces flowers yearly. Flowering events vary among populations within the same species and may depend on environmental conditions. During a flowering event, female plants are fertilised by pollen released into the water column by male individuals. Except for one species (*Enhalus acoroides*), whose pollen travels on the water surface, pollen is distributed through underwater currents. The seeds that emerge from a pollination event may not disperse very far if only transported by water currents (e.g., 20-30 m, or much less in species that produce basal seeds near the sediment) and may often be lost due to herbivory, physical damage, or lack of suitable habitat, among others. Seeds can be transported by ocean currents but among the seagrass populations in MPAs of West Africa the probability of inter-population connectivity by ocean currents is very low [11]; instead, seeds might be transported by herbivores such as green turtles along Atlantic Africa [12]. However, seeds that are retained in the sediment can remain dormant for several months before germinating, and, in general, only few seedlings survive initial growth stages. The combination of these factors (low flowering rates, seed dispersal distance and seedling survival rates) may cause a rather small contribution of sexual reproduction to the persistence of populations. Sexual reproduction plays an important role in maintaining genetic diversity in all living organisms, including seagrasses, but like many plants, seagrasses often rely on clonal growth to expand. In some instances, these clones can occupy very large areas (e.g., a 43 km clone of *Cymodocea nodosa* and a 26 km clone of *Zostera noltei*, both in the Ria Formosa, Portugal) [13].

1.2. PROVISION OF ECOSYSTEM SERVICES BY SEAGRASS MEADOWS

Seagrasses play a key role in providing a wide variety of highly valuable ecosystem services that benefit the planet and the people [14] (Figure 1.5), and which may vary among species and regions [15].

Fisheries support. Seagrass meadows support fisheries in a variety of ways: they are spawning, nursery and foraging habitats for many species of fish, molluscs, and crustaceans with commercial value [16,17]. They also export primary production to other ecosystems and species, providing support to fish stocks in other coastal areas. Seagrasses can reduce the pathogens causing diseases in fish [18]. In West Africa, fishing grounds in the National Park of Banc d'Arguin (PNBA) are mostly associated with seagrass beds, which also export their productivity to adjacent areas [19]. There, the number of species in their juvenile stages and their abundance are higher inside the seagrass meadows (Figure 1.6), and includes juveniles of species like *Citharichthys stampflii*, *Coptodon guineensis*, *Cynoglossus senegalensis*, *Fontitrygon margarita*, *Diplodus bellottii*, *Diplodus sargus*, *Epinephelus aeneus*, *Epinephelus guaza*, *Epinephelus marginatus* and *Etmalosa fimbriata*, which have a high economic value in the region [20].

Biodiversity support. Seagrass meadows provide habitat, shelter, food, and nursery areas to a high diversity and abundance of faunal species [21] (Figure 1.7). Many of these species are threatened and/or charismatic species, such as seahorses, sea turtles, and elasmobranchs [22]. For instance, the extensive seagrass meadows of the Banc d'Arguin in Mauritania are known to support a large array of shark and ray species, many of which are threatened with extinction [23]. Some species use the area as a nursery ground [24], benefitting from the shelter and food sources offered by seagrass meadows. The PNBA is also ranked as one of the most important foraging sites for green turtles since they are mostly herbivorous and seagrasses are one of their main food items (Box 1.3). Seagrass meadows in the PNBA are also vital foraging areas for many species of wetland birds (Figure 1.8), in particular waders, whose density during low tide is the highest in the world in the seagrass covered intertidal areas of the Banc d'Arguin [25]. Some of the species that are supported by seagrass meadows are considered flagship species, and are thus useful for conservation planning [26].

Water purification. Seagrasses improve the water quality through the filtering or storage of water pollutants, which involves fixing and storing nutrients and trapping suspended particles [32,33]. They also regulate the chemical composition of the seawater by controlling the concentrations of dissolved gases such as oxygen. Seagrasses remove dissolved inorganic (ammonium, nitrates, phosphates) and organic nutrients from the water column through their leaves and roots, which can uptake nutrients that are fixed and stored in their tissues. They are very efficient at retaining suspended particulate matter, including microplastics [34], fine sediments and associated nutrients and organic matter, making water clearer. In addition, seagrass ecosystems are one of the most productive ecosystems on Earth, releasing high quantities of oxygen through photosynthesis.

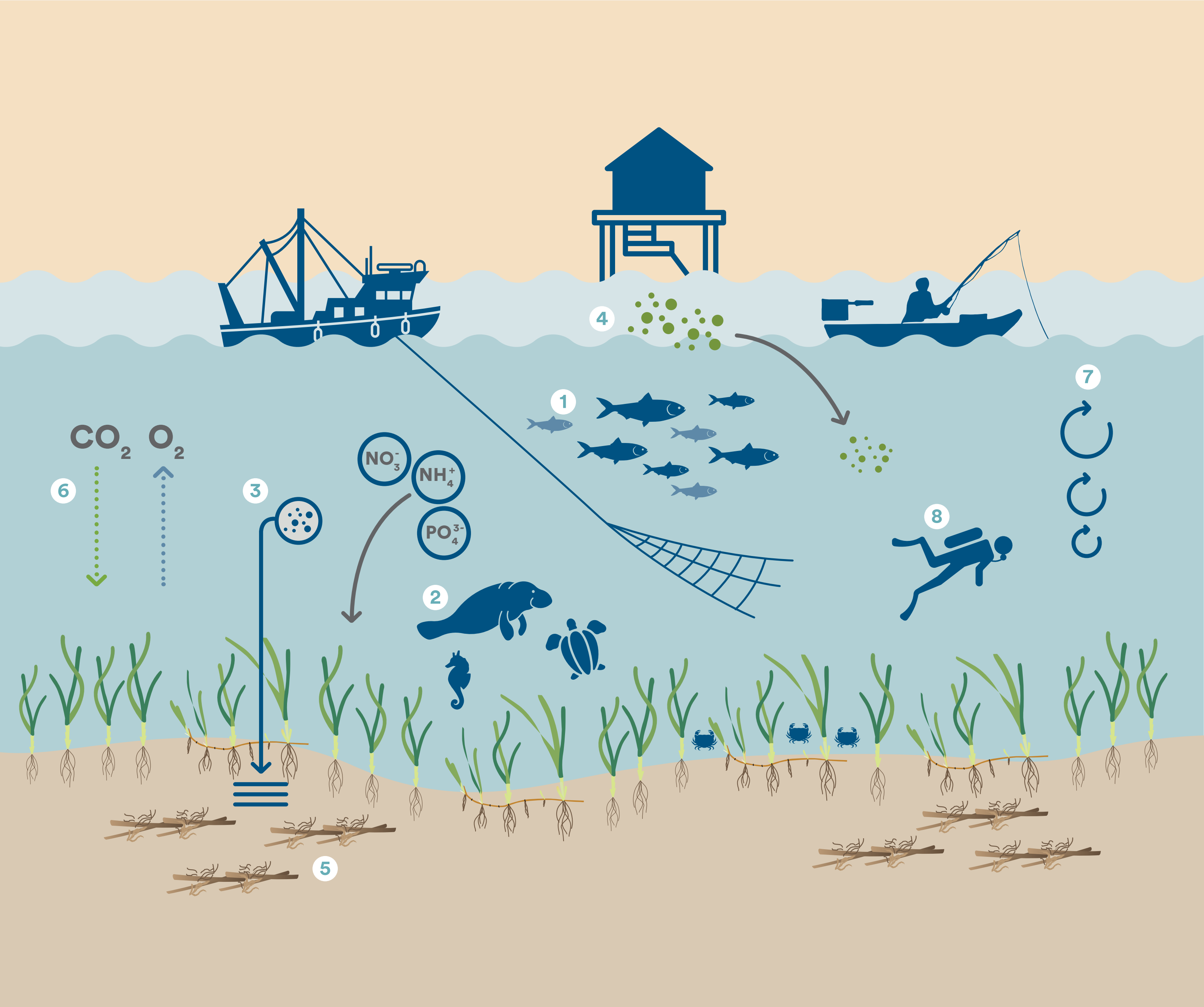


FIGURE 1.5. Ecosystem services provided by seagrass meadows. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

1. Fisheries support
2. Biodiversity support
3. Water purification
4. Disease control
5. Carbon sequestration and storage
6. Ocean acidification amelioration
7. Coastal protection
8. Cultural services

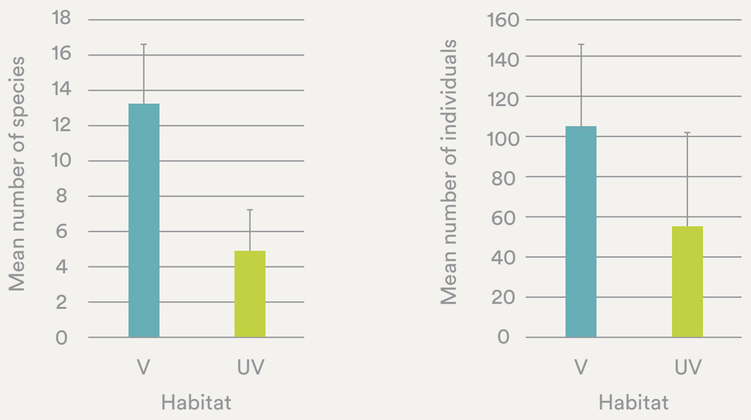


FIGURE 1.6. Example of fisheries support by seagrass meadows at the PNBA: A) Mean number of fish species and B) mean number of fish individuals in vegetated (V, seagrass) and unvegetated (UV, bare sediment) areas at the National Park of Banc d'Arguin. Adapted from [20].

Due to this important service, seagrasses are considered natural biofilters bringing benefits to economic activities such as aquaculture and bivalve farming.

Disease control. Seagrasses can remove and reduce microbiological contamination from the water, thus reducing fish, human and invertebrate exposure to pathogens. For instance, it has been demonstrated that the levels of potentially pathogenic marine bacteria are reduced by 50% in tropical areas where seagrasses are present, in comparison to areas where seagrasses are absent [18]. In temperate seagrasses, the concentration of *Vibrio* bacteria was also about 40 % lower in the presence of seagrasses when compared to non-vegetated areas [35]. Seagrasses can also produce chemical substances with antibacterial activity that kill or inhibit the growth of pathogens in humans [36].

Carbon sequestration and storage. Seagrasses, along with mangroves and salt marshes, rank amongst the most efficient carbon dioxide sinks [37], as they sequester CO_2 in the form of organic carbon (also called blue carbon [38]), both in their biomass and especially in their sediments. The accumulation and storage of organic carbon in the sediment of seagrasses is due to a combination of processes (Figure 1.9). First, seagrasses are highly productive, and generate large quantities of organic material that is kept in the ecosystem [39]. Also, their canopy and biomass interact with the currents and waves, reducing their velocity [40], enhancing the deposition and trapping of suspended particulate matter [41], and reducing sediment erosion and resuspension [42], all of it favouring the burial of the organic matter. Once the organic matter (and therefore the organic carbon) is buried in the sediment, its decomposition rate is very low due to the commonly anoxic conditions of the seagrass sediment [43]. In this way, seagrass can store and preserve the carbon for many centuries or millennia. The carbon sequestration and storage service is gaining high attention nowadays due to its contribution to combat climate change through carbon removal [44,45].

Ocean acidification buffering. Ocean acidification is a result of the increasing levels of CO_2 in the atmosphere, which is dissolved in the sea. As a consequence, the water becomes more acidic (the pH decreases), having potential negative effects on marine fauna and flora, especially affecting calcareous species (for example shellfish and calcareous algae [46,47]).

FIGURE 1.7. Fauna associated with seagrass meadows: A) Cuttlefish *Sepia officinalis* (Troia, Portugal), B) Bivalves (Iwik, Mauritania), C) Shore crab *Carcinus maenas* (Isles of Scilly, UK), D) Seahorse *Hippocampus guttulatus* (Ría Formosa, Portugal), E) Catshark *Scyliorhinus canicula* (Helford, UK), F) Gastropod (Greece). **Photos by:** S. Tavares (A); C. de la Hoz Schilling (B); M. Vos / Ocean Image Bank (C); C.B. de los Santos (D); S. Moran / Ocean Image Bank (E); D. Poursanidis / Ocean Image Bank (F).

Seagrasses are highly productive and remove large quantities of dissolved inorganic carbon from the water column, to be used in photosynthesis. As a result, the pH in the water surrounding the seagrass meadows increases, with the potential to offset ocean acidification and its negative consequences on the associated flora and fauna [48].

Coastal protection. The presence of seagrasses in coastal areas contributes to the protection of coastal zones from erosion, flooding, and storm surges [49]. This protection service is provided through their ability to decrease wave energy and reduce currents, thus favouring sedimentation, preventing erosion, and stabilising the sediment [42,50]. This ecosystem service is enhanced when seagrasses coexist with other ecosystems such as mangrove forests, salt marshes or coral reefs. Seagrasses normally generate large amounts of leaf litter that are transported

BOX 3.

GREEN TURTLES AND SEAGRASSES IN WEST AFRICA

West Africa is a particularly important region for loggerhead turtles (*Caretta caretta*) and green turtles (*Chelonia mydas*), with large populations of both species present in the region. The Cabo Verde archipelago [27] and the Bijagós archipelago in Guinea-Bissau [28] are important breeding sites for loggerheads and green turtles, respectively, and the Banc d'Arguin National Park in Mauritania is a key foraging site for green turtles due to abundant seagrasses.

The connection among these sites in West Africa over the life cycle of green turtles was investigated using satellite telemetry [29, 30]. Studies showed that a large proportion of individuals tagged in the nesting areas at Bijagós archipelago (where they also eat seagrass) [31], travelled over more than 1000 km to forage in the extensive seagrass meadows of the Banc d'Arguin, after laying their eggs. Seagrass provides an important food source for green turtles and, in turn, seagrass benefits from the sea turtles because productivity is generally enhanced by the removal of seagrass biomass through grazing, and because green turtles can disperse seagrass seeds across long distances along West African countries, counteracting oceanographic barriers [12].

In conclusion, the conservation of seagrass meadows and green turtles in West Africa is co-dependent, therefore it is essential to implement management measures that take this interdependent relationship into consideration.

Green turtle (*Chelonia mydas*) in Tenerife, Spain. *Photo by:* L. McGuire / Ocean Image Bank.

Illustrated as a story-map at: Potouroglou, M., Vinaccia, M., Fylakis, G., & Bhakta, D. 2020. Follow sea turtles in their search for greener pastures: tracking the green turtles' 1,000-kilometre migration from Guinea-Bissau to the lush seagrass meadows in Mauritania. Story Map, GRID-Arendal. https://storymaps.arcgis.com/stories/61c7a049833f4149a9fdd596f7aa10db

FIGURE 1.8. Selected bird species using seagrass beds on the Banc d'Arguin (Mauritania), where there is little terrestrial vegetation in contrast with abundant seagrasses, therefore seagrasses are a precious resource for birds there. Bird species that use seagrass leaves to build their nests: A) *Thalasseus maximus* (Zira), B) *Platalea leucorodia balsacii* (Arel), C) *Croicocephalus cirrocephalus* (Nair), D) *Onychoprion anaethetus* (Arel). Bird species that use seagrass beds as feeding areas: E) *Calidris alpina* (Nair), F) *Larus genei* (Zira), G) *Arenaria interpres* (Kiaone), H) *Phoenicopterus roseus* (top) and *Pelicanus onocrotalus* (bottom) (Bellaat), I) *Calidris alba* (Cap Tagarit). **Photos by:** E.A. Serrão (A-F); A. Araújo (L); M. Broquere, BACOMAB (H); C. de la Hoz Schilling (I).

to and deposited along the coastline, forming a first natural barrier that protects the shoreline from wave action [51], promoting the growth of terrestrial plant species such as *Arthrocnemum macrostachyum*, which trap eolian sediments, favour the establishment of dunes, and are an important breeding stand for bird species like the endemic spoonbill in Banc d'Arguin. The coastal protection service is particularly important in the context of climate change, as it helps coastal zones adapt to the increasing frequency and intensity of waves and storm surges [49].

Cultural services. Seagrasses can provide cultural services, such as attracting tourism and providing recreational opportunities (diving, observation of wildlife), as well as being of spiritual and religious importance. For example, in some regions, seagrass areas attract many nature-enthusiastic tourists as these areas are home to charismatic megafauna such as green turtles, dugongs, and also seahorses or birds. In other regions, fishers and coastal local communities are directly linked to seagrass meadows, which represent their main source of food, and therefore ensure their livelihood, giving seagrasses an additional value for identity and spiritual fulfilment [52].

The wide variety of services provisioned by seagrasses underlines the importance of these habitats in maintaining the functioning of coastal ecosystems and provides a strong motivation to protect and conserve them, in order to ensure their benefits for the well-being of nature and present and future generations [53].

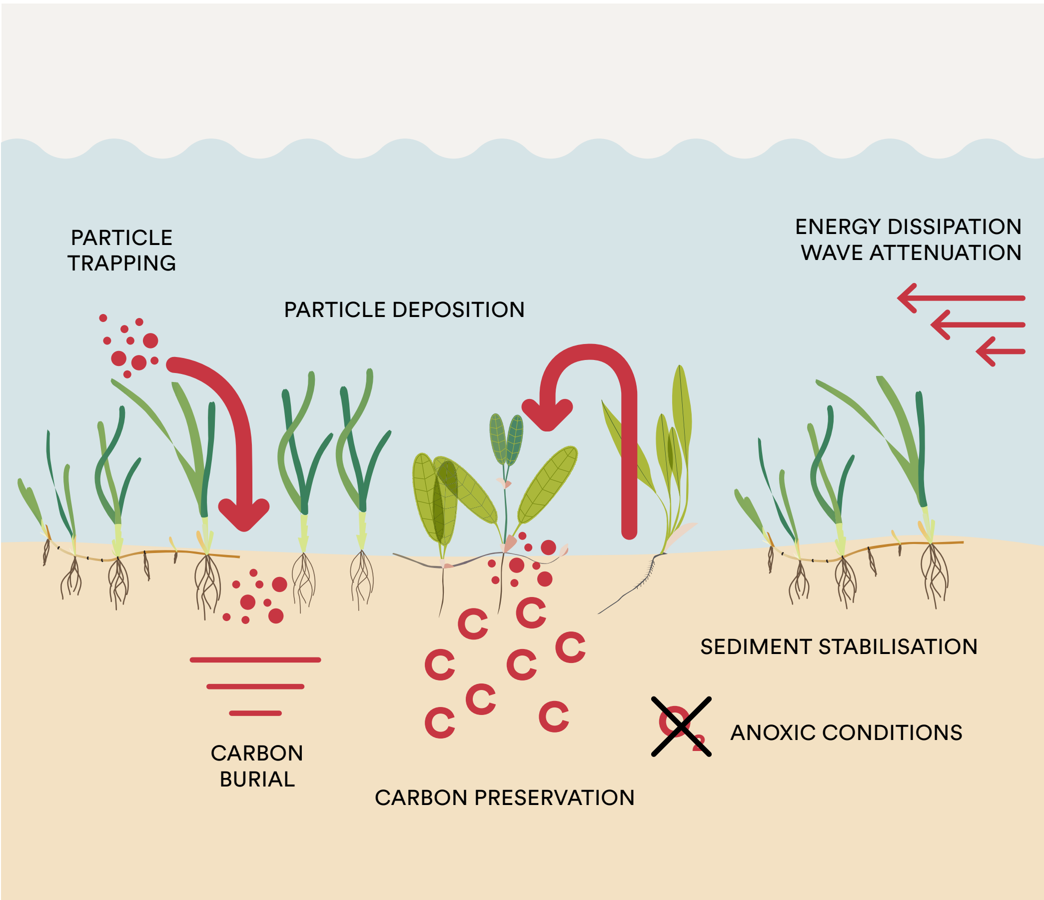


FIGURE 1.9. Processes involved in the carbon sequestration. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

1.3. SEAGRASS SPECIES IN WEST AFRICA: IDENTIFICATION, BIOLOGY, AND DISTRIBUTION

There are four known species of seagrass in West Africa and the seven RAMPAO countries: *Cymodocea nodosa*, *Zostera noltei*, *Halodule wrightii*, and *Ruppia maritima* (Table 1.1).

TABLEAU 1.1. Presence of seagrass species in the RAMPAO countries, based on real recent observations. * Uncertainties in the identification of the species. ** Historically present but currently not verified.

COUNTRY	*Cymodocea nodosa*	*Zostera noltei*	*Halodule wrightii*	*Ruppia maritima*
Cabo Verde	No	No	Yes	Yes
Mauritania	Yes	Yes	Yes	Yes*
Senegal	Yes	Yes	Yes	Yes**
The Gambia	Yes	No	Yes	No
Guinea Bissau	No	No	Yes	No
Guinea	No	No	Yes	No
Sierra Leone	No	No	Yes	No

1.3.1. *CYMODOCEA NODOSA*

Cymodocea nodosa is a temperate species that is found in subtidal zones throughout wide depth gradients, ranging from shallow waters to 50-60 m depth in oceanic transparent waters like in the Canary Islands. However, the depth range of the species tends to be very shallow in the coastal African meadows due to light limitation caused by turbid waters. The reported maximum depth is around 4 m, but often even less [54]. It can occur in more exposed, open coastal waters as well as in more sheltered environments such as coastal lagoons and estuaries. The species is distributed along the Mediterranean bioregion and the temperate and subtropical north-eastern Atlantic coast, ranging from mid Portugal to The Gambia as well as the Canary Islands and Madeira Islands. Some sources indicate that it can be also found in Cabo Verde, yet multiple searches have not confirmed its presence there. The past descriptions of *C. nodosa* records in Cabo Verde could be a misidentification of *Halodule wrightii* or an incorrect assignment of records from Cabo Verde Peninsula in Senegal, a temperate region influenced by upwelled colder seawater. In West Africa, the distribution of *C. nodosa* [54] is limited to large meadows within the Banc d'Arguin (Mauritania) and in Senegal, mostly in the Delta of the Sine-Saloum rivers. There are also smaller meadows along the Senegalese Petite Côte (e.g. Joal Fadiouth) and south of the Gambia River (Figure 1.10, Figure 1.11). In the Banc d'Arguin, *C. nodosa* forms large, dense meadows that support a large amount of biodiversity.

The species can be distinguished from other seagrasses based on the following characteristics: shoots of *C. nodosa* contain between 3 – 4 leaves each that can reach a maximum length

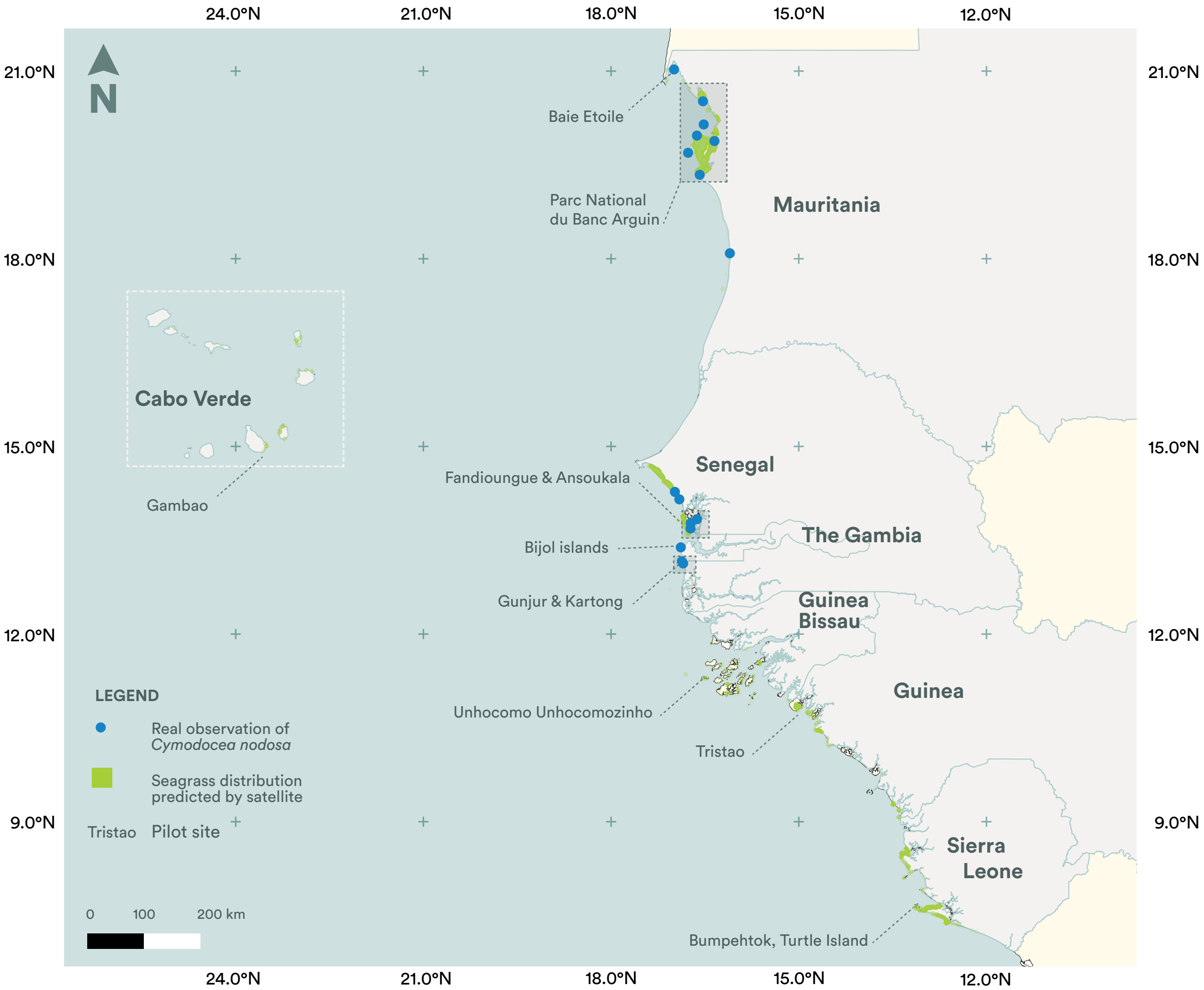


FIGURE 1.10. *Cymodocea nodosa* distribution in the seven RAMPAO countries based on real observations (blue dots) and satellite predicted distribution of all seagrass species (green area).

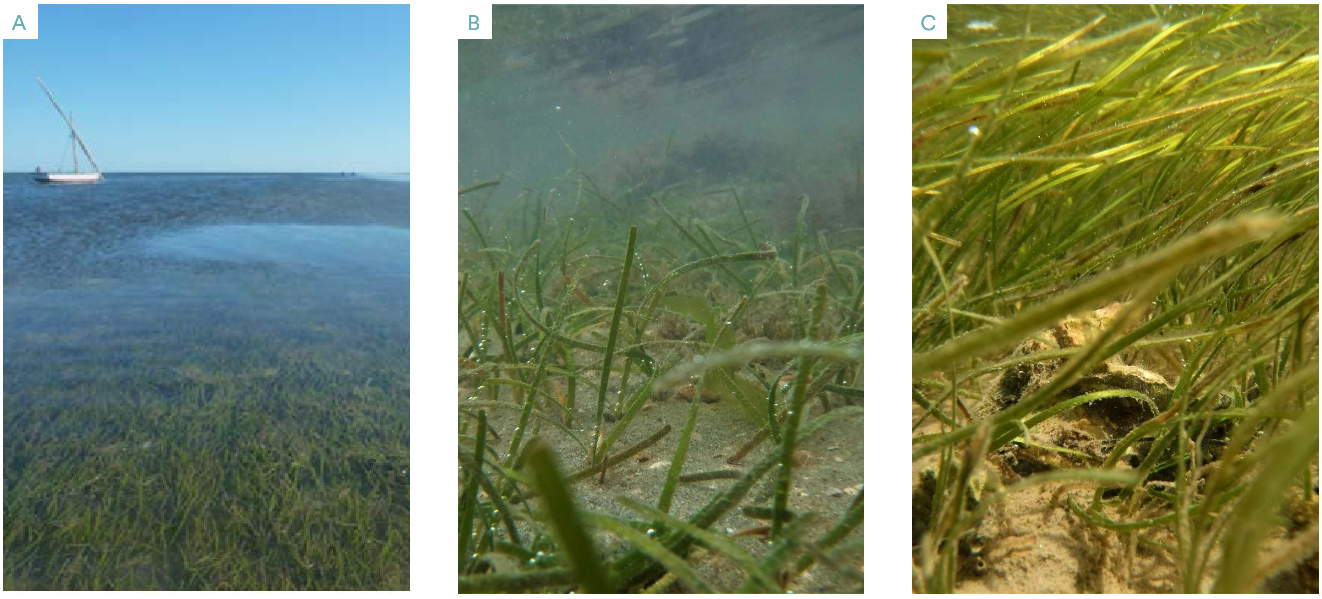


FIGURE 1.11. *Cymodocea nodosa* meadows in the RAMPAO countries: A) Banc d'Arguin, Mauritania, B) The Gambia, C) Senegal. **Photos by:** E.A. Serrão (A); M. Potouroglou (B,C).

of 60 cm and a width of 1.5 – 6.0 mm [55]. Each leaf displays between 5 – 7 veins and has an open sheath and a serrated tip. The rhizome is thicker than 2 mm and has a pink-brownish tonality. Rhizomes can be horizontal or vertical. At each node on the horizontal rhizome grows one single, vertical root with a length of up to 35 cm that, in contrast with other co-occurring species in West Africa, is strongly branched (Figure 1.12). *Cymodocea nodosa* is dioecious, with separate female and male plants. Flowering occurs at the beginning of spring and may last until summer [56,57,58]. Female plants produce two relatively large (8 mm) lentil-shaped seeds (Figure 1.12), which can remain attached to the plant or dormant in the soil for several months.

FIGURE 1.12. Features and reproductive structures of *Cymodocea nodosa*: A) detail of the leaf tip, B) shoots and horizontal rhizome with roots, C) shoots and vertical rhizome arising from horizontal rhizomes, D) male flower, E) seeding (above) and paired lentil-shaped seeds at the bottom of the shoot (below), F) seeds. **Photos by:** EDEA research group, University of Cádiz (B,C,E), C.B. de los Santos (A,D), and E.A. Serrão (F).

1.3.2. *ZOSTERA NOLTEI*

Zostera noltei is a temperate seagrass species that can thrive in very different temperature regimes, as its distribution range includes three global seagrass bioregions: the Temperate North Atlantic, the Mediterranean, and the Tropical Atlantic regions. In West Africa, *Z. noltei* is known to occur in the Banc d'Arguin and the Baie d'Etoile (Mauritania), and in Fandioungue and Ansoukala (Senegal) (Figure 1.13, Figure 1.14).

Zostera noltei, similar to *C. nodosa*, can form dense meadows, but thanks to its high tolerance to desiccation, it grows mainly in intertidal areas where it is exposed to air for long periods of time at low tide and where it has a competitive advantage to other seagrass species. However, during air exposure, leaves usually remain moisturised through the thin layer of water found on muddy soils (Figure 1.14).

Zostera noltei has leaves reaching a maximum length of 25 cm and a maximum width of 0.5 – 1 mm [55]. Each shoot may contain between 2 – 5 leaves. Each leaf has an open sheath and displays 3 veins and a blunt, notched tip. The thickness of the rhizome can range between 0.5 – 2 mm, and, although older rhizome sections turn a yellow-brownish colour, younger rhizome segments are light green. Each node can contain between 1 – 4 thin, non-branched vertical roots (Figure 1.15).

Zostera noltei is monoecious, meaning that male and female flowers both grow on the same individual, on specialised shoots (Figure 1.15). To avoid self-pollination, male and female flowers mature at different rhythms, and the seeds, once formed, are released into the water column where they may be spread through their consumption by different animals that feed in the intertidal seagrass beds.

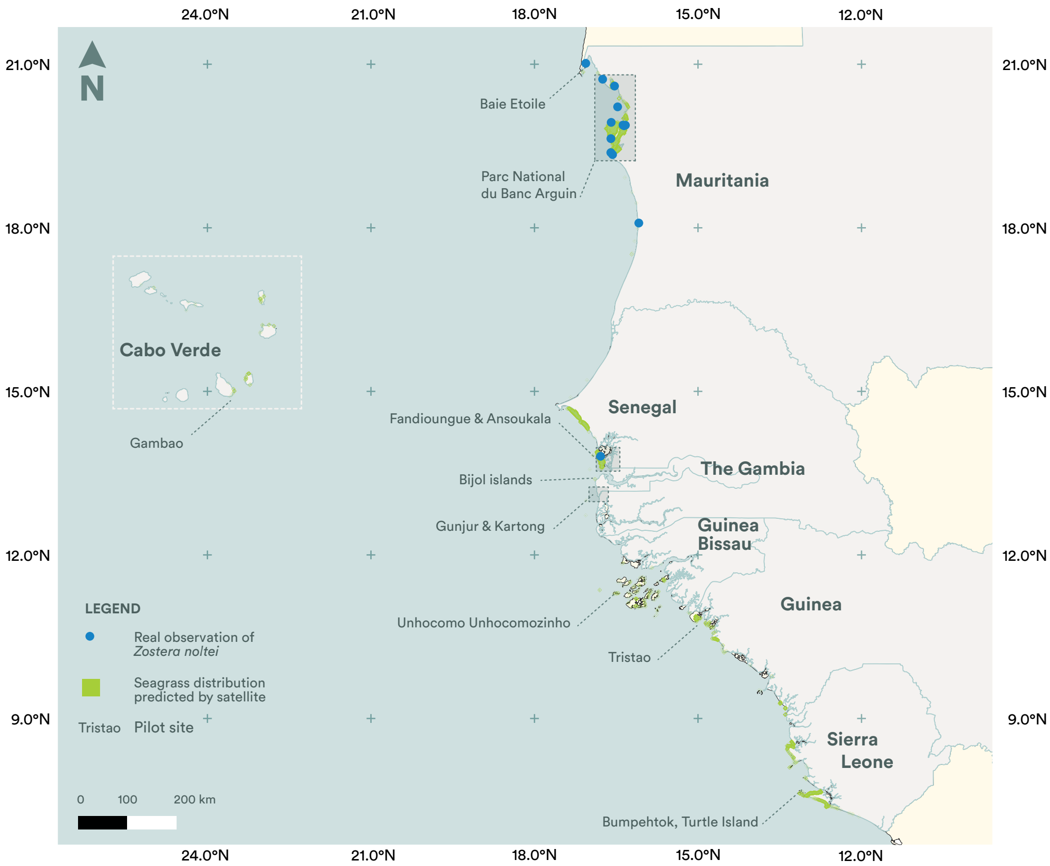


FIGURE 1.13. *Zostera noltei* distribution in the seven RAMPAO countries based on real observations (blue dots) and satellite predicted distribution of all seagrass species (green area).

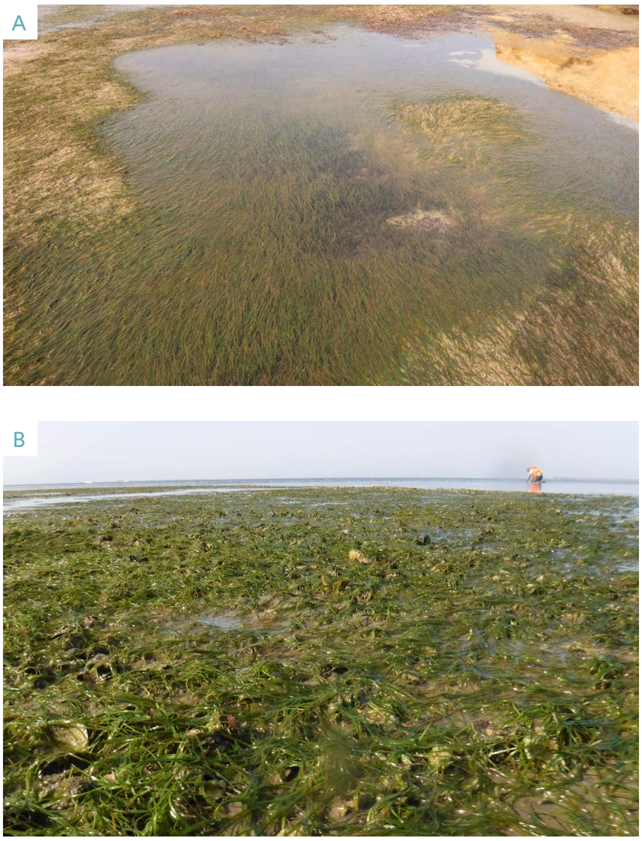


FIGURE 1.14. *Zostera noltei* meadows in RAMPAO countries: A) Banc d'Arguin, Mauritania, B) Senegal, C) Senegal. **Photos by:** C. de la Hoz Schilling (A), M. Potouroglou (B,C).

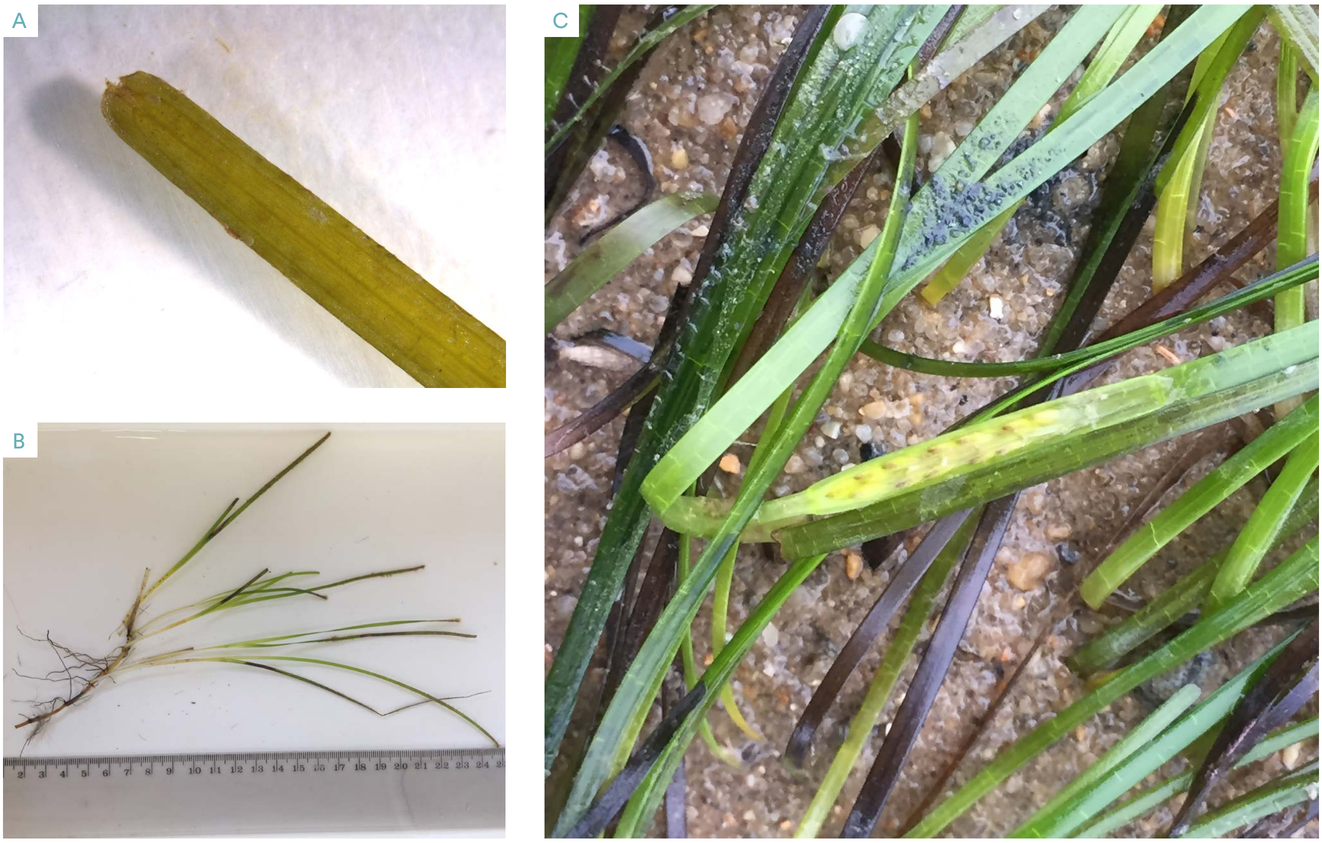


FIGURE 1.15. Features and reproductive structures of *Zostera noltei*: A) detail of the leaf tip, B) rhizome with roots, C) reproductive shoot carrying the flowers. **Photos by:** C.B. de los Santos.

1.3.3. *HALODULE WRIGHTII*

Halodule wrightii is the only tropical species found in West Africa, where it is the only seagrass species that occurs in all countries from Mauritania to Sierra Leone, including Cabo Verde [54,59] (Figure 1.16, Figure 1.17). It is an Atlantic species, as previous reports of *H. wrightii* in the Indian Ocean are currently known to correspond to *Halodule uninervis*, which has been confirmed by DNA evidence [9,12].

Halodule wrightii has a depth range between 0 and 30 m in the transparent waters of the Caribbean [60] but can also be found in the very low intertidal (Figure 1.17). However, in Africa, it occurs mainly in areas where waters are turbid and depth limits rarely extend beyond approximately 2 m, often even less, except in rare locations with more transparent waters. It is primarily found in sheltered or semi-sheltered environments such as shallow shorelines, estuaries, or lagoons, often associated with other structural elements such as mangroves or coral reefs or in combination with other seagrass species.

Each shoot of a *H. wrightii* plant contains between 2 and 4 leaves and can range between 3 – 30 cm in length, and 2 – 5 mm in width [61]. The leaf apex has two small lateral extensions as well as an occasional small median one, or more frequently just a concave central apex. The whitish-brownish horizontal rhizome is thin and ends in a foliar shoot. Three to five simple, unbranched vertical roots usually spring from the rhizome nodes and terminate in a dark point (Figure 1.18). The roots are usually shallow, not exceeding 5 cm of depth.

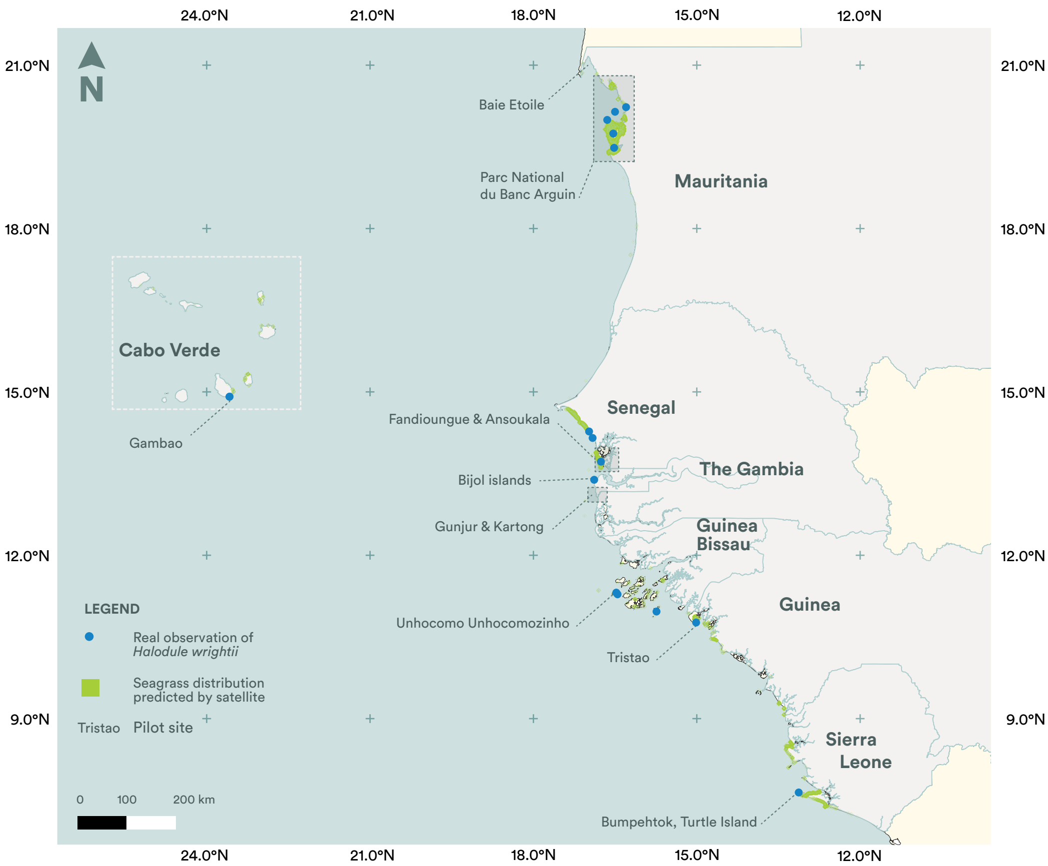


FIGURE 1.16. *Halodule wrightii* distribution in the seven RAMPAO countries based on real observations (blue dots) and satellite predicted distribution of all seagrass species (green area).

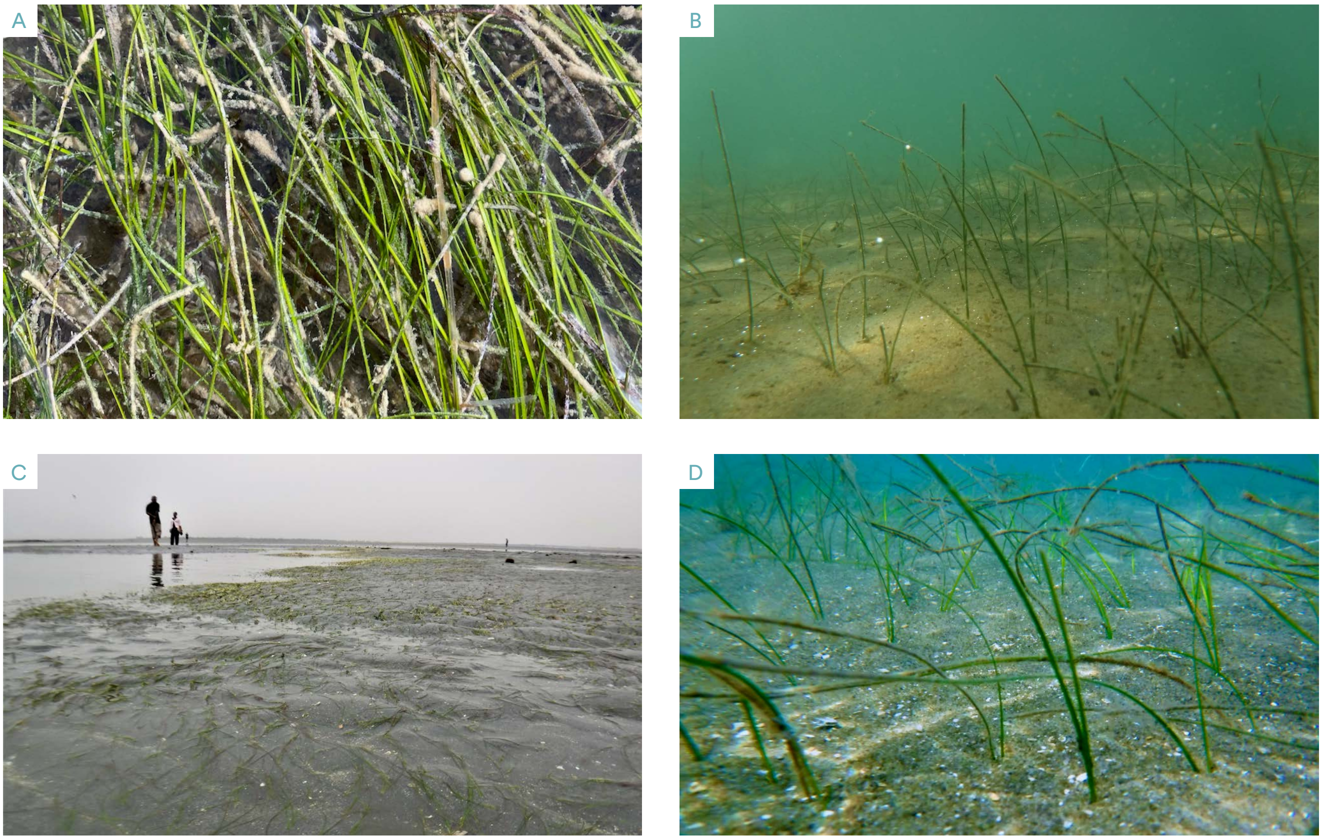


FIGURE 1.17. *Halodule wrightii* meadows in RAMPAO countries : A) Banc d'Arguin, Mauritania B) Santiago Island, Cabo Verde C) The Gambia D) Sierra Leone. **Photos by**: E.A. Serrão (A), with permission from [59] (B), and M. Potouroglou (C,D).

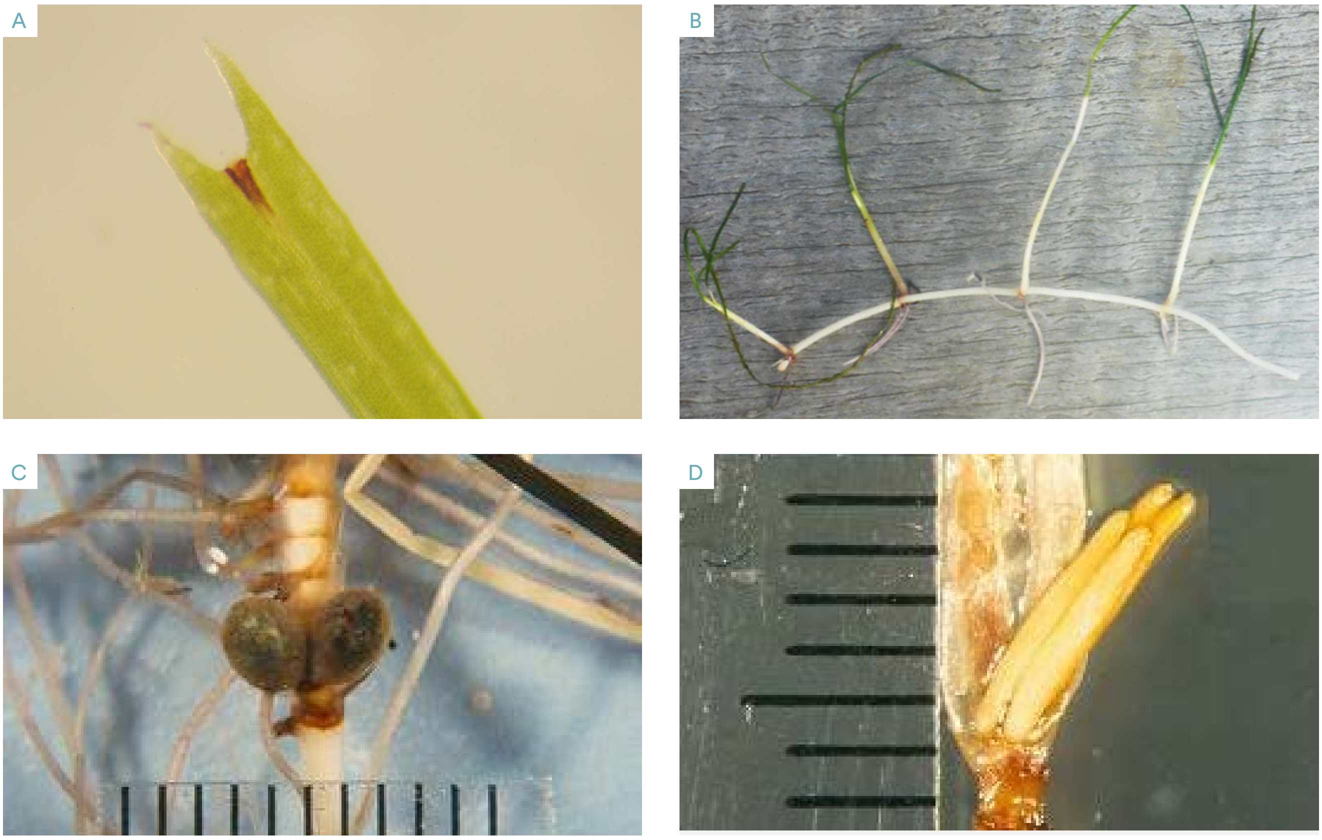


FIGURE 1.18. Features and reproductive structures of *H. wrightii*: A) detail of the leaf tip from Banc d'Arguin, B) rhizome with roots in Banc d'Arguin, C) fruit attached to the maternal shoot, D) flower. **Photos by:** E.A. Serrão (A), M.A. Sidi Cheikh (B), and J. Kowalski, with permission (C,E).

Like all seagrasses, *H. wrightii* can propagate by clonal growth or seeds (Figure 18). Additionally, seed dispersal is spatially limited because seeds are produced at the shoot basis (as in *Cymodocea nodosa*). Seeds can remain dormant in the sediments for long periods of time, ensuring the potential of the species to continue to thrive after possible disturbances.

1.3.4. *RUPPIA MARITIMA*

Ruppia maritima has a wide distribution range. It is the only *Ruppia* species that has been reported from West Africa, with confirmed populations in Cabo Verde, where it has been reported from Sal, Boavista and Santiago Islands [62] (Figure 1.19, Figure 1.20). The species has also historically been collected in several parts of Senegal and Mauritania. However, the taxonomy of the genus is still unresolved, and other species may be present in the region as other parts of Africa hold considerable diversity of *Ruppia* species [63].

Ruppia maritima is an intertidal seagrass species that is primarily found in coastal lagoons (Figure 1.20), small saline or brackish ponds near the sea, or drainage channels in saltpans. However, the species can grow in a wide range of habitats, with a greater salinity range than fully marine seagrasses.

The bright green leaves of *Ruppia maritima* can reach a length of 2 - 11.5 cm, but are thinner than those of other regional seagrass species, with a leaf width range between 0.2 - 0.5 mm. The apex has pointed and slightly toothed tips. Leaves are usually alternate,

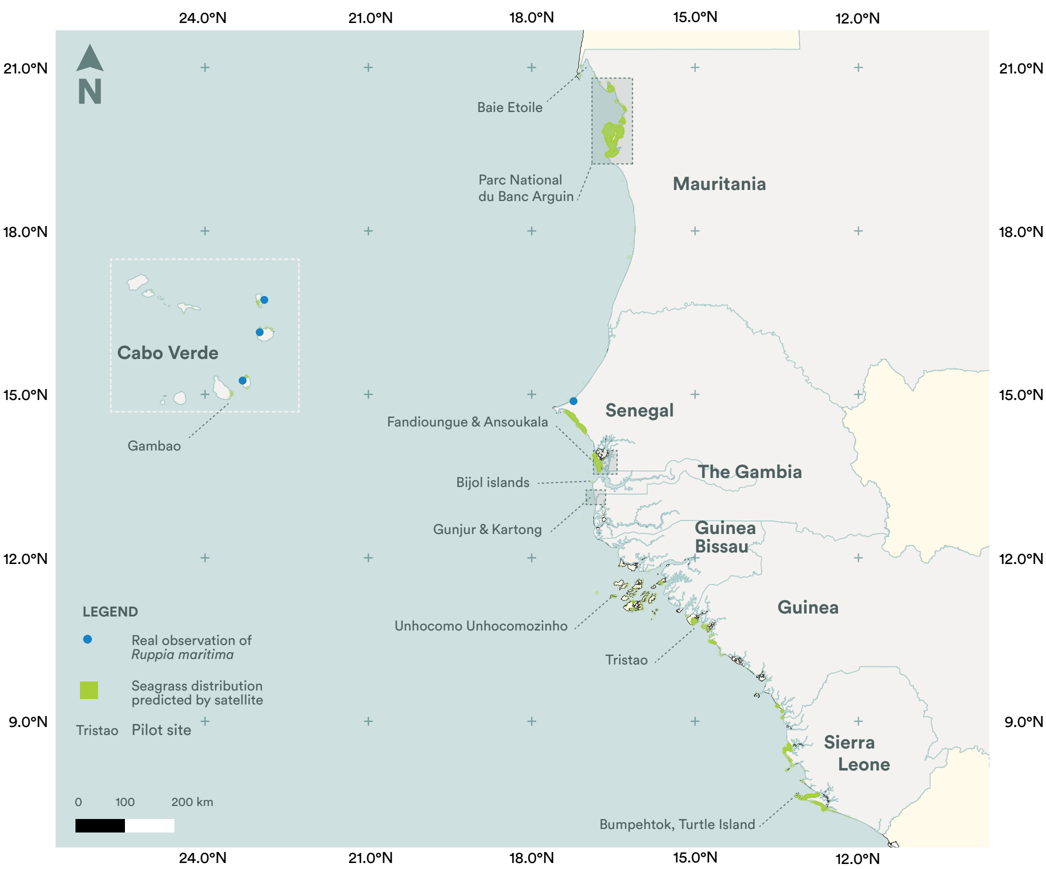


FIGURE 1.19. *Ruppia maritima* distribution in the seven RAMPAO countries based on real observations (blue dots) and satellite predicted distribution of all seagrass species (green area).

FIGURE 1.20. *Ruppia maritima* meadows in RAMPAO countries: A) Santiago Island, Cabo Verde, B) Santiago Island, Cabo Verde. Photos adapted from [62].

meaning that there is a single leaf at each node ascending along the stem. However, sometimes leaves appear to be placed subopposite to each other, emerging near the same node, with one slightly above the other. The species has thin and greenish rhizomes with a single root (sometimes two) per node; the unbranched roots rarely penetrate the substrate beyond a few centimetres. Unlike the other seagrasses described above, plants typically form long vertical stems of up to 3 m. This morphology (long stems with shallow roots) makes plants easily detachable, making them unable to survive in habitats with strong tides or currents.

Plants generally flower and fruit abundantly, and these reproductive structures can be useful to identify *Ruppia* species (Figure 1.21). Each inflorescence contains two flowers facing opposite directions; each flower has both female and male parts and is therefore monoecious. Inflorescences form inside the leaf sheaths and in *Ruppia maritima*, flowers typically self-pollinate inside air bubbles produced by the plant. The fruits are joined to the peduncle by pedicels that give them a star-like arrangement. *Ruppia maritima* is generally annual and produces up to 10 dark brown, 2 - 2.8 mm long, pear-shaped seeds. Seeds can remain dormant in habitats that are seasonally dry in order to increase chances at survival.

FIGURE 1.21. Features and reproductive structures of *Ruppia maritima*: A) detail of the leaf tip, B) rhizome with roots, C) Inflorescence D) Seeds. **Photos by:** D. Frade (A-C), S. Hurst, USDA-NRCS PLANTS Database (D).

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MODULE 2:
GLOBAL, REGIONAL, AND LOCAL THREATS TO SEAGRASS MEADOWS IN THE RAMPAO MEMBER COUNTRIES

Henrique Queiroga, Carmen B. de los Santos, Mohamed Ahmed Sidi Cheikh, Samir Martins, Duarte Frade, Antonio Araújo, Ester A. Serrão

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2.1. INTRODUCTION TO THREATS TO SEAGRASS MEADOWS

Declines in the important marine coastal habitats created by seagrasses have been recorded since the 1930s [1,2] and continue to spread, negatively impacting the key services provided by these ecosystems, including carbon sequestration, coastal protection, and support to fisheries (see module 1). Although a recent study found that the decline of European seagrass meadows is slowing down, and that fast-growing species are recovering in some parts [3], current trends remain largely unclear for some bioregions, especially those where monitoring is lacking [2,4]. Future projections based on different climate change scenarios, however, indicate further range loss or contraction for some species [5], and many unmonitored locations are at risk of decline [4].

Seagrass threats can be due to natural and anthropogenic causes. The main threats to seagrass meadows are actions that affect their essential habitat conditions, which are linked to habitat suitability (e.g., water temperature, depth, type of substrate, and current velocity) and water quality (e.g., light availability, nutrient concentration, salinity, and pollutants) [6]. These conditions are mainly altered due to the reduction of light through water turbidity caused by terrestrial runoff carrying sediments, sewage, and fertilisers, or to the mechanical disturbance or removal of seagrasses caused by dredging, coastal construction, and other physical stressors [7]. Additionally, climate change and biotic factors, such as invasive species or diseases, also represent threats to seagrasses. These effects are described in the following sections and summarised in Table 1.

This module presents a general introduction on threats to seagrasses and a compilation of the observed and expected threats to seagrass meadows in the RAMPAO member countries (section 2.7). In many cases, several of the activities that are listed as threats in these countries have taken place on small, sustainable scales by local human populations dependent on marine habitats. However, with fast population and tourism growth, the balance between use and recovery can be rapidly lost, as increasing pressures can start to cause more drastic and irreversible effects.

2.2. THREATS THAT AFFECT WATER QUALITY

Two critical factors for seagrasses to grow, reproduce and maintain healthy populations are light and nutrients. Light (also called irradiance) is required for photosynthesis, and seagrasses usually need an underwater irradiance level of at least 10 % of surface irradiance in order to grow [8]. However, they often require higher levels, of above 40 % surface irradiance [9]. Therefore, generally, factors that reduce light levels or shade seagrasses will cause their widespread or localised loss, depending upon the extent of the threatening factors. The main cause of light reduction is increased water turbidity caused by sediment runoff from upstream watersheds where terrestrial vegetation has been removed for commercial deforestation, construction, and agriculture (e.g., [10]; Figure 2.1). Another main cause of decreased light penetration is phytoplankton and macroalgae blooms (i.e., the rapid growth of biomass of phytoplankton and macroalgae that is uncharacteristically high for a given water body). Such blooms are typical during eutrophication events, due to increased organic matter and nutrient loads originating from effluents, derived for instance from agriculture and aquaculture activities (e.g.,[11]).

For seagrasses to grow and thrive, nutrient availability in the environment is essential, yet in general, seagrasses are adapted to oligotrophic waters (i.e., water with low concentration of nutrients). Inorganic nutrients, such as ammonium, nitrate, and phosphate are crucial for the growth of seagrasses, but in excess they can degrade habitat quality. High nutrient loads may result from organic matter decomposition or from water runoff rich in chemical fertilisers. One notorious consequence of high nutrient loads is eutrophication, as previously explained. This process starts by favouring phytoplankton and macroalgae growth, which are very efficient in absorbing dissolved nutrients from the water. Abnormal phytoplankton and macroalgae abundances prevent enough light to reach the seagrasses and decrease their growth rates. Eventually, the accumulation and decomposition of organic matter will lead to low oxygen rates and toxic sulphide formation, further degrading the quality of seagrass habitat [12]. Eutrophication is a major cause of seagrass disappearance worldwide.

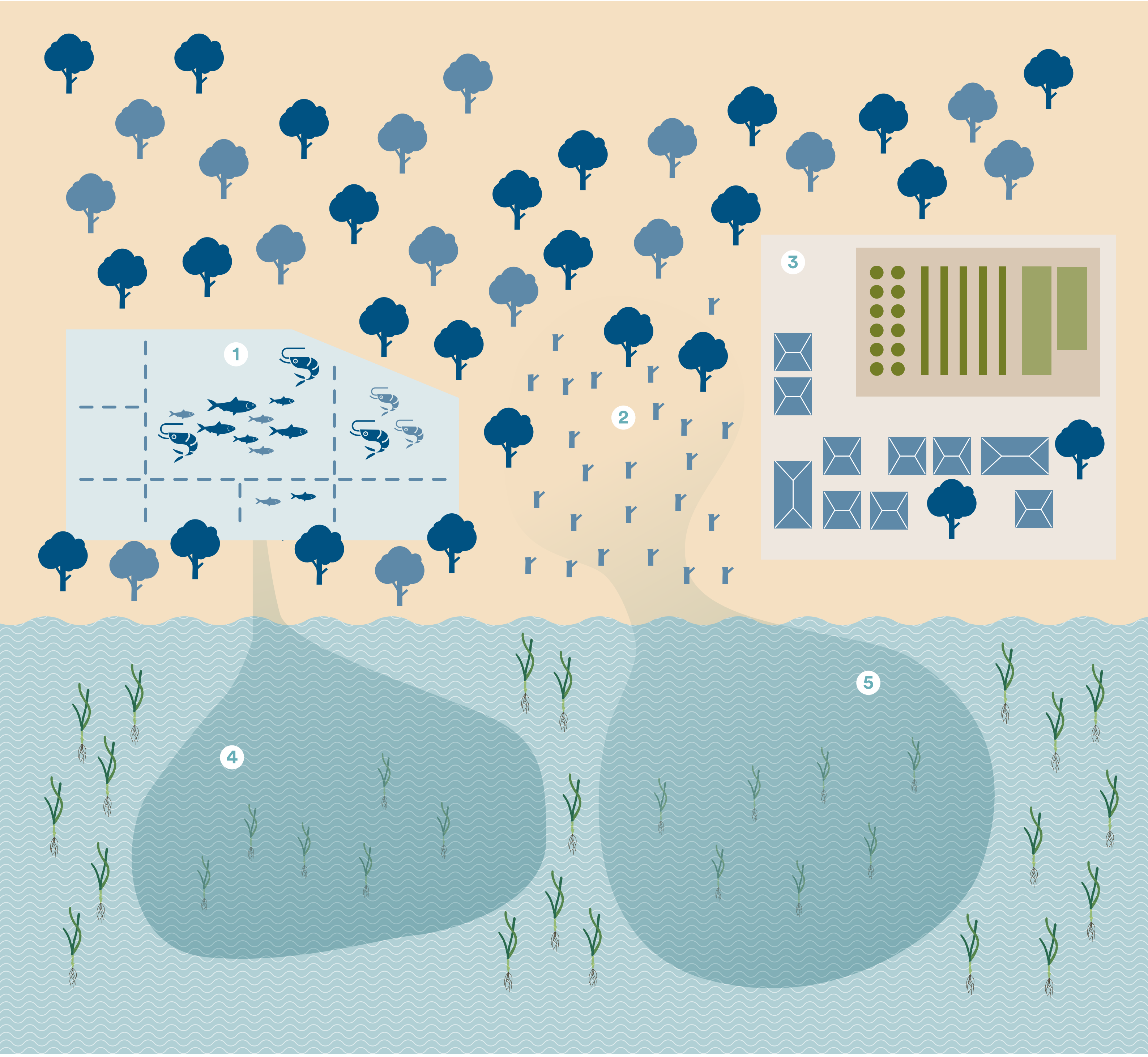

FIGURE 2.1. General threats to seagrasses that affect water quality:

1. Aquaculture farm
2. Deforestation
3. Agriculture, urban and industrial constructions
4. Shading and nutrient enrichment caused by effluent from aquaculture
5. Shading, siltation and nutrient enrichment caused by runoff from cleared area and from agriculture

Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

2.3. THREATS THAT AFFECT HABITAT SUITABILITY

Suitable seagrass habitats require sediment stability and the absence of mechanical disturbance. The rhizome and roots of seagrasses are embedded in the sediment, which provides nutrients and a physical scaffold to the plants. In turn, the dense network of roots and rhizomes stabilises the sediment, and the leaves create proper conditions for increased deposition of sediment particles, creating additional habitat for further seagrass growth [13,14]. Young seagrass recruits and fragmented meadows do not have a large rhizome and well-established root systems to keep them in place, and therefore need calm waters and sheltered sediments to not be removed by the currents. Such environments can occur in calm areas like coastal lagoons and sheltered shores. This sediment balance is threatened by physical disturbances such as boat anchors and chains dragging the sea bottom, as well as boating [15], harvesting of shellfish, fishing with bottom-contacting gear and dredging [16], which may remove seagrasses and fragment meadows, leaving local scars or causing erosion over extensive areas (Figures 2.2). It is common to see massive accumulations of seagrass leaves following physical disturbance by boat anchors and destructive fishing activities. Seagrasses are also destroyed by anything that transforms naturally stable sediments into other types of habitats, such as coastal development, tourism, housing and building of infrastructures in general. Management strategies to avoid seagrass loss and ensure seagrass continuity should focus on preventing, reducing, or eliminating factors that decrease sediment stability, which may include, for example, regulation of the use of fishing activities and boating in seagrass areas. There has been human use of seagrass areas for a long time in equilibrium, but development and human growth can bring increases in damaging activities such as boat uses, resource extraction and other tourism industries, which if uncontrolled can reach unsustainable levels.

FIGURE 2.2. General threats to seagrasses that affect sediment stability and that cause physical damage:

1. Coastal erosion due to constructions including roads and parking lots
2. Trampling
3. Invertebrate harvesting
4. Fishing practices that affect the bottom (nets, seines, dredges)
5. Marinas and harbours, boat propellers
6. Anchoring
7. Mooring cables
8. Industrial dredging
9. Sea storms, causing either sediment deposition or mobilisation

Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

2.4. BIOLOGICAL THREATS

Biotic effects such as the introduction of invasive non-indigenous species and other competing species can be a concern. One organism that tends to occupy seagrass habitats and may prevent seagrasses from re-establishing is the green macroalgae of the genus *Caulerpa* (e.g., [17]). This algae can cause habitat alterations that reduce or prevent seagrass recruitment. Large quantities of other invasive macroalgae can also accumulate and decay on top of seagrasses, increasing the seagrass mortality and decreasing its total biomass beneath these turf patches [18].

Pathogens that commonly attack seagrasses are endophytes of two main groups: Labyrinthulomycetes and Oomycetes, which caused a massive seagrass wasting disease in the past [19]. An excessive load of epiphytes (e.g. filamentous algae or bryozoans) growing on seagrass leaves can also have a negative impact on the meadows.

Finally, seagrasses can be heavily consumed by herbivorous macrofauna (turtles, dugongs, fish) and mesograzers (gastropods, small crustaceans). These, however, are natural processes that are not expected to be a threat to seagrasses except when food webs are disrupted. This is the case, for example, when the overfishing of predators, such as sharks, causes a large increase in grazers in a certain area [20] or when a certain herbivorous species causes seagrass habitat collapse after overgrazing in marine protected areas [21,22].

2.5. THREATS ASSOCIATED WITH WEATHER EVENTS AND WITH CLIMATE CHANGE

Weather and climate are different concepts. According to [23], weather describes the conditions of the atmosphere at a certain place and time with reference to temperature, pressure, humidity, wind, and other key parameters such as presence of clouds and the occurrence of thunderstorms or tornadoes. Climate is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities (for instance temperature, precipitation, or frequency of storms) over a period ranging from months to thousands or millions of years. Classically, the period for averaging these variables is 30 years, as defined by the World Meteorological Organization. When speaking about climate change we need to consider not only the average weather and its variability over a certain period, but also its past and future trends. That is, we need to understand if the average weather has changed throughout the past, but also what are the expected increases or decreases of the weather variables in the future.

Both the weather events typical of a certain region, as well as the modification of climate that is happening and is expected to accentuate in the next future because of anthropogenic emissions of greenhouse gases, can constitute threats to seagrasses, especially as they interact with the stressors that affect water quality and sediment stability.

2.5.1. GENERAL EFFECTS ASSOCIATED TO WEATHER EVENTS ON SEAGRASSES

Storms are, and always have been, typical elements of the weather of any region of the globe. Ocean storms, because of the intensity of the wind and drop in atmospheric pressure, can originate large waves and raise sea level near the coast. These effects are known as storm surges, and result in flooding and eroding of coastal habitats, especially in low and flat coastlines. Storm surges have been related to important damaging impacts on seagrass meadows [24,25], especially when these have been affected previously by other stress factors such as scars left by motor vessels [26].

Eolian dust outbreaks are a weather factor that affect some regions of the globe. One of the most impacted regions is the North Atlantic, in a belt between 10 and 25° N that extends from the African coast to the Caribbean. In this region, dust loads in the atmosphere are caused by dust raised by convective disturbances in the arid regions of the Sahara and Sahel regions [27], which are the most important sources of eolian dust worldwide [28].

2.5.2. GENERAL EFFECTS OF CLIMATE CHANGE ON SEAGRASSES

The increase in the concentration of greenhouse gases in the atmosphere (mainly carbon dioxide, but also methane and nitrous oxide), caused by the burning of fossil fuels (oil, coal, or natural gas), by changes in land use (e.g., deforestation, either for agriculture, livestock, domestic firewood or furniture, use of artificial fertilisers), and by several industrial processes (e.g., cement and steel production) is driving three major changes at the global level [23]:

1. The temperature of the atmosphere and of the ocean surface layer is increasing as a direct effect of the greenhouse gases.

2. Sea level is rising due to the thermal expansion of the water and melting of glaciers.

3. Ocean acidity is increasing due to the dissolution of excess carbon dioxide in the water that creates a weak acid (carbonic acid).

Temperature increase and sea level rise have already had or are predicted to have an effect on seagrasses in the near future (a few tens of years) [5]. Temperature increases above the thermal tolerance of seagrass species disrupts photosynthesis and leads to shoot mortality and regional declines of seagrass abundance [29,30]. The global increase in temperature also creates new compatible habitats poleward of the natural distribution range of species, which in seagrasses may lead to the colonisation of higher latitude areas as seagrass propagules (seeds or vegetative fragments) are transported by currents. In fact, a review study of the effect of climate change on marine life showed that in more than 60% of the cases, seagrasses are responding to global warming by changing the seasonality of growth and reproduction, or by expanding their geographic distribution toward the poles [31]. Warmer temperatures may also cause range contractions if temperatures toward the equator rise above physiological limits, particularly in the intertidal zones where seagrasses may be exposed to very high temperatures during daytime low tides. In situ measurements in tropical meadows indicate that high temperatures during daytime low tides reduce available carbon dioxide in the water pools and reduce photosynthesis. These effects are reversed as soon as temperature lowers (or incoming tides flood the area). However, temperatures above 45° C result in leaf damage [32]. The effect of global warming on seagrasses may also be felt indirectly, as herbivores move poleward with increasing temperature simultaneously. Mega-grazers abundant in tropical coastal waters, such as manatees and green turtles, consume large amounts of seagrass biomass and have a strong effect on the trophic structure of seagrass ecosystems [20]. Sea urchins and several fishes also feed on seagrasses and are abundant in the tropics. As temperatures rise and seagrass habitats shift, the possibility exists that these herbivorous species invade the region or increase their abundances, impacting density and extent of seagrass meadows.

The occurrence of heat waves associated with climate change is also a threat to seagrasses. A heatwave is a series of unusually hot days. There is evidence that seagrass meadows can be catastrophically affected by heatwaves. Such is the case of Shark Bay, in Australia, where a marine heatwave drove massive seagrass dieback in 2010 and 2011, with a loss of 1,310 km^2 of seagrass area [33]. The consequences of heatwave go beyond the loss of the seagrasses themselves, since it implies the exposure of the seagrass sediment to oxic conditions, and then the degradation or the organic carbon stock, resulting in emissions of huge amounts of carbon dioxide to the atmosphere [34]. Also, the shrink of the seagrass habitat had impacts in the community in the long-term, since it was observed a decline in the health status of green turtles (C*helonia mydas*) in the 2 years following the heat wave [35]. The frequency and intensity of extreme events such as heatwaves is predicted to increase over the next decades due to climate change.

TABLEAU 2.1. Threats to seagrasses, their effects and environmental consequences.

THREAT	PHYSICAL OR CHEMICAL EFFECT	ECOLOGICAL CONSEQUENCES
Weather events	Storm surges	Fragmentation Habitat shrinkage Smothering Uncovering roots and rhizomes
Weather events	Eolian dust deposition Rain washes terrestrial sediments to the coast Turbidity	Smothering Light limitation Shoot mortality
Climate change	Temperature increase regionally Seawater heat waves on subtidal Air heat waves on intertidal	Shoot mortality Regional declines Poleward shift Local declines Vertical range shifts
Climate change	Sea level rising Erosion and burial Increased frequency of storms	Habitat shrinkage (dependent on coastal zone morphology and occupation)
Boating, anchoring	Scars Erosion	Fragmentation Habitat shrinkage
Epiphytes (filamentous algae, colonial encrusting animals) and endophytes (Oomycete and Labyrinthulomycete parasites)	Leaf loss, seagrass disease and mortality	Fragmentation Generalised seagrass loss, lower density, shorter leaf length, habitat shrinkage
Harvesting, fishing	Trampling Erosion Food web imbalance, removal of predators increases herbivory	Seagrass biomass decrease Marine life biomass and diversity decrease
Tourism	Trampling Erosion Boating Constructions and loss of physical habitat	Seagrass biomass decrease Marine life biomass decrease Habitat shrinkage

THREAT	PHYSICAL OR CHEMICAL EFFECT	ECOLOGICAL CONSEQUENCES
Deforestation	Turbidity Shading Siltation Nutrient loading	Light limitation Decreased growth rates Eutrophication Smothering
Aquaculture farms	Turbidity Shading Siltation Nutrient loading	Light limitation Decreased growth rates Eutrophication Smothering
Agriculture	Turbidity Shading Siltation Nutrient loading	Decreased growth rates Eutrophication Smothering
Piers, harbours and marinas	Habitat changed Scars Erosion Shading	Seagrass loss to construction Habitat shrinkage Decreased growth rates

2.6. SYNERGISTIC AND INTERACTIVE EFFECTS OF DIFFERENT FACTORS

Environmental factors that threaten seagrasses such as light deprivation, physical damage, high nutrient loads and climate change do not happen in isolation. Synergistic effects and interactions between factors on seagrass, either global or local, and between anthropogenic and natural disturbances, could have a larger magnitude and impact than the sum of the isolated pressures [36]. For instance, seagrass meadows tend to occur in sheltered coastlines, which favour the deposition of sediments and the maintenance or spread of the meadows. But these are the areas that are more prone to the deleterious effects of pollution, nutrients excess and siltation derived from terrestrial sources, because currents and waves are slow at dispersing these agents. Temperature increases due to climate change, a global factor, may also interact with excess nutrient loadings, a local threat. Temperature increase has the effect of reducing the solubility of gases in water and, if excess nutrients lead to the development of eutrophic situations, the hypoxic conditions may be aggravated by the decrease in oxygen solubility during heat waves. As another example, the erosional effect of storm surges, a natural disturbance in many regions, may be magnified by the local effect of scars and erosion caused by boating, anchoring, and fishing, which are anthropogenic disturbances, retarding or impeding the recovery of the meadows.

Since the interactions between different threats are common and complex, managers should have a holistic approach to the conservation of seagrasses. No single variable should be considered independently of other existing or potential synergistic factors. Managers need to understand the biology and ecology of seagrasses in general. Additionally, they must be aware of the local and regional factors that might impact the seagrasses in their area, of the global stress factors that may act locally, and of the array of possible interactions among the different factors that might arise in the short, medium and long terms.

2.7. REGIONAL AND LOCAL THREATS TO SEAGRASS MEADOWS IN THE RAMPAO MEMBER COUNTRIES

2.7.1. THREATS TO SEAGRASSES IDENTIFIED THROUGH REGIONAL SURVEYS

According to a recent survey conducted to managers and other regional and local stakeholders from the RAMPAO member countries, aimed at understanding the main regional and local threats, a great majority of respondents believed seagrasses at their regional sites to be threatened. The main threats identified from terrestrial sources centered around habitat destruction through coastal development, and habitat pollution through industrial and soil runoff caused by deforestation. The main threats identified from sea-based sources included common problems such as physical removal or destruction through fishing or boating, as well as sea level rise and ocean acidification. Beach-seine was appointed as the most destructive fishing gear in terms of seagrass removal, followed by trawling, with other regionally used fishing methods (e.g., crab net, shrimp net, hand net, launch net) not deemed as important threats to seagrasses. Impacts of aquaculture plants were assessed as of least concern. Overall, it was largely acknowledged that the region has suffered from both environmental as well as human-induced changes over the last few years or decades.

2.7.2. OBSERVED AND POTENTIAL EFFECTS OF NATURAL AND ANTHROPOGENIC THREATS ON SEAGRASSES IN THE RAMPAO MEMBER COUNTRIES

The seagrass meadows of the RAMPAO countries are subjected to natural and anthropogenic impacts as other meadows elsewhere across the globe. Here we present those impacts and threats that were already identified in the region and others that might occur in the future. The major anthropogenic influences on seagrasses originate in terrestrial habitats, and their reduction requires terrestrial management changes, as such problems cannot be solved exclusively by marine management measures such as MPAs.

2.7.2.1. PHYSICAL IMPACTS

Seagrass meadows in the RAMPAO member countries can be threatened by coastal development and building of new infrastructures, (ports, marinas, piers, urbanisation), boating and anchoring. In the bays around Dakar (Senegal), *Cymodocea nodosa* meadows were observed to be seriously damaged by boat anchoring [37] (Figures 2.3 and 2.4).

Seagrass meadows are also physically impacted by fishing activities (Figure 2.3). Shell harvesting may affect seagrass beds locally (for example, Delta du Saloum in Senegal and Bijagós in Guinea Bissau) and may result in severe fragmentation of the meadows. Along the southern coast of Dakar, large accumulations of seagrass leaves and rhizomes are frequently observed on the beaches, mainly because of coastal fishing activities [37]. Beach seines, widely used in some regions as part of subsistence fishing, seem to be an important threat to seagrasses, at least in some areas [37]. The damage caused by fishing activities seems to be considerable, especially in Senegal, where a large fleet of small-scale fishing boats is anchored close to the shore. These are pushed by the sea breeze, and the long ropes and chains attached to the anchors permanently scrape the seafloor, destroying seagrass beds, corals, and algae. Their impact is so significant that it can sometimes be observed in aerial photographs.

A

B

C

FIGURE 2.3. Pictures showing some of the physical impacts on seagrass meadows in the RAMPAO member countries: A) Bivalve harvesting in Bijagós (Guinea-Bissau), B) fishing nets that contact with the bottom in Unhocomo, Bijagós (Guinea-Bissau), and C) coastal construction that heavily impacted a seagrass meadow in praia de Gamboa (Praia, Santiago, Cabo Verde).
Photos by: E.A. Serrão (A,B), A. Aráujo (C).

FIGURE 2.4. Physical impacts of boats on seagrass meadows: A) Accumulation of *Cymodocea nodosa* leaves and rhizomes on the beach because of the physical impact of boats (pirogas) in Senegal, B) anchor scars on the bottom at Unhocomo, Bijagós (Guinea-Bissau), C) and D) boats anchored on a seagrass meadow at Unhocomozinho, Bijagós (Guinea-Bissau). **Photos by:** A. Araújo (A,B), E.A. Serrão (C,D).

2.7.2.2. WATER QUALITY IMPOVERISHMENT

The effects of water quality impoverishment due to human activities (e.g., industrial and domestic wastes, aquaculture) on seagrass ecosystems of the RAMPAO member countries are not studied. It is however known that they impact seagrass meadows with different levels of intensity, depending on the countries' development stages. The effects of industrial pollution and the increase in dissolved organic matter from untreated sewage, are an issue, at least close to large cities such as Dakar (Senegal) (e.g., Ngor bay, Hann and Bargny), where seagrass meadows occur. Aquaculture-related activities, such as fish meal factories in Nouadhibou (Mauritania), for instance, could also constitute a potential threat to seagrasses, due to the high organic matter loads associated with the production. These may cause anoxia and eventually seagrass loss.

Water quality can also deteriorate due to natural causes (Figure 2.5). The increase in turbidity due to heavy rains in short periods of time and the increase of wind speed and storms occurring in most countries in the RAMPAO member countries may have negative impacts on seagrass meadows. Sediment inputs into seagrass areas from adjacent muddy mangroves or turbid river outflows, increased dust in the vicinity of the Sahara and in the Sahel region (see section 2.7.2.5.), or torrential concentrated rains also cause an increase in the turbidity of the water, reducing the light available for seagrass thus impairing their photosynthetic activity and growth.

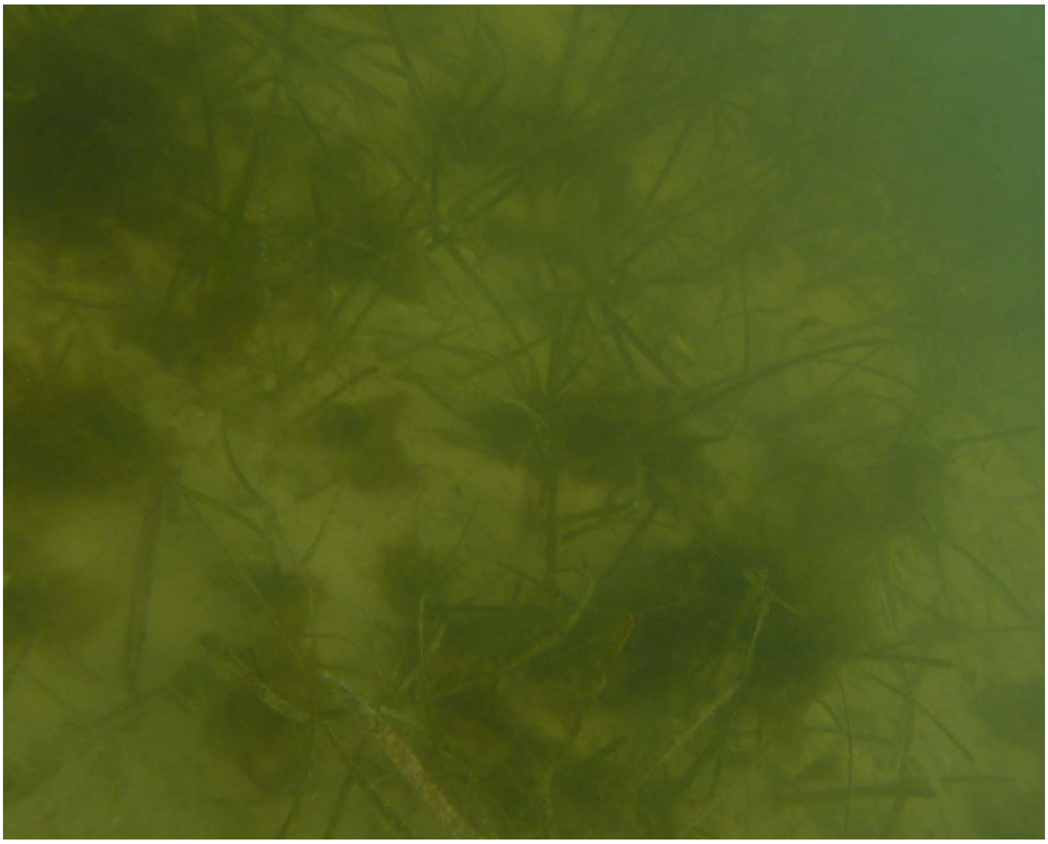

FIGURE 2.5. Seagrasses at 2 m depth in the Banc d'Arguin (Mauritania) in very turbid water.
Photo by: E.A. Serrão.

2.7.2.3. BIOTIC EFFECTS

2.7.2.3.1. OVERGRAZING

In West Africa, including in the RAMPAO member countries, seagrasses are an important part of the diet of green sea turtles (*Chelonia mydas*, [38]) and African manatees (*Trichechus senegalensis* [39,40]). These herbivores can strongly influence the levels of ecosystem services that are provided by the seagrass on which they feed [41]. Overfishing of top predators, such as sharks, has been shown in different parts of the world to negatively impact seagrasses by increasing turtle populations to very large proportions [42]. Although there are no studies reporting this threat in West Africa, predatory sharks are subject to fishing (e.g., Figure 2.6) and it is important to prevent actions that alter the equilibrium of food webs, such as overfishing.

FIGURE 2.6. Juvenile tiger shark (*Galeocerdo cuvier*) caught in Mauritania. Tiger sharks are known predators of turtles, and green turtles are main grazers of seagrasses. **Photo by:** C. de la Hoz Schilling.

2.7.2.3.2. COMPETITION

One particular type of competitor that tends to occupy seagrass habitats are the green macroalgae of the genus *Caulerpa* (e.g., [17]) (Figure 2.7). These can cause habitat alterations that reduce or prevent seagrass recruitment. Fast growing macroalgae like *Caulerpa* can occupy the space more rapidly than seagrasses. However, the consequences for the environment and for their grazers can be distinct, as shown by their different microbial communities, that are healthier in seagrasses than in *Caulerpa*, with disease-causing bacteria like the genera *Vibrio* and *Mycoplasma* found in *Caulerpa* and not in seagrasses (personal observation).

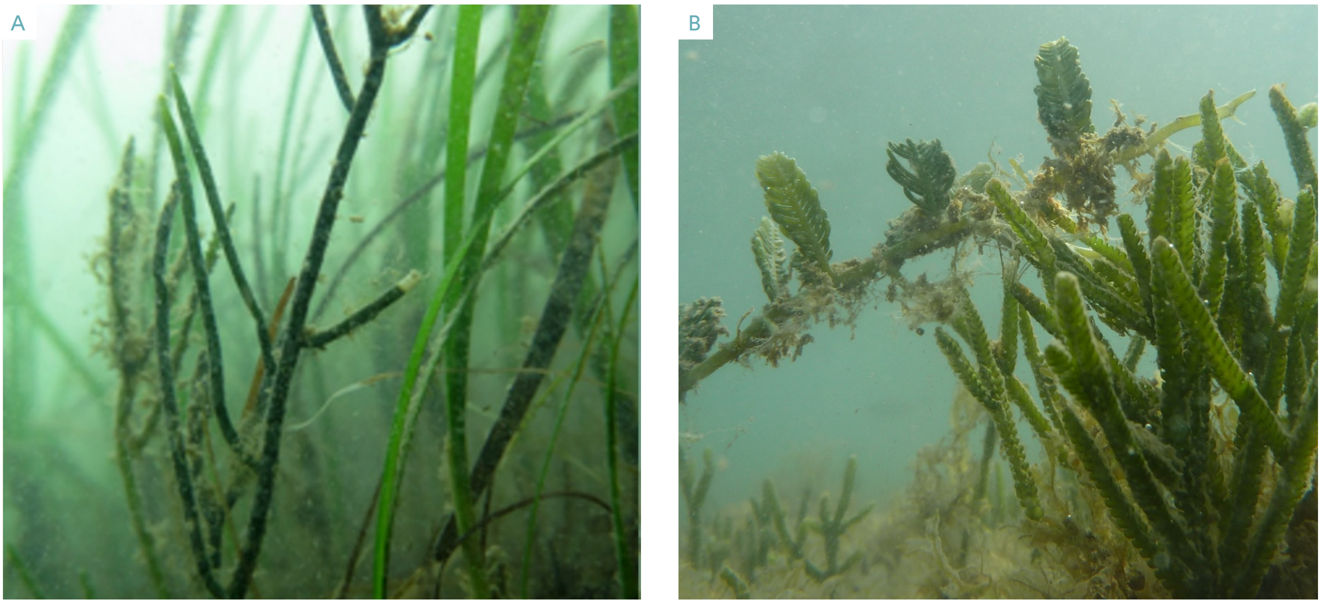

FIGURE 2.7. Three distinct species of macroalgae of the genus *Caulerpa* found in mixed meadows with seagrass in in the RAMPAO member countries: A) Arguin island (Banc d'Arguin, Mauritania), and B) Unhocomo (Bijagós, Guinea-Bissau). **Photos by:** E.A. Serrão.

2.7.2.3.3. EPIPHYTES

One of the major local threats observed in the region are epiphytes, species that grow on top of the leaves of seagrasses. These are also competitors, but rather than occupying the same habitat as the seagrass, they actually live attached to the surface of seagrass leaves. These can be mainly filamentous algae and colonial animals:

A. FILAMENTOUS ALGAE: In some sites and times of the year in West Africa, small filamentous algae cover the seagrass leaves very densely (Figure 2.8), competing with them for light and nutrients. This effect tends to be more serious in locations and times of the year when conditions are hypertrophic, due to excessive nutrients. So, this effect can be correlated with nutrient enrichment factors (see sections 2.7.2.2 on water quality and 2.7.2.5 on dust loads). The subtidal seagrasses tend to be more affected by high loads of epiphytic filamentous algae because the low tide stress exposure experienced by intertidal seagrass is harmful to the survival and development of epiphytic filamentous algae.

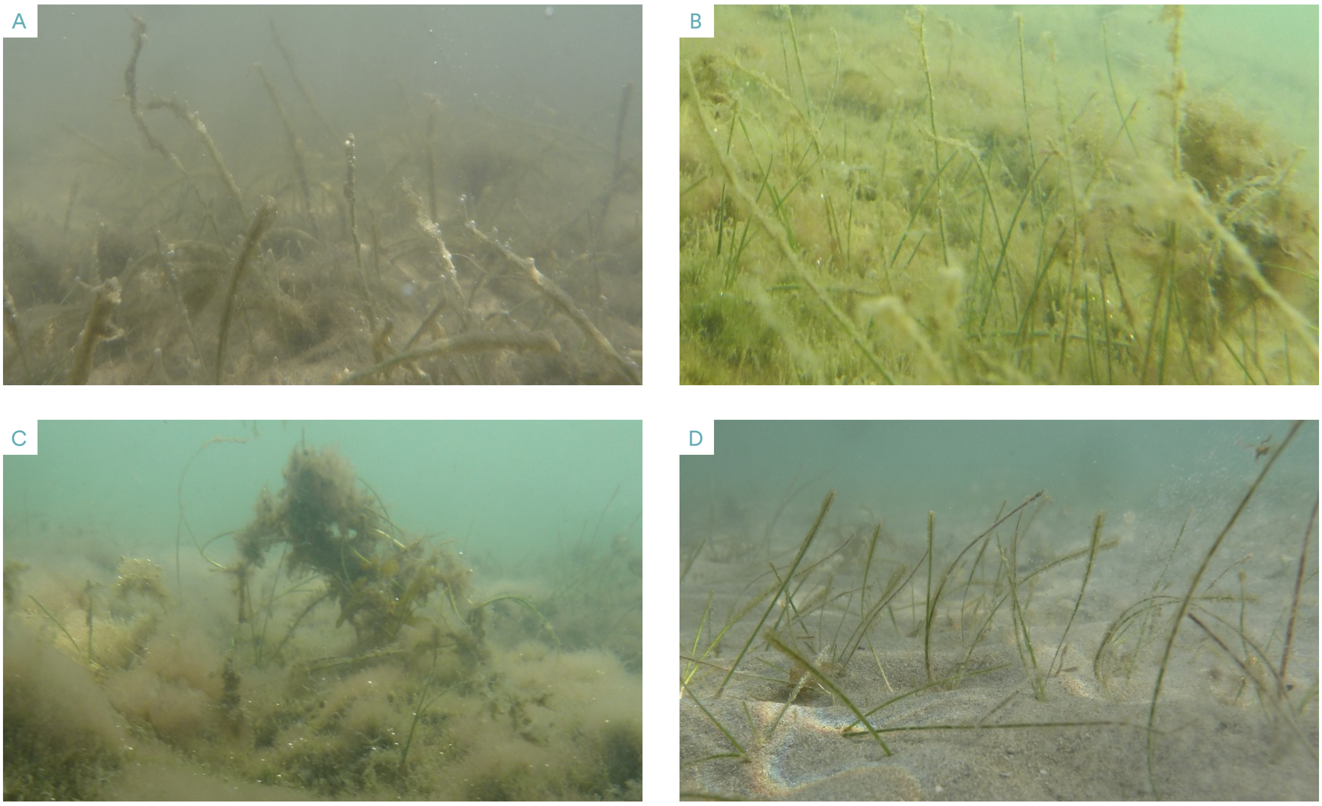

FIGURE 2.8. Filamentous algae epiphytic on *Halodule wrightii* in the Bijagós (Guinea-Bissau), in João Vieira (A), and Unhocomo (B,C), compared to less epiphytised seagrass on the outer open coast at Unhocomo (D). **Photos by:** E.A. Serrão.

B. COLONIAL ANIMALS: Epiphytic animals, such as colonies of encrusting ascidians and bryozoans, are especially common on leaves of *C. nodosa*, given its larger support area to harbour colonies. These can be locally and temporally abundant, causing leaf loss either by lowering the leaf capacity to acquire resources or by the mechanical impact of the weight and drag consequences of being covered by a colonial animal (Figure 2.9).

FIGURE 2.9. Frequent colonial animals epiphytic on *Cymodocea nodosa* in the Banc d'Arguin (Mauritania): A) bryozoans, and B) ascidians. **Photos by:** E.A. Serrão.

2.7.2.3.4. PATHOGENS

Endophytes are species that live inside the cells of the seagrass, in contrast with epiphytes that live on them but outside the cell walls. Endophytic pathogens of the groups Oomycetes and Labyrinthulomycetes can be major causes of seagrass mortality, causing an effect known as "seagrass wasting disease", that has been reported to have caused major mortality and loss of seagrass meadows in Europe. In the Banc d'Arguin more than 50% of leaves may be infected by this pathogen in some sites (personal observation; Figure 2.10).

FIGURE 2.10. Details of seagrass leaves infected by endophytic pathogens in the Banc d'Arguin (Mauritania). **Photos by:** E.A. Serrão.

2.7.2.3.5. POPULATION CONNECTIVITY

Maintaining inter-population connectivity (by dispersal or migration between populations) is essential to prevent populations from becoming too small and isolated to be viable to persist. Seagrasses can only migrate if they are transported (e.g., by herbivores) or by rafting of drifting fragments transported by ocean currents, that can reattach or release seeds after reaching a suitable habitat. Threats that block dispersal between populations leave them functioning isolated with small effective sizes that reduce their resilience to perturbations or to stochastic occasional unfavourable events. Such threats can be the destruction of stepping- stone populations along dispersal corridors, or the loss of vectors for transportation such as grazers.

In this region there is evidence supporting a relevant role of turtles on seagrass dispersal between distant regions, therefore conservation of green turtles is essential for conservation of seagrasses (unpublished data).

2.7.2.4. WEATHER EFFECTS: STORM SURGES

Ocean storms are common in the RAMPAO member countries. Many of the storms in the Atlantic originate as disturbances that form over sub-Saharan Africa from June to October, during the West African Monsoon season [42]. Most of these depressions intensify as they move westward across the Atlantic to the Caribbean and east coast of North America, but some may reach strong intensity not far from the African coast, impacting the weather there. Other depressions may follow less frequent trajectories moving northward and impacting the weather and sea conditions along the coast of Guinea to Mauritania. Sea surges caused by these storms can damage seagrass meadows because they can erode large areas of seagrass habitat, redistribute sediments with the risk of smothering remaining habitat patches, and rupture protective dune cords [47]. The risk of damage is especially strong if storm surges happen to coincide temporally with high tide. A modelling study, based on time series of storm activity in the period 1979-2014 and expected tidal fluctuations, predicts that extreme sea levels with a return period of 100 years (i.e., that may occur once in every 100 years) can reach 1.5 to 5.0 m regionally [44]. Such events (which do not include the effect of sea level rise due to climate change) have the potential to dramatically alter the physiography of shallow sandy coastlines and the seagrass habitat.

2.7.2.5. WEATHER EFFECTS: EOLIAN DUST

Eolian dust originating in the arid regions of the Sahara and Sahel regions is transported to the Atlantic by the Saharan Air Layer and deposited over very wide areas of the North Atlantic, from the NW African coastline to the Caribbean [27,45]. This Saharan dust that reaches the coast is in fact the largest source of dust to the atmosphere in the entire planet [46] and has a major impact on marine ecosystems, which can be positive as nutrient enrichment for primary productivity of oligotrophic regions but can also have drastic negative impacts on the shallow coastal ecosystems. Indeed, data from a coral reef on Cabo Verde indicates a strong correlation of eolian dust deposits with precipitation anomalies in the Sahel region [47]. Strong events of dust deposition, such as those detected in the Banc d'Arguin in 2020 can smother the seagrasses and lead to mortality of the shoots over wide areas. Coincidentally, massive mortality of intertidal seagrass leaves was recorded in seagrass monitoring sites of the Banc d'Arguin during these dust storms in 2020 (Figure 2.11, personal observations).

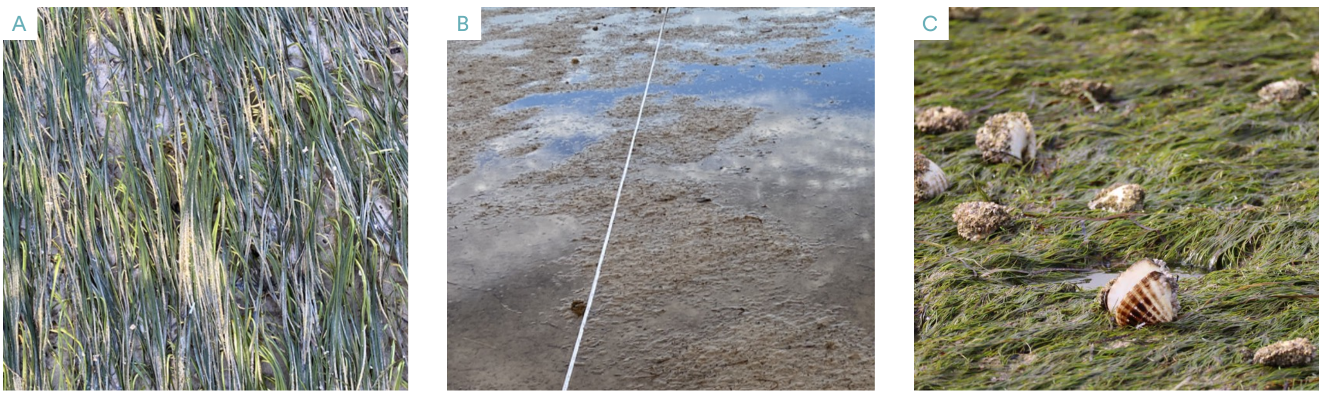

FIGURE 2.11. A region in the Banc d'Arguin (Mauritania) that lost all *Zostera noltei* leaf cover in late 2020 but recovered some months later. **Photos by:** E.A. Serrão (A, B): C. de la Hoz Schilling (C).

2.7.2.5. CLIMATE CHANGE EFFECTS

Frequency and intensity of storms and hurricanes are also expected to increase globally with climate change, although the future trends pertaining to tropical storms in the North Atlantic remain for the moment with low confidence [23]. However, even if these increases do not happen, storms are an important threat to seagrass meadow persistence, as sediment movement caused by hurricane storm surges can uproot the plants, thereby destroying the marine vegetation regionally. Available evidence also indicates that the dust emissions originating from the Sahara and Sahel regions have increased in the 20th century, associated with drought periods in tropical West Africa and land use changes in the Sahel region [28]. This factor could also constitute a hazard to NW African seagrasses, increasing the risk of shading and smothering.

The North-Western African seagrasses covered by this manual are located between 6 and 21 degrees of latitude, in a region that has suffered sea surface temperature increases between 0.1 and 0.2° C per decade [23]. The average seawater temperature trend, however, may not be the best indicator to assess the risk of thermal stress, because global warming is associated with the increase in frequency and magnitude of heatwaves and other extreme weather events. Marine heatwaves have increased in intensity and duration globally during the last decade [48]. Atmospheric heat waves have also increased over North and West Africa [49] and are expected to increase in the future, especially under the most extreme climate change scenarios [50]. These trends may accelerate in the future and threaten the composition and extent of seagrass meadows in the region. The largest seagrass threat of concern derived from climate change in the region is predicted to be the loss of temperate seagrasses that encounter their southern range limits in this region, *Zostera noltei* and *Cymodocea nodosa* [5]. Comparing present distributions with predictions based on species distribution models for all the species in each of the RAMPAO member countries are variable per country but show that in general it is expected that the temperate species *Z. noltei* and *C. nodosa* will tend to disappear in contrast with the tropical species *H. wrightii* (unpublished data). However, in the most extreme scenarios of greenhouse gas emissions even the tropical species could disappear from the lower latitude countries.

According to IPCC [51], sea level rose by 2 mm per year during the last 100 years at the global level and is expected to rise at the rate of 5 mm per year during the 21st century. North-West Africa is one of the most exposed regions to sea level rise, with a World Bank [52] study estimating that 25% of the Senegal shoreline is currently at high risk of erosion and loss, whereas the expectation for 2080 is that 75% will be under high risk of erosion because of sea level rise. A recent study using a probabilistic model [53,54] indicates that sea level at Dakar is expected to rise (with a 95% confidence) 31 and 33 cm by 2050 under IPCC RCP 2.6 and RCP 8.8 scenarios, and 60 and 111 cm by 2100 under the same scenarios. These projections indicate that seagrasses in the region will be severely affected by coastal erosion and habitat compression caused by sea level rise [5]. For instance, projections for The Gambia indicate that all seagrass species may disappear by 2050 even under the most favourable RCP 2.6 scenario, whereas for all other continental countries of the region seagrasses may be severely reduced or disappear by 2100 under the most extreme RCP 8.8 scenario (unpublished data).

In the Banc d'Arguin, seagrass species composition and the shoot densities and leaf lengths of each species show strong variation

(Figure 2.12), according to local conditions that reflect the climatic gradient of this temperate/tropical transition zone (unpublished data). There, seagrass distributions and their population structure show a strong gradient from temperate conditions in the North, where temperate seagrasses prevail, to the warmer conditions in the south, where the tropical species thrives. In a few decades, species distribution models predict that the temperate species could disappear and only the tropical one would remain and even expand. Sea-level rise will also restrict the habitat available for the intertidal species [5].

FIGURE 2.12. In the southernmost region of the Banc d'Arguin (Mauritania), near the range limit of the temperate seagrass *Cymodocea nodosa*, it is frequently observed unhealthy (A) while in the same conditions the co-occurring tropical species in mixed meadows remains green (B). **Photos by:** E.A. Serrão.

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MODULE 3:
POLICY AND MANAGEMENT OPTIONS OF SEAGRASS MEADOWS IN THE RAMPAO MEMBER COUNTRIES

Henrique Queiroga, Carmen B. de los Santos, Mohamed Ahmed Sidi Cheikh, Samir Martins, Duarte Frade, Salomão Bandeira, Pierre Failler, António Araújo, Ester A. Serrão

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3.1. CONSERVATION NEEDS OF SEAGRASS MEADOWS IN THE RAMPAO MEMBER COUNTRIES

The preparation of the present manual was preceded with a questionnaire to environmental managers and other stakeholders of the RAMPAO member countries (Senegal, The Gambia, Sierra Leone, Guinea-Bissau, Mauritania, Guinea, Cabo Verde) aiming to know the perception of them on seagrass governance, management, surveillance, monitoring, and conservation needs in their countries, among other aspects [1]. The questionnaire was conducted on 31 participants. Most respondents work for governmental agencies or departments (77%), have a higher education (23% Bachelors, 48% MScs and 10% PhDs) and use French (77%), English (42%) or Portuguese (26%) as their main language of communication. Here we present the main results of those questionnaires.

3.1.1. PERCEPTION ON PRESENT MEASURES AND ACTIONS ON SEAGRASS GOVERNANCE, MANAGEMENT, SURVEILLANCE, AND MONITORING IN THE RAMPAO MEMBER COUNTRIES

A vast majority of the respondents (72%) stated that the seagrass meadows in their country or region are not legally protected (Figure 3.1). Those that are protected are within protected marine areas (57%). Protection at the species level was rarely mentioned (14%). Respondents gave the name of the seagrass areas that are not legally protected, yet many of them are presently designated as MPAs, indicating that managers and other local stakeholders may not be well informed about protection instruments, measures and regulations already implemented in their regions.

According to 60% of the respondents, seagrasses are managed in their country or region, and they evaluated the management system as moderately efficient (53% of respondents), efficient (27%), or inefficient (20%). About half of the respondents stated that surveillance systems for the protection of seagrass meadows are present in their country or region, consisting of government appointed wardens (92%), local community representatives (58%), NGOs (17%) or others (8%).

Regarding seagrass monitoring programs to survey the status of seagrass meadows, 68 % of the respondents stated that they exist in their country or region, and, that they are conducted by government appointed wardens (88%), local NGOs (29%), local community representatives (12%), or others (12 %).

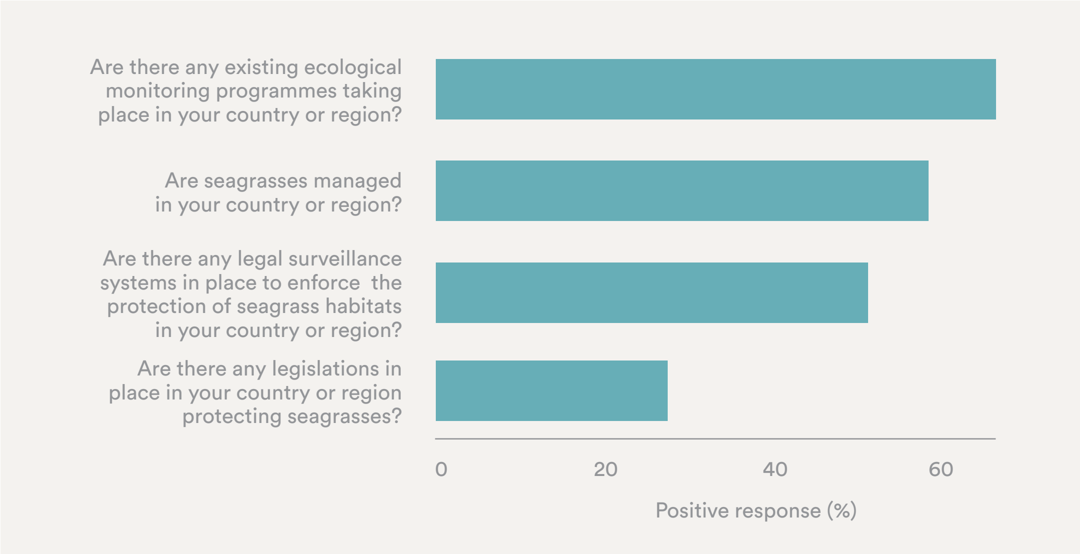

FIGURE 3.1. Perception of the existence of measures and actions on seagrass governance, management, surveillance, and monitoring of seagrasses in the RAMPAO member countries, according to the questionnaire's respondents.

3.1.2. PERCEPTION ON SEAGRASS CONSERVATION NEEDS IN THE RAMPAO COUNTRIES

Responses showed that 80% of the participants think that it is necessary to generate scientific research to support conservation actions in their region, 72% thought that local threats should be identified to better target management actions, 68% that legal protection is necessary, 68% that it is necessary to understand the value of seagrasses in a socio-economic context, 64% that achieving social recognition of the value and importance of seagrasses is needed, and 64 % that it is necessary to obtain and maintain information on the status and condition of seagrasses (Figure 3.2).

Participants believed that efficient conservation actions in their region would be raising public awareness (80%), raising public awareness among politicians and stakeholders (68%), community-based projects (68%), amplification or designation of MPAs (60%), restoration of seagrasses in areas where they are degraded or they disappeared (52%), and payment for ecosystem services (16%) (Figure 3.3).

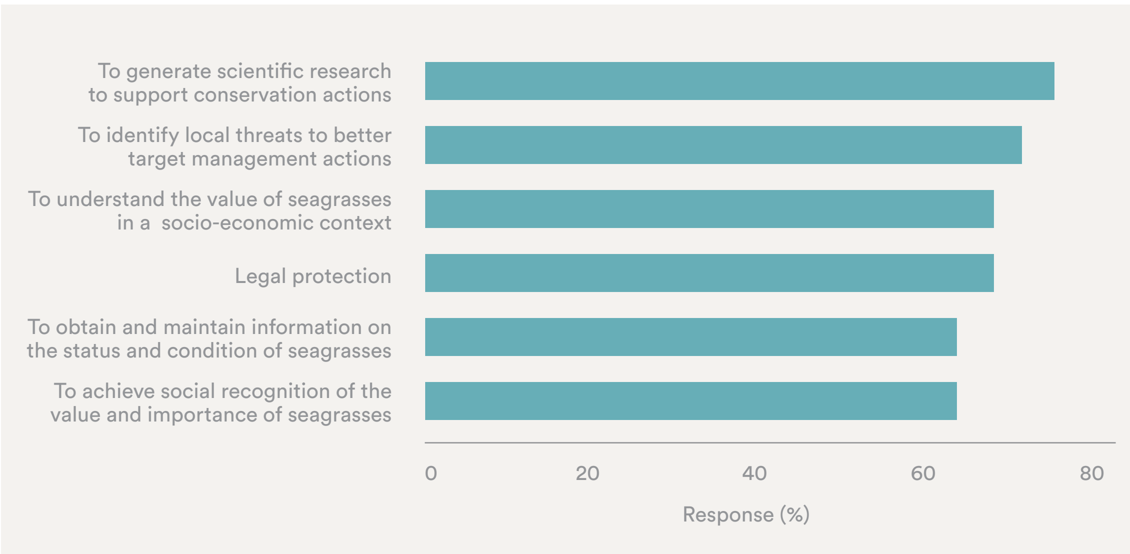

FIGURE 3.2. Evaluation of the seagrass conservation needs to be implemented or reinforced in the RAMPAO member countries, according to the questionnaire's respondents.

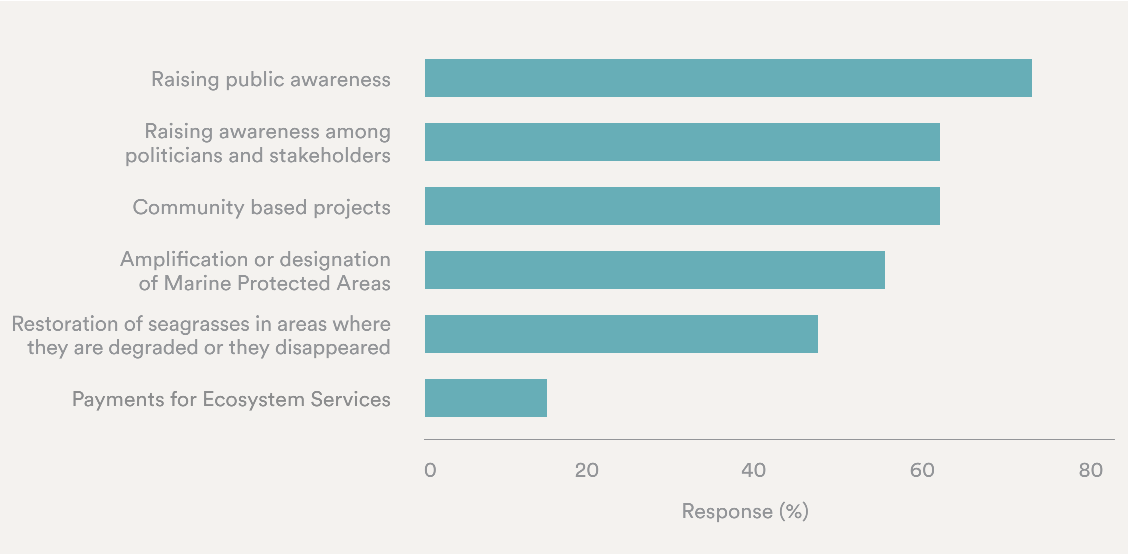

FIGURE 3.3. Evaluation of conservation actions that would be efficient in the RAMPAO member countries to cover the conservation needs, according to the questionnaire's respondents.

3.2. POLICY GUIDELINES

According to the *Out of the Blue* report [2], seagrass ecosystems have not been the priority focus for conservation of coastal habitats around the world, with only 26% of the known area being included within a Marine Protected Area. This level of protection contrasts with that for mangrove, saltmarsh, and warm-water coral ecosystems, where the known area within a MPA exceeds 40%. In the case of the Tropical Atlantic bioregion (where the RAMPAO member countries are located), 32% of the known seagrass area is included within an MPA. Yet, seagrass meadows provide irreplaceable ecological functions that are essential for the health of marine ecosystems and for providing unique benefits for mankind. Many international policy guidelines have been adopted by the international community during the last few decades that provide the conceptual and binding framework for the conservation of ecosystems at the global level, and for the well-being and sustainable development of local communities. These policy guidelines, which are based on concepts that are widely accepted by scientists and managers are summarised in this section, highlighting their relevance for the conservation of seagrasses, starting first with general concepts on management and conservation, and proceeding then to policy instruments (Table 3.1).

TABLE 3.1. Outline of the major concepts and international agreements relevant for seagrass conservation. IUCN: International Union for the Conservation of Nature; UN: United Nations; UNESCO-IOC: Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation. Date of adoption of the policy instrument is given.

AGREEMENT, DECISION, OR SEMINAL DOCUMENT	ORGANISATION	DATE	MAIN OBJECTIVE OR CONCEPT AS IT RELATES TO SEAGRASSES
NATURE CONSERVATION CONCEPT	IUCN	1980	"[...] the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations".
SUSTAINABLE DEVELOPMENT CONCEPT	IUCN	1980	"[...] the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations."
PRECAUTIONARY APPROACH CONCEPT	UN	1992	"[...] in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."
AICHI BIODIVERSITY TARGETS	UN	2010	**Strategic Goal A:** Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society. **Strategic Goal B:** Reduce the direct pressures on biodiversity and promote sustainable use. **Strategic Goal C:** Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity. **Strategic Goal D:** Enhance the benefits to all from biodiversity and ecosystem services. **Strategic Goal E:** Enhance implementation through participatory planning, knowledge management and capacity building. **Relevant indicator:** "[...] by 2020, at least 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes".

TABLE 3.1. Continued

AGREEMENT, DECISION, OR SEMINAL DOCU-MENT	ORGANISATION	DATE	MAIN OBJECTIVE OR CONCEPT AS IT RELATES TO SEAGRASSES
2030 SUSTAINABLE DEVELOPMENT AGENDA	UN	2015	"a plan of action for people, planet and prosperity". **SDG 14:** "Conserve and sustainably use the oceans, seas and marine resources for sustainable development". **SDG 13:** "Take urgent action to combat climate change and its impacts".
POST-2020 GLOBAL BIODIVERSITY FRAMEWORK	UN - Convention on Biological Diversity	2022	2050 Vision of "Living in harmony with nature".
PARIS AGREEMENT	UN	2015	"[...] to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change; (b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and (c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development."
NATIONALLY DETERMINED CONTRIBUTIONS	UN	2015	"[...] to undertake rapid reductions thereafter in accordance with best avail-able science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable devel-opment and efforts to eradicate poverty."
SENDAI FRAMEWORK FOR DISASTER RISK REDUCTION 2015-2030	UN	2015	"The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental as-sets of persons, businesses, communities and countries."

AGREEMENT, DECISION, OR SEMINAL DOCU-MENT	ORGANISATION	DATE	MAIN OBJECTIVE OR CONCEPT AS IT RELATES TO SEAGRASSES
RAMSAR CONVENTION	The Contracting Parties to the Convention	1971	“The conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world.”
UNITED NATIONS DECADE ON ECO-SYSTEM RESTORATION 2021–2030	UN	2019	“Ecosystem restoration means assisting in the recovery of ecosystems that have been degraded or destroyed, as well as conserving the ecosystems that are still intact.”
UNITED NATIONS DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT 2021–2030	IOC-UNESCO	2017	“Towards the ocean we need for the future we want”, “with the following preliminary objectives: (i) stimulate international cooperation regarding marine science requirements needed to support implementation of the 2030 Agenda; (ii) understand the impacts of cumulative stressors and seek sus-tainable solutions for sustaining benefits from the ocean; (iii) share knowledge and enhance interdisciplinary marine research capacities leading to benefits for all Member States, particularly for SIDS and Least Developed Countries (LDC); (iv) gain a better quantitative knowledge of ocean dynam-ics, ecosystems and their contribution to society, through the whole ocean column, from the surface to the bottom, and from the perspective of both natural and anthropogenic forcings; (v) complete the map of the ocean floor and its resources to support their sustainable management”.

3.2.1. NATURE CONSERVATION CONCEPT

According to the International Union for the Conservation of Nature [3], Nature Conservation is “the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations”. Another definition states that conservation is “the human intervention in the dynamic processes which determine the composition of plant and animal communities, so as to maintain a particular desired pattern or series of processes” [4]. Conservation therefore implies active action on the ecosystem, either to proactively prohibit certain activities that might cause excessive exploitation of resources and damage, or to minimise the damage by reducing the intensity of these activities or by applying mitigation measures. Another critical aspect of conservation, very well expressed in IUCN’s definition, is that conservation of nature must have in mind the future functioning of ecosystems in order to sustainably support mankind in the long-term.

3.2.2. THE SUSTAINABLE DEVELOPMENT CONCEPT

The Sustainable Development concept was formalised in a report of a series of meetings of the World Commission on Environment and Development, which were convened by the United Nations between 1983 and 1987: Our Common Feature [5]. This report is also known as the Brundtland Report, since it was coordinated by Gro Brundtland, a former prime minister of Norway. The report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The report recognized that human development, in the form of poverty reduction and wealth distribution, is crucial to formulate strategies for environmental conservation, but also that there are limits to economic growth that are imposed by the environment. Therefore, there is a need to balance the economy with ecology.

3.2.3. THE PRECAUTIONARY PRINCIPLE CONCEPT

The Precautionary Principle concept was defined in the Rio Declaration on Environment and Development [6], one of the conclusions of the United Nations Conference on Environment and Development. The Declaration states that "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature" and that, "in order to protect the environment, the precautionary principle shall be widely applied by States according to their capabilities. Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Therefore, if managers are not sure if a certain activity is harmful for the environment, then it is better to err on the negative side and not allow such activity. Additionally, if any allowed activity damages the environment, then it should be the promoter of such activity to bear the cost of applying mitigating measures to reduce the harmful impact.

3.2.4. THE AICHI BIODIVERSITY TARGETS AND THE POST-2020 GLOBAL BIODIVERSITY FRAMEWORK

The Aichi Biodiversity Targets were adopted at the COP 10 that met in Aichi, Japan, in 2010, to continue the conservation efforts initiated by the Convention on Biological Diversity. The parties agreed on a Strategic Plan for Biodiversity 2011-2020 [7] that included five Strategic Goals, all of which are directly relevant for the conservation of seagrasses in the RAMPAO member countries. These goals are:

STRATEGIC GOAL A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society.

STRATEGIC GOAL B: Reduce the direct pressures on biodiversity and promote sustainable use.

STRATEGIC GOAL C: To improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity.

STRATEGIC GOAL D: Enhance the benefits to all from biodiversity and ecosystem services.

STRATEGIC GOAL E: Enhance implementation through participatory planning, knowledge management and capacity building.

The Strategic Plan for Biodiversity advised on an implementation plan to be adopted by the signatory partners in each country, setting several explicit targets. Among these, one of the most challenging, and one that would be a major step forward in marine conservation, is that, by 2020, "at least 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services", should be "conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes".

This Aichi target has not been met in any of the RAMPAO member countries [8] nor globally [9]. Recognizing that many of the Aichi Targets have not been met, a Working Group is tasked with advancing preparations for the development of the post-2020 global biodiversity framework. This process is expected to lead to the adoption of a post-2020 global biodiversity framework during the second phase of the UN Biodiversity Conference in 2022, in Kunming, China.

3.2.5. THE 2030 SUSTAINABLE DEVELOPMENT AGENDA AND THE SUSTAINABLE DEVELOPMENT GOALS

The Sustainable Development Agenda that was agreed by the United Nations [11] is a "plan of action for people, planet and prosperity" that should be accomplished by 2030. This Agenda is operationalized through 17 Sustainable Development Goals (SDGs; Figure 3.4), each one comprising several targets and respective indicators. SDS 14 covers Life Below Water and intends to "Conserve and sustainably use the oceans, seas and marine resources for sustainable development".

The most relevant targets for the conservation of seagrasses are Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution. Target 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans. Target 14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported, and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time possible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics. Target 14.5: By 2020, conserve at least 10 percent of coastal and marine areas, consistent with national and international law and based on the best available scientific information. Most of these targets have not been accomplished during the indicative time frame, either in the RAMPAO member countries or globally, but there is a general consensus that they should be pursued continually.

FIGURE 3.4. The 17 Sustainable Development Goals.

3.2.6. THE PARIS AGREEMENT AND THE NATIONALLY DETERMINED CONTRIBUTIONS FOR GREENHOUSE GASES REDUCTION

The Paris Agreement is a legally binding international treaty on climate change adopted in 2015 by 196 Parties at COP 21 in Paris [11]. Its goal is to limit global warming to well below 2, preferably 1.5 degrees Celsius, compared to pre-industrial levels. To achieve this long-term goal, countries aim to achieve a climate neutral world by 2050. A key element to achieve the global targets set out in the Paris Agreement is the Nationally Determined Contributions (NDC), in which each country provides a self-determined climate action plan to reduce national emissions and adapt to the impacts of climate change. NDCs include climate-related targets for greenhouse gas emission reductions, policies, and measures that governments aim to implement in response to climate change. The Paris Agreement requires each country to prepare, communicate and update every five years the NDCs that it intends to achieve. The countries shall adopt national mitigation measures in order to achieve the objectives of these contributions.

Seagrass meadows are nature-based solutions for climate change mitigation and adaptation (see module 1), so the protection and restoration of these ecosystems can be included in the NCDs (Box 3.1), in particular as part of the national greenhouse gas inventories, following IPCC guidelines [12], acting as a strategy to cut emissions [13,14]. Yet, the pairing of ocean conservation and climate action in the NDCs is still deficient in terms of specific ocean actions as climate solutions [15]. In fact, less than 20% of the parties with coastal blue carbon ecosystems recognise them as carbon sinks in their NDCs [15]. In 2019, ten countries had explicitly included seagrass meadows in their NDCs, either for climate adaptation, mitigation, or both [16]. However, measurable targets in the NDCs of these countries regarding seagrass ecosystems are mostly lacking [16].

The seven countries of the seven RAMPAO countries are signatories of the Paris Agreement (Table 3.2). Among them, both Cabo Verde and Sierra Leone include seagrasses in their NDC (Box 3.1). The Gambia is another country to highlight in the region, since it was once acknowledged as the only country to be on course to achieve the 1.5-degree climate target, yet recently it was evaluated to get off track [17].

TABLE 3.2. Details of the participation of the RAMPAO member countries in the Paris Agreement and the status of the Nationally Determined Contributions (NDCs). NDCs can have different status: first (if it is the one submitted for the first time), archived (if it is archived because a new update was submitted), and update (being the last update then the active one).

COUNTRY	% OF GHGS FOR RATIFICATION	DATE OF SIGNATURE	DATE OF RATIFICATION	DATE OF ENTRY INTO FORCE	NDC STATUS
SENEGAL	0.05%	22 April 2016	21 September 2016	04 November 2016	29/12/2020 (first)
THE GAMBIA	0.05%	26 April 2016	7 November 2016	7 December 2016	07/11/2016 (archived) 12/09/2021 (update)
SIERRA LEONE	0.04%	22 September 2016	01 November 2016	01 December 2016	01/11/2016 (archived) 31/07/2021 (update)
GUINEA-BISSAU	0.02%	22 April 2016	22 October 2018	21 November 2018	22/10/2018 (archived) 12/10/2021 (update)
MAURITANIA	0.02%	22 April 2016	27 February 2017	29 March 2017	27/02/2017 (archived) 12/10/2021 (update)
GUINEA	0.01%	22 April 2016	21 September 2016	4 November 2016	21/09/2016 (archived) 28/07/2021 (update)
CABO VERDE	< 0.00%	22 April 2016	21 September 2017	21 October 2017	21/09/2017 (archived) 02/04/2021 (update)

BOX 3.1.

CASE-STUDY:
INTEGRATION OF SEAGRASS MEADOWS IN NATIONALLY DETERMINED CONTRIBUTIONS (NDCS) OF CABO VERDE.

Cabo Verde became the first country of the RAMPAO member countries to integrate seagrass meadows in its NDC in 2021. Specific measures for wetlands, and therefore seagrasses, included in the NDC are [22]:

MITIGATION CONTRIBUTION #5: FOSTERING THE NATURAL SINK FUNCTION OF ECOSYSTEMS (PAGE 30)

- Explore ocean-based natural carbon sequestration;
- Improve the collection and management of wetland data, update current wetlands inventory, and improve access and sharing of data and methodologies;
- Integrate wetlands information, including data and plans on conservation and restoration, into municipal development plans;

ADAPTATION CONTRIBUTION #5: EXTENDING MARINE PROTECTED AREAS (PAGE 39)

- Use knowledge and spatial analysis tools to identify carbon sequestration potential and optimal locations for marine protected areas;

ADAPTATION CONTRIBUTION #6: DEFENDING MARINE RESOURCES AND COASTAL ZONES (PAGE 40)

- Implement coastal protection in each island, giving priority to seagrasses, by using "nature-, ecosystem- and landscape-based solutions" combined with (or substituted for) grey infrastructure, taking advantage of carbon sequestration among other adaptive benefits;
- Develop an inventory of seagrass meadows, a protection strategy and a comprehensive seagrass conservation regime by 2024, providing continuity to the existing seagrass inventory project currently developed in Santiago and Maio.
- Enhancement of knowledge expertise in this area within the Cabo Verde scientific and university community, as well as identify and support research in collaboration with international research centres on marine biology, including seagrass;

ADAPTATION CONTRIBUTION #7: USING SPATIAL PLANNING AS AN ALLY IN CLIMATE CHANGE ADAPTATION AND MITIGATION (PAGE 42)

- Identify areas with greatest potential for mitigation and adaptation and climate risk hotspots, including wetland protection;
- Conserve and protect marine biodiversity, including seagrass areas, thus adapting the planning of this area to climate change, including the prediction of sea level rise.

3.2.7. THE SENDAI FRAMEWORK FOR DISASTER RISK REDUCTION

The Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted at the Third UN World Conference in Sendai, Japan, on March 18, 2015 [18]. The Sendai Framework emphasises that, more than managing disasters after their occurrence, regional, national, and local authorities should act in order to prevent and reduce the risk of disaster occurrence in the future and develop measures to prevent and mitigate these hazards should they occur. Disaster risk reduction is a complex task requiring a multi-hazard approach, where climate change and its variability are critical factors implying appropriate environmental management.

Conservation of seagrass meadows is very relevant in this regard, as they have a known effect in attenuating the risk of coastal erosion and inundation during storm surges and sea-level rise caused by global warming. This function relies on the seagrass canopy height, density and meadow area, and its interaction with the water column, currents, and waves [19]. However, the role of seagrasses in coastal protection depends on the physical conditions of the location and the seagrass properties, meaning that not all seagrasses have the same ability to protect the shoreline from risks [20]. In the RAMPAO member countries, the most common seagrass species, *Halodule wrightii*, has lower potential for disaster reduction due to its smaller size among all the species (see [21] for comparisons of size and density across species). In contrast, the intertidal species *Zostera noltei* has stronger potential for disaster reduction due to its high density and *Cymodocea nodosa* also due to its large leaves. In any case they all can be conserved with the aim of contributing to some extent to disaster reduction.

3.2.8. THE RAMSAR CONVENTION ON WETLANDS OF INTERNATIONAL IMPORTANCE ESPECIALLY AS WATERFOWL HABITAT

The Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat was adopted in the city of Ramsar, Iran, in 1971 and came into force in 1975. The Ramsar Convention [23] is an intergovernmental treaty that aims for "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world". The Contracting Parties of the Ramsar Convention agreed on "three pillars", whereby they commit to: work towards the wise use of all their wetlands; designate suitable wetlands for the list of Wetlands of International Importance (the "Ramsar List") and ensure their effective management; and cooperate internationally on transboundary wetlands, shared wetland systems and shared species.

The seven RAMPAO member countries are contracting parties of the RAMSAR convention, with entry dates that ranged from 1977 to 2005: Senegal 1977, Mauritania 1983, Guinea-Bissau 1990, Guinea 1993, The Gambia 1997, Sierra Leone 2000, and Cabo Verde 2005. There are in total 40 RAMSAR sites designated in the RAMPAO member countries: 8 sites in Senegal, 3 sites in The Gambia, 1 site in Sierra Leone, 4 sites in Guinea-Bissau, 4 sites in Mauritania, 16 sites in Guinea, and 4 sites in Cabo Verde. Among these sites, seagrasses are known to be present in 7 of them and need to be verified in 4 sites (Table 3.3).

TABLE 3.3. Ramsar sites in the RAMPAO member countries in which seagrasses presence is confirmed or needs to be confirmed. Year of site designation is given in brackets.

COUNTRY	SEAGRASS PRESENCE	RAMSAR SITE NAME AND YEAR OF DESIGNATION
SENEGAL	Confirmed	Parc National du Delta du Saloum (1984)
	To be confirmed	Réserve Naturelle Communautaire de Palmarin (2017)
	To be confirmed	Réserve Naturelle d'Intérêt Communautaire de la Somone (1917)
GUINEA-BISSAU	Confirmed	Archipel Bolama-Bijagós (2014)
THE GAMBIA	Confirmed	Niumi National Park (2008)
MAURITANIA	Confirmed	Parc National du Banc d'Arguin (1982)
GUINEA	Confirmed	Iles Tristao (1992)
	Confirmed	Rio Pongo (1992)
	Confirmed	Rio Kapatchez (1992)
	Confirmed	Ile Blanche (1993)
CABO VERDE	To be confirmed	Lagoa de Rabil (2005)*
	Confirmed	Lagoa de Pedra Badejo (2005)
	To be confirmed	Salinas de Porto Inglês (2013)
	Confirmed	Salinas de Pedra de Lume (2018)

* Seagrass is probably extinct at this site.

3.2.9. THE UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION (2021–2030) AND THE UNITED NATIONS DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT (2021–2030)

According to the UN Decade on Ecosystem Restoration [24], "ecosystem restoration means assisting in the recovery of ecosystems that have been degraded or destroyed, as well as conserving the ecosystems that are still intact".

Global loss of seagrass area was estimated to be 7% per year by the end of the twentieth century [25]. Being remarkable coastal habitats providing key coastal ecosystem services to people and nature [26], seagrasses should be central in the global restoration agenda. To preserve these benefits, it is necessary to reduce or eliminate pressure on seagrass ecosystems, in order to enable natural recovery, or take positive actions, in order to actively restore the habitat and the associated community (see section 3.3.6).

The vision of the United Nations Decade of Ocean Science for Sustainable Development is the "science we need for the ocean we want" [27]. The Ocean Decade is a convening framework for diverse stakeholders to co-design and co-deliver solution-oriented research needed for a well-functioning ocean in support of the 2030 Agenda, coordinated by UNESCO's Intergovernmental Oceanographic Commission, the United Nations body responsible for supporting global ocean science and services. Contributing to capacity development, ocean literacy and the removal of barriers to full gender, generational, and geographic diversity are essential elements of the Ocean Decade, which are key aspects to implement Sustainable Development Goal 14.

3.3. ENVIRONMENTAL MANAGEMENT STRATEGIES

Environmental management consists of environmental initiatives to address environmental issues that are affecting a specific region or location, or even at the global level. The aim of encouraging environmental management initiatives is to prevent environmental degradation and biodiversity loss, and to ensure that ecosystems are kept in a healthy state for generations to come.

In the RAMPAO member countries, effective management is required at regional and local scales to protect seagrass meadows and promote their resilience at the long-term basis. In this section, we present general management instruments that could be applied in the region.

Many of the management options presented here contribute to increasing the resilience of seagrass meadows. In ecology, resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly. Thus, improving the resilience of seagrass meadows should be in the central agenda of environmental managers, and should be science-based [28].

3.3.1. ENVIRONMENTAL IMPACT ASSESSMENT

Human development and activities can have negative impacts on ecosystems, putting at risk the biodiversity and the ecosystem services they provide, eventually having negative consequences for people and human wellbeing. Human activities may be preceded by the proposal of projects by private or public entities. In this sense, Environmental Impact Assessment (EIA) in a management strategy that can be defined as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" [29]. As defined by the International Association for Impact Assessment (IAIA), the purpose of the EIAs are:

• To ensure that environmental considerations are explicitly addressed and incorporated into the development decision making process;

• To anticipate and avoid, minimise or offset the adverse significant biophysical, social and other relevant effects of development proposals;

• To protect the productivity and capacity of natural systems and the ecological processes which maintain their functions; and

• To promote development that is sustainable and optimises resource use and management opportunities.

Overall, EIA is a key instrument for managers to plan development which is "compatible with the conservation and sustainable use of biodiversity and ecosystems" [30]. The International Best Practice Principles for Biodiversity and Ecosystem Services in Impact Assessment [30] list 9 principles (Box 3.2) that can be applied to all stages and types of impact assessment, and that aim to support efforts to achieve sustainable outcomes for biodiversity, ecosystems, and the services they provide.

These practices should be applied in the RAMPAO member countries for a critical assessment of the consequences for seagrasses and their services before any coastal management decisions such as deforestation and coastal construction.

3.3.2. INTEGRATED COASTAL ZONE MANAGEMENT

Integrated Coastal Zone Management (ICZM) is a "dynamic, multidisciplinary, and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics. 'Integrated' in ICZM refers to the integration of objectives and also to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space" [31].

In the RAMPAO member countries it is essential that the coastal zone management integrates the consideration of marine ecosystem health, and seagrasses in particular, in the planning of management of terrestrial areas, because terrestrial sediment and nutrient runoff from land is a major cause of seagrass loss:

• Construction should be regulated and there should be no deforestation in the coastal zone where seagrasses are present because the sediments will be eroded to the sea and will bury the seagrasses and destroy them and reduce the essential light thereby lowering the depth range of the habitat.

• Outlets or runoff rich in nutrients should be avoided and strongly regulated near the seagrass sites because the high nutrients will promote growth of phytoplankton and filamentous algae that will compete with seagrasses for light.

BOX 3.2.

INTERNATIONAL BEST PRACTICE PRINCIPLES FOR BIODIVERSITY AND ECOSYSTEM SERVICES IN IMPACT ASSESSMENT (IA).

PRINCIPLE 1: Use IA to maintain and enhance biodiversity, with a goal of no net loss (NNL) outcomes as a minimum and an aspiration for net gain (NG).

PRINCIPLE 2: Integrate biodiversity and ecosystem services in development planning and IA from the earliest possible stages.

PRINCIPLE 3: Take an ecosystem perspective to framing of IA, allowing the significance of ecological changes to be assessed at appropriate spatial and temporal scales.

PRINCIPLE 4: Address the rights, values, dependencies, and benefits that people derive from biodiversity and ecosystems in IA, taking a participatory and transparent approach throughout.

PRINCIPLE 5: Design IA baseline surveys and assessments to generate the information and understanding needed to support evidence-based approaches to assessment of impacts on biodiversity and ecosystems.

PRINCIPLE 6: Ensure that implications for biodiversity and ecosystem services are fully addressed using transparent, evidence-based approaches and appropriate expertise.

PRINCIPLE 7: Apply the mitigation hierarchy (MH), with emphasis on preventive measures and including offsets for residual impacts on biodiversity, ecosystems, and the services they provide.

PRINCIPLE 8: Use precautionary approaches where the consequences of development for biodiversity and ecosystem services are unclear and there is insufficient information to exclude the possibility of unacceptable, irreversible, or non-offsetable impacts.

PRINCIPLE 9: Establish robust adaptive management systems to ensure that IA commitments will be met, mitigation measures will be implemented and that no net loss/net gain (NNL/NG) outcomes can be demonstrated through monitoring, auditing, and reporting.

3.3.3. MARINE SPATIAL PLANNING

Marine Spatial Planning (MSP) is a "public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process" [32]. MSP aims at minimising conflicts between human activities while ensuring the well-functioning and resilience of marine ecosystems. Examples of MSP are the allocation of space for particular uses (and exclusion of uses) or specific conditions for the use of sea areas or resources. MSP is commonly done by identifying and mapping all marine issues and activities that occur in the area of interest.

MSP can be applied to seagrass areas to understand which are the activities that may be interfering with the seagrass condition. This activity would give spatial guidance to properly manage seagrass areas and their activities occurring on them (e.g., fishing activities).

In the RAMPAO member countries, MSP should be applied to define that in seagrass areas bottom contacting activities should be strongly regulated and minimised where possible. This includes mooring or anchoring of boats, fishing practices with nets that touch the bottom, and bivalve harvesting with digging or dredging techniques. If these activities cannot be eradicated because of social or economic reasons, then environmental education programmes should be organised by local authorities to explain the damage done to seagrasses and to explore less impacting alternative practices. Active surveillance of these activities is mandatory, either to alert users of the seagrass habitat of the damage caused and recruit them to the environmental education programmes or to apply fines to those unwilling to comply with the regulations set in place. Furthermore, MSP should be used to improve the land-sea interactions and more particularly the pollution management and the human pressures. For the NDC implementation, MSP is also required to monitor the evolution of surfaces of seagrasses and their ecological condition to estimate their contribution to the mitigation objectives.

3.3.4. ECOSYSTEM APPROACH TO FISHERIES

The Ecosystem Approach to Fisheries (EAF) is a concept adopted by the Food and Agriculture Organisation [33] that recognizes that fisheries management will not be successful if ecosystem integrity is not maintained. According to this approach, it is not sufficient to manage single species separately from the other components of the ecosystem. The EAF can be defined as "an extension of conventional fisheries management recognizing more explicitly the interdependence between human well-being and ecosystem health and the need to maintain ecosystems productivity for present and future generations, e.g., conserving critical habitats, reducing pollution and degradation, minimising waste, protecting endangered species" [34]. This concept is similar to the Ecosystem-Based Fishery Management [35], although the latter does not explicitly address the societal implications and dependencies of ecosystem management.

The EAF is especially relevant for the conservation of seagrasses because these are critical habitats for the completion of the life cycle of many marine species of commercial importance [36], acting as nurseries where the juvenile stages of many of these species find good conditions for food, shelter, and growth

[37]). Local populations and governing bodies should therefore adopt a precautionary approach to these ecosystems, balancing the direct short-term benefits that may be derived from exploitative practices that, in many instances, produce direct damage to seagrasses, with more long-term benefits that are obtained from healthy fish and shellfish stocks.

In the RAMPAO member countries, the seagrasses are essential habitat for species of commercial interest, which survive until capture size in larger numbers then if they were in the absence of seagrass, and upon which much marine biodiversity depends for food and shelter [38]. For instance, in the Banc d'Arguin, Mauritania, artisanal fisheries targeting meagres, mullets, soles and smooth-hounds contributed to an added value of 1 million euros per year over the period 2006–2017, while estimates based on a bio-economic model predict that the nursery function of the PNBA contributes to 15% of the fisheries in the Mauritanian Exclusive Economic Zone, representing an added value creation of 71 million euros per year [38]. The benefits of the conservation of seagrasses extend therefore much beyond the direct protection of the seagrass habitat and must be considered as protecting all these functional ecosystem benefits.

3.3.5. LEGAL FRAMEWORKS FOR THE PROTECTION AND DESIGNATION OF MPAS IN THE RAMPAO NETWORK

The identification of areas with seagrass meadows is relatively recent in most of the RAMPAO in the RAMPAO network. Although most seagrass habitats in the region are in fact located inside MPAs, their management plans do not include targeted measures for the protection of these habitats, such as zoning that might restrict damaging activities, nor plans for rehabilitation. Additionally, seagrass beds are often considered in general laws protecting coastal and marine habitats, such as environmental or fisheries codes, effectively diluting the efficiency of these codes to protect and restore seagrasses. This situation is not unique to countries in the RAMPAO network but affects seagrass conservation efforts across the globe.

In the RAMPAO member countries, the first large-scale formal identification and mapping of seagrass habitats was done in 2010, under a project funded by MAVA related to the evaluation of the ecosystem services of MPA (6 ecosystems including seagrasses) versus non protected areas [39]. According to the ResilienSea project [40], several pilot sites benefit from protection frameworks that were originally devised for the conservation of particular ecosystems, habitats, and species such as marine turtles, fishes or birds. Phase II of the ResilienSea project focuses on the implementation of appropriate monitoring techniques and management measures for the protection of seagrass pilot sites, through the production of knowledge, communication, and advocacy, in order to lead to actions for the conservation of seagrass beds in the 7 target countries. RAMPAO is responsible for carrying out Strategy 3 (Strengthening site management and protection) in the pilot sites, through the existing MPA network. This section provides information on the protection status of seagrass meadows in the pilot sites, which is taken from the ResilienSea project documents that were presented at the November 2021 steering committee meeting in The Gambia [40].

A) CABO VERDE:

Gamboa (Praia, Santiago Island). The Gamboa site in Praia is already threatened by the tourism industry due to the construction of a hotel complex and a bridge, in addition to its proximity to port activities. The site has no binding legal status for the protection of seagrass beds, despite containing the only population of *Halodule wrightii* known for Cabo Verde [41]. However, it is envisaged that its protection will be linked to the Integrated Coastal Zone Management programme which is under consideration. Marine protection regulations can potentially include clauses on the conservation and protection of seagrass beds. Another approach is the promulgation of Integrated National Policies on seagrass conservation within the framework of Cabo Verde's Nationally Determined Contribution to reduce the emission of greenhouse gases. This is a great step forward for the country and an example to follow in the region.

Pedra Badejo (Santiago Island). The Pedra Badejo wetland is located on the east coast of Santiago Island. It is characterised by two separated lagoons, the "lagoa" and "lagoinha". These lagoons are connected with the sea but are fed occasionally by rainfall floods. The wetland was declared as Ramsar site in 2005 (nº 1577), however currently the area needs urgent conservation measures. After building the Poilão dam, the lagoinha stopped receiving rainwater, getting fed only by the sea water. The lagoa has reduced its flow and size drastically due to road construction debris dumped in the area. Intensive agriculture activities are also reducing the size of the wetland, mainly in the lagoinha, thus endangering the seagrass bed (*Ruppia maritima*) in this wetland, thus far the only published record of this species in Atlantic Africa [42].

Pedra de Lume (Sal Island). The salt marshes of Pedra de Lume are a private property located within the caldera of an extinct volcano, located on the island of Sal, the most touristic island in the archipelago. The area was classified as a Protected Landscape (through Decree-Law 3/2003, of 24 February), with the objective of preserving the natural and cultural elements that it holds, and in 2012 the site was declared Natural, Historic and Cultural National Heritage (Resolution No. 21/2012, of April 24). It is one of the most visited tourist places in Sal Island, which can be a high risk for the little seagrass bed of *Ruppia sp.* present in the salt marshes.

Ribeira de Rabil (Boa Vista Island). The Ribeira de Rabil lagoon in Boa Vista Island has been considered a Ramsar site since 2005 (Ramsar site nº 1576), due to its high importance for migratory birds. Furthermore, due to its landscapes values in preserving and maintaining the ecological resources derived from the dynamics of the sand dunes, it was inserted in the Boa Esperança Natural Reserve (Regulatory Decree No. 16/2014 of 10 February). Currently, it borders coastal areas for tourist development, which leads to strong anthropogenic pressure, due to touristic and water sports activities, leading to the degradation of the lagoon. Unfortunately, the construction of bridges and roads that cross the lagoon led to the disappearance of the seagrass (*Ruppia sp.*) in this area, and the site must be monitored to detect whether recovery will take place.

Porto Inglês (Maio island). The Salt Marshes of Porto Inglês in Maio island are characterised by a salt flat with a lagoon basin, sand dunes and rocky semi-desert areas. The area is currently used for salt extraction, and livestock grazing. The area was classified as Protected Landscape in 2003 (Decree-Law 3/2003, of 24 February) and declared as Ramsar site (nº 2182) in 2013. The zone constitutes an important site for a seagrass bed (*Ruppia sp.*) that is seasonal, varying with the water level at the site, but it faces emergent threats like the circulation of all-terrain vehicles, the inert extraction, and expansion of the island's main dock.

B) **THE GAMBIA:**

Bijol islands-Tanji, Ganjur et Kartong. The Gambia has high priority feeding grounds for green turtles, particularly in and around the Bijol Islands. The Bijol Islands site has protected status for turtles and therefore, indirectly, for seagrass beds. In addition, seagrass conservation has been integrated into national legislation such as the Wildlife Act of 2020 and the Tanji Bird Sanctuary Management Plans. The ResilienSea project team in The Gambia and the GEF 6 PMU have agreed to extend the two proposed MPAs to cover the seagrass pilot sites at Gunjur and Kartong. The GCCA+ project has included the seagrass pilot sites in the Integrated Coastal Zone Management plan, and discussions are ongoing with the GCCA+ project to consider seagrass restoration as part of the ecosystem-based Coastal Greening component. ResilienSEA and 'Ba Nyamo Tango' (seagrass restoration) will work closely together to protect, conserve, and restore seagrass in The Gambia. The Gambia has just received funding from UNEP to expand and replicate seagrass conservation and restoration along the entire Gambian coastline.

C) **GUINEA:**

Tristan islands. The Tristan islands have been listed in the Ramsar Convention on Wetlands since 1992. Since 2013, the site has been granted a Community Marine Protected Area status, which aims to preserve and enhance the biological, social, and cultural diversity of the site. The Tristan islands also have BirdLife IBA status. They form a valuable ecosystem as a result of the large amounts of mangrove forests that grow in the area. At present, there is an ongoing process for the integration of seagrass conservation into the MPA management plan of Guinea.

D) **GUINEA BISSAU:**

Unhocomo and Unhocomozinho. Unhocomo and Unhocomozinho islands are part of the Bolama Bijagós Biosphere Reserve designated by UNESCO in 1996. The Bolama Bijagós Biosphere Reserve covers the entire Bijagós archipelago and includes three protected areas, the Community MPA of Urok, the Orango National Park and the João Vieira-Poilão National Marine Park. The areas around Unhocomo-Unhocomozinho islands have been reported as a concentration site for juvenile green turtles and as a mating ground for nesting adults but are not recognised as a national park. However, there is an ongoing process to revise the artisanal fisheries regulations to incorporate the protection of seagrass beds into national legislation. The revision has been validated by the Council of Ministers and is awaiting promulgation.

E) **MAURITANIA:**

Parc National du Banc d'Arguin et Baie de l'Etoile. The Parc National du Banc d'Arguin is a World Heritage Site and has the status of Marine Protected Area with a specific law adopted since 2000 through the law 2000/24 and its application decrees. The site is known worldwide for its high importance for biodiversity, including seagrass beds. The Baie de l'Étoile site, located close to Nouadhibou, North of Banc d'Arguin, holds seagrass beds but has not yet been granted protection status despite various attempts led by the IUCN.

F) **SENEGAL:**

Réserve Biosphère du Delta du Saloum. The large area hosting seagrass beds is included within the boundaries of the Saloum Delta National Park and in the Marine Protected Area of Joal-Fadiouth. Here, the major risk to seagrass beds is often bottom trawling and anchoring of fishing boats. Binding regulations are included in the 2015 Maritime

Fishing Code and its 2016 Decree defining a maritime fringe, extending from 0 to 6 nautical miles from the baseline, where the use of bottom trawls is prohibited. In addition, fishing operations take place beyond the maritime limits of the MPAs, as defined by Decree No. 2004-1408 creating the MPAs of Bambung, Kayar, Abene, St Louis and Joal Fadiouth.

Saline and brackish lagoons. Seagrasses of the genus *Ruppia* have been historically present in several saline and brackish lakes north of Dakar, including Lake Retba (Lac Rose) and Lake Tanma (seasonal water body), although their present status in the area is unclear. The main threat to these seagrasses appears to be permanently high salinity, because these wetlands have been reduced since the 1970s due to drought and over-pumping, which resulted in very high salinity. Lake Retba contained *Ruppia sp.* at least in 1985 [43]; it is currently used for salt production and is under consideration by UNESCO as a World Heritage Site. None of these lakes is a Ramsar site or protected area of any kind so far.

G) SIERRA LEONE:

Turtle islands (Bumpetuk Island). The Turtle Islands are located in the South-eastern Province of Sierra Leone. They are part of the Bonthe-Sherbo Estuary Marine Protected Area. The environment is characterised by extensive mangrove forests, mudflats, and sandbanks. The presence of seagrass beds adds to this variety of habitats. The ResilienSea project team in Sierra Leone has developed a White Paper that promotes the integration of seagrass conservation into national and local laws governing coastal areas and marine habitats in Sierra Leone. The White Paper provides recommendations on the need to strengthen the conservation of natural resources in the coastal and marine environment. The literature review of national policies and legislation identified institutions with the required mandate for the protection and management of seagrass beds. The review also analysed existing policies and legislation and determined the appropriate legal framework for seagrass conservation and management. The outcome of the review is a set of recommendations that prioritise and support seagrass conservation at the national level.

3.3.6. SEAGRASS RESTORATION

The main reason for seagrass restoration is to recover disturbed or lost seagrass populations. Restoration of seagrass is not usually aimed to change other pristine natural habitats into artificially planted seagrass habitats, because all natural habitats have their own complementary value and should not be destroyed to be transformed into something considered more valuable without a very strong justification.

The objective of seagrass restoration is usually to recover the many ecosystem functions provided by seagrasses, rather than to protect the seagrasses themselves due to species conservation concerns. Although there are many ecological and economic benefits of healthy seagrass meadows (see module 1), such benefits cannot all be achieved in the same time scales in restoration programs. Some benefits such as fish provisioning services can be enhanced as soon as healthy seagrass canopies are re-established, which also stimulate biodiversity and charismatic fauna such as manatees, sea turtles and seahorses. In contrast, carbon sequestration by seagrasses takes place mainly by accumulation of organic matter in the sediments over long temporal scales. Therefore, if an ancient stable seagrass meadow is destroyed and the sediments are mobilised, then the carbon that had been accumulated over centuries is lost and it would take again centuries to recover the same functions that the original seagrass meadow was providing. Just replanting a healthy seagrass meadow cannot rapidly, in a few years, accumulate a thick layer of carbon rich sediments similar to the amounts found in centuries-old meadows. For example, if construction of a marina destroys a seagrass meadow, replanting the seagrass meadow elsewhere is positive to recover some nursery effect of the canopy, but cannot recover the carbon sequestration destroyed by the construction of the marina. The important message to highlight for management is that restoration is not a substitute for conservation.

Seagrass restoration can be very labour intensive, expensive and the results are often uncertain and often unsuccessful. When a seagrass meadow is lost, the physical and biological environment may change so much that it no longer allows seagrass to grow in the area. The switch between a seagrass meadow and a bare area is a tipping point of change between distinct ecosystem stable states that once changed can take an enormous effort (e.g., [44]) to reverse back to seagrass, or even be impossible to reverse due to the altered environmental setting after the seagrass is lost. Hence, it is imperative that managers and practitioners always prioritise the protection and conservation of existing seagrass meadows. An important first step is to support the natural recovery of seagrass meadows by addressing the drivers that caused the decline or loss in the first place (passive restoration). When the cause of seagrass loss is outside management control, then seagrass restoration through active intervention may be necessary (active restoration).

Seagrass restoration may be undertaken in a network with a centralised platform for key stakeholders to communicate and share information around the restoration, monitoring, management, protection, and conservation of seagrasses. Such network can meet periodically to coordinate dialogue around restoration work in a way that promotes transparency and mitigates confusion by encouraging open discussion and dissemination of seagrass science, and long-term ambitions and challenges in restoration and conservation of seagrass. As a network initiative moves forward, it should create a unified community that welcomes open discussion, shares knowledge (both local and scientific) and breaks down the communication barriers that exist between stakeholders and restoration implementers.

Several seagrass restoration methods have been developed and tested. The most suitable method will be different for each location and species. When selecting a method, the following should be considered:

- causes of seagrass loss and remaining threats in the site,
- size of restoration site and seagrass species,
- previous outcomes in similar environments and for similar species,
- cost and potential risks,
- results of small-scale pilot trials.

The transplantation of seagrasses manually requires wild stock, in the form of adult plants or seeds. Projects that use manual transplanting as a restoration method, typically involve either the use of seagrass sods with sediment and intact rhizome/root systems, sediment free seagrass shoots, or seeds/fruits.

In general, transplantation of seagrass with sediment ensures the root and rhizome system remains relatively intact and provides a reservoir of the original rooting medium. This technique involves the removal and planting of a shovel-full of seagrass with sediment and rhizomes/roots intact. The equipment required for this technique are shovels and some sort of (large) basins to hold the sods. The plug method, which is a seagrass-with-sediment method, utilises tubes as coring devices to extract the plants with the sediment and rhizomes intact. The core tubes can be made of any diameter PVC plastic pipe (widely used in building construction) with a cap to initially create a vacuum and keep sediments from washing out the bottom. The tube is inserted into the sediment, squeezed up to around 10 cm belowground, capped (which creates a vacuum), then pulled from the sediment and capped at the other end to avoid losing the plug. A seagrass-sediment-method has the advantage of having a larger survival rate however with the disadvantage of being harder to carry the sods or plugs especially when the donor bed is located far from the restoration site.

The sediment-free method involves plants to be removed from the sediment using a shovel. Sediment is shaken off from the roots and rhizomes and the plants are placed in flowing seawater tanks, floating pens or similar for holding until made into planting units. When using this method, it is essential to ensure growing rhizome tips are present within individual planting units as these provide a source of new shoots and horizontal growth, and a subsequent means to extend a meadow. Seagrass should be planted either directly into the bed by means of sprigs, using fingers or anchored using one of a variety of devices such as rods, pegs, rings, nails, stones, shells, rebar, skewers, or staples. U-shaped metal staples or robust wire hooks (e.g., fencing wire) are the most common anchoring devices that have been used successfully in sediment-free seagrass planting projects to date. A modification of this can be using the construction wire which helps anchoring seagrass species and the wire gets rusted and degrades quite quickly in seawater. The seagrass sediment-free method is most likely to succeed in areas with fine sands, moderate water movement and good light availability. Transporting the plant without sediments is a great advantage for the lower weight and volume, however with the disadvantage of being quite labour intensive, and having sometimes lower survival rates.

The Gambia is the only country from the RAMPAO network, and only country in western Africa, developing a seagrass restoration initiative, which is called Ba Nyamo Tanko and started in January 2022. Ba Nyamo Tanko, meaning Conserving Seagrasses in Mandika, is a new initiative unique to The Gambia and West Africa, aiming to restore, manage and strengthen the capacity for seagrass conservation in this country.

Ba Nyamo Tanko is a multi-actor project brought by The Gambia's Department of Parks and Wildlife Management. It is funded by the International Coral Reef Initiative (ICRI) and the United Nations Environment Program (UNEP) and supported by The Eduardo Mondlane University (Mozambique) and Alma Group (UK). Ba Nyamo Tanko hosted its first training workshop at the Gunjur Project Lodge between the 17th – 21st January 2022. The initiative is centred on communities of Gunjur and envisages to build capacities in applying techniques for the restoration, management, and conservation of local seagrass meadows, as well as promoting best practices and appropriate advocacy for the well-being of these important ecosystems. Up to 7 ha are envisaged for restoration, corresponding to around 5% of the estimated seagrasses area in the country. The seagrass restoration and monitoring network partnership enhances the implementation of the CEPA (Communication, Education and Public Awareness) strategy in The Gambia.

3.3.7. MONITORING PROGRAMMES AND SEAGRASS MAPPING

Environmental monitoring consists of the processes and activities to periodically measure, evaluate, and determine the environmental parameters of a system in order to prevent negative and damaging effects to the environment. Since seagrass meadows are located in the coastal zones, under the pressure of multiple and cumulative human impacts (see module 2), including climate change, environmental monitoring is necessary to assess their status and detect changes over time. Thus, in case of detection of signs of deterioration through monitoring activities, management measures could then be implemented to avoid, reverse, or mitigate further degradation. Monitoring can be also used to assess the recovery of seagrass meadows when new management tools have been adopted such as, for example, restoration projects, or the implementation of a marine spatial plan regulating boat anchoring on seagrass meadows. Monitoring programs are normally tailored to the specificities of the meadows to monitor (area, depth, species, etc.) and the impacts they are subjected to.

Seagrass meadows present in the RAMPAO network lack monitoring programs, making it difficult to understand the past and present trends. Implementing a monitoring program is therefore a priority in order to provide information to managers about seagrass status and to avoid seagrass degradation and loss in the future. Module 4 of the present manual includes an extensive overview of seagrass monitoring techniques and a specific protocol to be implemented in the RAMPAO member countries.

3.3.8. RAISING PUBLIC AWARENESS

Having a society well-informed on the values and benefits of natural ecosystems is key to supporting appropriate management decisions. Seagrass meadows, because of being underwater, are out of sight of citizens, so they are commonly unknown to the general society or confused with algae. The recognition of the benefits and contribution of seagrass ecosystems to human well-being is also still limited in many regions [45]. Exceptions may occur, as small-scale fishers normally associate seagrass meadows to fisheries, thus valuing them. Yet, other services, which are not directly observed, are poorly or not recognised. An example is the value of seagrasses in climate change mitigation through carbon sequestration or their role in water purification and hygenization. Enhancing seagrass public awareness of the importance of seagrass meadows is among one of the greatest challenges in seagrass conservation [46], and it is critical to aim well-informed decisions, from the level of individuals (e.g., fishers) to the regional and national actions taken by governments.

Raising public awareness of seagrasses should be done through education and experience opportunities for people of all ages [46] and stakeholders' groups. Activities could involve field trips to areas with seagrass meadows, so people can experience first hand the contact with seagrasses, either in intertidal areas (which provide an easy access) or in shallow waters where participants can use goggles and snorkel (providing a view of the full complexity and enchantment of the habitat). Other activities to increase public awareness include school activities (talks), publication of children's books, exhibitions, outreach articles in local media, etc. Over the last years, the seagrass research community has celebrated in March the Seagrass Awareness Month and the United Nations recently declared March 1st as the World Seagrass Day. These dates are also good opportunities to celebrate activities to commemorate the huge benefits of seagrass meadows to humans.

3.3.9. ENGAGEMENT OF LOCAL COMMUNITIES

Management and conservation efforts can incorporate the interests and views of local people, an approach often referred to as community-based management (CBM) or community-based conservation (CBC). This management strategy is increasingly being adopted in many regions, and it is characterised for combining conservation and development, and for being centred around the people who depend on the natural resources, who take an active participation in the projects [47]. The design of community-based conservation projects should be carefully done, following social principles [48], considering the characteristics of the local communities and the conservation and development needs. This approach, when well-designed and conducted, has been proved to facilitate more sustainable management practices.

Community-based management is an "opportunity for effective, efficient and socially just conservation of seagrass" [48]. There are initiatives, yet still in their early stages, that are considering projects of Payments for Ecosystem Services (PES) as a model to support community-based conservation for seagrass meadows [48].

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MODULE 4:
MONITORING AND MAPPING METHODS TO ASSESS SEAGRASS CONDITION AND TRENDS

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4.1. THE IMPORTANCE OF MONITORING SEAGRASSES

The rapid growth of human population in coastal zones is altering the marine environment through coastal constructions and the input of nutrients, organic matter, and other contaminants. As a result, coastal ecosystems, such as seagrass meadows, are experiencing a widespread deterioration of environmental quality, which causes seagrass degradation and eventually their loss (see module 2). Additionally, climate change is already having a visible impact on seagrass meadows, which is expected to increase in the future due to rising sea level and temperature, heatwaves, and increased storm frequency (see module 2).

Environmental monitoring is the repeated observation of a system and is designed to detect changes within that system. Considering the high human pressure on coastal areas, seagrass meadows should be monitored for early signs of degradation due to local and global human impacts [1]. At the same time, seagrasses are used as indicators to assess the environmental status of coastal areas in many regions [2]. Seagrasses are used as bioindicators because they are essential habitat for associated biodiversity, they provide essential services (see module 1) and they are very sensitive to environmental degradation (e.g., eutrophication, erosion, decreased water transparency).

Seagrass monitoring programmes, and the use of seagrasses as environmental indicators, provide valuable information to coastal managers, enabling them to make decisions with greater confidence on which measures to adopt to minimise the risk of seagrass loss and general environmental degradation. Monitoring programs can also be applied to assess the recovery of seagrasses following restoration projects or after the application of measures to reduce impacts. Since seagrass species may differ in their responses to environmental stress, and coastal areas are exposed to different impacts, monitoring programs should be tailored to the species and habitats in question [3]. However, global standardised monitoring protocols also exist to allow comparisons among sites across the globe. These global protocols are provided by the SeagrassNet [4] and SeagrassWatch [5] networks. The implementation of conservation measures and the decision-making concerning the protection and restoration of seagrass meadows depend on the quality of the monitoring programs and the data collected.

As explained in module 2, seagrass meadows in the RAMPAO member countries are threatened by global and local human impacts. To adopt well-informed management strategies to protect and recover seagrasses, it is necessary to understand the changes and tendencies in their state of health and their vulnerability to degradation. The lack of monitoring programmes in the past makes it difficult to understand the trends of seagrass meadows in the RAMPAO countries in the last decades, as well as their present status. Thus, initiating a seagrass monitoring network is essential to avoid further seagrass degradation and loss.

4.2. INDICATORS OF SEAGRASS CONDITION AND SEAGRASSES AS BIOINDICATORS

The indicators used to assess seagrass health are many, and different monitoring programmes may use their own set of indicators to assess seagrass status. In Europe, for example, more than 49 seagrass indicators have been identified from 42 monitoring programmes [2]. The indicators can represent different structural and functional levels, from spatial distribution and area extension of the meadow to chemical composition of the plants, to processes such as population dynamics or biodiversity associated with the meadows (Table 4.1 [2]).

TABLE 4.1. List of common seagrass indicators by category (modified after [2]). Each monitoring program is usually focused on only a subset of these indicators, considered more adequate for the particular system and objectives.

DISTRIBUTION	- Depth limits - Area	- Spatial fragmentation
ABUNDANCE	- Shoot density - Percent cover - Aboveground biomass	- Belowground biomass - Dead matte cover
SHOOT CHARACTERISTICS	- Shoot biomass - Shoot leaf area - Flowering shoot density - Number of leaves per shoot	- Leaf width - Leaf length - Leaf necrosis - Broken leaves
PROCESSES	- Leaf production - Rhizome production - Rhizome elongation - Shoot recruitment - Shoot mortality - Shoot burial	- Flowering time (phenology) - Seed recruitment - Seed production - Seed bank density - Gene flow (shoots/seeds/pollen) - Herbivore pressure
CHEMICAL CONSTITUENTS	- Nutrients (N and P) contents in rhizomes or leaves	- Metal contents in rhizomes or leaves
ASSOCIATED FLORA AND FAUNA	- Diversity of macroalgae - Diversity of fauna - Presence of invasive species	- Epiphyte biomass - Endophyte identification (disease-causing) - Macrofauna abundance

When seagrasses themselves are used as bioindicators, they can be organised according to the levels of biological organisation: physiological and biochemical, morphological and growth, and structural and demographic [6]. The selection of the indicators to use will depend on the stressors that are evaluated (Table 4.2). For example, when seagrasses are under burial stress, structural indicators such as biomass, shoot mortality and shoot density are robust indicators [6]. Most of the structural and demographic parameters (such as shoot density and biomass) are unspecific, that is, these parameters respond to many different stress factors. However, biochemical, and physiological indicators present more stressor-specific responses and are more sensitive to early warnings of environmental recovery [6].

TABLE 4.2. Example of robust seagrass indicators for specific environmental stressors. **Source:** [6].

	SHADING	NUTRIENTS	BURIAL	ORGANIC MATTER	HYPERSALINITY
PHYSIOLOGICAL AND BIOCHEMICAL					
Leaf nitrogen content	•	•			
Rhizome nitrogen content	•	•			
Chlorophyll a content		•			
Photosynthesis rate					•
Rhizome sucrose content	•			•	
Leaf delta ^{13}C	•				
Leaf carbon to nitrogen ration		•			
MORPHOLOGICAL AND GROWTH					
Leaf growth	•	•		•	•
STRUCTURAL AND DEMOGRAPHIC					
Density	•	•	•	•	
Aboveground biomass	•	•	•	•	
Belowground biomass			•		
Shoot mortality			•		•

4.3. SEAGRASS MAPPING METHODS

4.3.1. INTRODUCTION TO METHODS FOR SEAGRASS MAPPING

Seagrass distribution maps are the most important information for managers, so they know where the resources to manage are located. Seagrass maps are also essential to select an appropriate monitoring site when designing a monitoring program in a specific region [7].

Techniques to map seagrasses can be grouped into three main groups [8]: **1)** optical-based techniques using remote sensing instruments such as satellites and drones; **2)** acoustic-based techniques using remote sensing instruments such as side-scan sonars; and **3)** field-based techniques conducted through diving, snorkelling, walking or from boats. This manual only presents approaches to map seagrasses based on field-based methods, for both intertidal and subtidal meadows.

A mapping process aims at determining the edges of a seagrass meadow and recording basic information such as species present, cover, sediment type, and depth (if subtidal) [7]. There are two important elements in the map of a seagrass meadow: the inner edge or upper depth limit (i.e., the edge of the meadow near to the land) and the outer edge or lower depth limit (i.e., the edge towards the open sea).

Selecting a mapping strategy will depend on the following points:

1) SCALE: the mapping approach is different depending on whether the area to map is at a scale of tens of kilometres or tens of metres. The scale is related to resolution, i.e., the intensity of the sampling, which means that the larger the area to map, the lower the resolution of the mapping. For large areas, field-based mapping is very limited and needs to be combined with optic-based or acoustic-based methods [8].

2) RESOURCES: the mapping approach is determined by the financial and human resources, as well as the technical skills of the people involved. For example, mapping subtidal seagrasses can be done by scuba diving using transects, but alternatively, if divers are not available, it could be done from a boat with a drop camera (if turbidity and currents allow it) or using sediment grabs.

3) ACCURACY: accuracy is the quality of being correct, with minimum error. If the final map needs to be very accurate, methodological errors should be minimised when collecting the data in the field. For example, for very accurate mapping, marking the position of a seagrass limit with a GPS (Global Positioning System) will require being placed as close as possible to that limit.

Prior to selecting a mapping strategy, it is recommended to do an initial assessment based on the available information such as aerial images (e.g., GoogleEarth), old maps, personal communications from local people, etc. If needed and possible, a preliminary survey can be done in the field with a boat, a drone, or by walking. This will give an initial idea on the general extent of the seagrass meadows to be mapped and will assist in choosing the most appropriate mapping strategy. After conducting the fieldwork to map seagrasses, collected data should be digitized using Geographical Information Systems (GIS) software to create a digital map. In cases where access to GIS software is not possible, the approximate location and extent of the meadows should be drawn on an existent map.

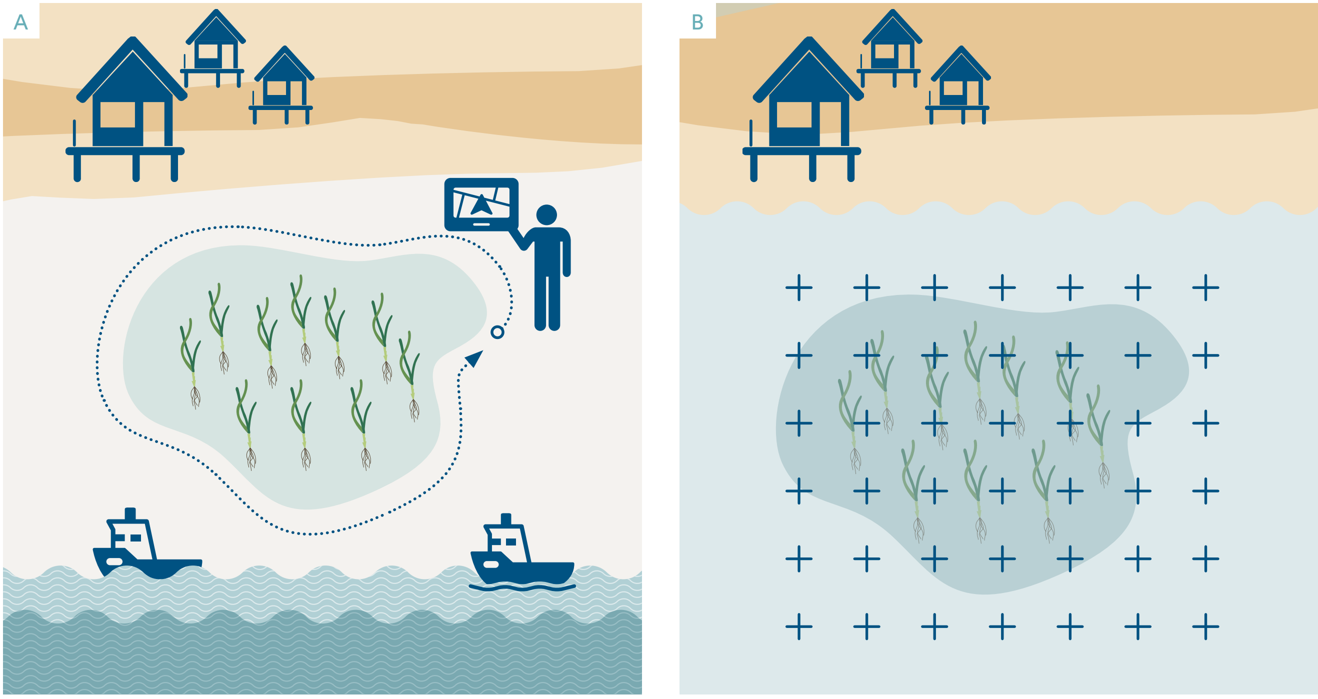

FIGURE 4.1. Diagrams showing the two common techniques to map seagrasses, with adaptations to intertidal or subtidal meadows: A) using the perimeter technique, and B) using the grid or transect technique. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

4.3.2. MAPPING INTERTIDAL SEAGRASS MEADOWS

Mapping intertidal meadows is easier to do during low spring tides, when the meadows are exposed to air. The time for the fieldwork will then be limited by the duration of the low tide, so it is necessary to check the time of the low and high tides in advance. Safety rules must also be considered while working in the intertidal, especially in very muddy areas.

To record the positions, it is preferable to use a hand-held GPS. If a GPS is not available, consider using a smartphone with a GPS App. GPS apps for smartphones are becoming increasingly efficient and much less expensive than a hand-held GPS, and good digital maps can be downloaded prior to fieldwork.

Two common techniques to map intertidal meadows are (Figure 4.1):

1) **PERIMETER TECHNIQUE.** This technique is based on mapping the boundaries of the meadow by walking around its perimeter and registering the positions of the points with a hand-held GPS every 5 to 25 metres, depending on the area to map and the available time during low tide. Many GPS devices can be set to continuously record the position while walking (track method), however, this consumes more memory and batteries.

2) **GRID OR TRANSECT TECHNIQUE.** This technique is based on the layout of transects (normally in parallel, forming a grid) across the area to be mapped, and taking observations at regular intervals. The transect can be established with a metric tape if the area is not too big. For small meadows, points can be recorded at short distances (few metres). For medium size meadows, points can be recorded at 20-50 m, and in large meadows points can be 100 or 500 m apart [7]. At each point, the coordinates must be registered with a GPS.

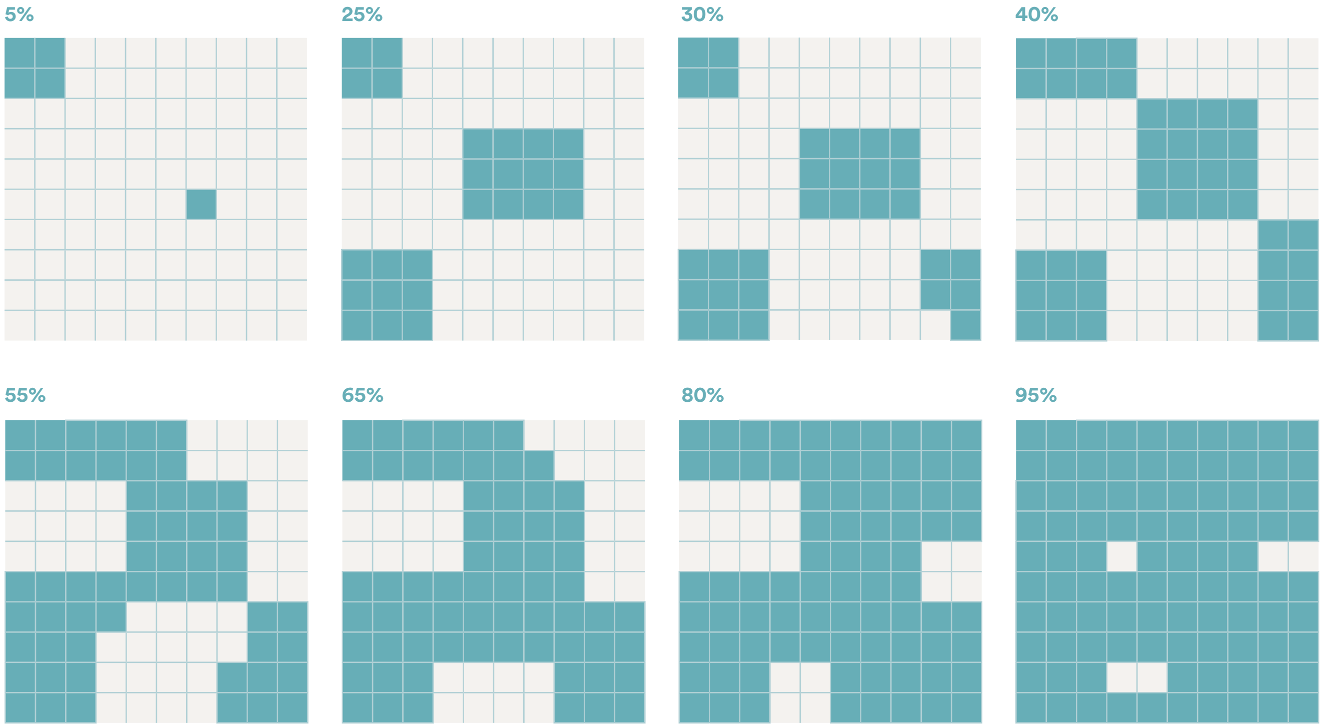

FIGURE 4.2. Example of a guide to estimate the seagrass cover percentage.

For any selected technique, field observations must be recorded in a waterproof notebook (following the template in Annex 2.1) at each point. If possible, a quadrat should be haphazardly tossed at each observation point to record the percentage cover of the seagrasses. The field mapping datasheet should include the following information:

- Date and time
- Location name
- Observers (name of the people doing the fieldwork)
- ID of the GPS recorded waypoint
- Water depth (in metres) at that point
- Sediment type (sand, mud, gravel, shell grit) at that point
- Seagrass species present at that point
- If possible, seagrass cover percentage at each point (e.g., Figure 4.2)
- Any other comments (e.g., presence of many algae, signs of seagrass degradation, etc.)

For very extensive intertidal meadows, other techniques based on aerial imagery may be needed. For instance, a recent study used high-resolution images from Sentinel-2 in combination with field data to update the distribution map of seagrass meadows at the National Park Banc d'Arguin (PNBA) [9].

4.3.3. MAPPING SUBTIDAL SEAGRASS MEADOWS

Mapping subtidal meadows requires access to a boat and, if done underwater, people with snorkelling or SCUBA diving skills. If the subtidal seagrasses are in a very shallow area (< 1 m), mapping could be done just by wading through the water. The moment of the tide is not very important for mapping subtidal seagrasses, yet it may be desirable to do it during low tide if snorkelling or wading are the selected techniques, so the water level will not be very deep. Same as for the intertidal meadows, it is necessary to check the time of the low and high tides in advance for the day the fieldwork will be carried out. Safety rules must also be considered while working in the subtidal, especially when diving.

Two common techniques to map subtidal meadows are (Figure 4.1):

1) **PERIMETER TECHNIQUE.** This technique is based on mapping the boundaries of the meadow by wading, snorkelling or SCUBA diving around its perimeter and registering the position with a hand-held GPS. When diving or snorkelling, the GPS must be safely set on a buoy that is attached to the person with a rope, with the GPS set to continuously record the position (track method). This technique may include an error of a few metres if there are currents that cause the rope and buoy to be dragged. This technique may have limitations given the available diving time, the visibility, or the duration of the low tide (when snorkelling).

2) **GRID OR TRANSECT TECHNIQUE.** This technique is based on the records of observations at regular intervals through a set of transects normally laid out in parallel across the area to be mapped. The grid can be established through a navigation route (if done by boat) or with a metric tape underwater. Points can be recorded at short distances (5 m) for small meadows, at 20-50 m for medium size meadows, and 100 or 500 m apart in large meadows [7]. When done from a boat, the observations can be done by a person who enters the water and checks the sea bottom by snorkelling or SCUBA diving at each point. Alternatively, observations can be done by using a waterproof camera connected to a cable that transmits the image to a tablet on the surface. However, this method is only valid if visibility is good enough, currents are not very strong, and there are no items on the seafloor where the camera can get entangled (e.g., fishing nets). Another alternative to record the presence of seagrasses at each point is using a sediment grab to take samples from the boat, yet this method is destructive and should be avoided. In any case (SCUBA diving, snorkelling, camera, or grab), the record of the position where seagrass presence is being checked must be done on the boat using a hand-held GPS.

For any selected technique, field observations must be recorded in a waterproof notebook (following the template in Annex 2.1) at each point. If possible, a quadrat should be haphazardly tossed at each observation point to record the percentage cover of the seagrasses. The field mapping datasheet should include the following information:

- Date and time
- Location name
- Observers (name of the people doing the fieldwork)
- ID of the recorded GPS point
- Water depth (in metres) at that point
- Sediment type (mud, sand, gravel, shell grit) at that point
- Seagrass species present at that point
- If possible, seagrass cover percentage at that point (e.g., Figure 4.2)
- Any other relevant comment (e.g., upper or lower meadow limit, presence of many algae, signs of seagrass degradation, etc.)

For very extensive subtidal meadows, other techniques based on acoustic methods may be needed.

4.3.4. CREATING THE SEAGRASS MAP

The easier way to create a map with the seagrass distribution is to draw the limits and observed points on a paper marine chart, using the geographical coordinates recorded in the field. If you do not have access to GIS software, you should use this method. However, this is a method that does not allow you to easily share the information or transform the data and makes it difficult to compare with future maps.

Thus, if resources are available, the recommendation is to create a digital map using GIS software. This type of software allows you to import the coordinates recorded during the mapping process and to create point maps or polygons of the mapped meadow (Figure 4.3). There are some GIS software that are free and open source, and can be downloaded from the internet without registration, such as QGIS (https://www.qgis.org/). The use of QGIS requires some training, which can be done online through many available tutorials (https://docs.qgis.org/). GoogleEarth is also an appropriate tool to create maps using the recorded positions from the GPS. Alternatively, an expert in geographical systems could be consulted for assistance.

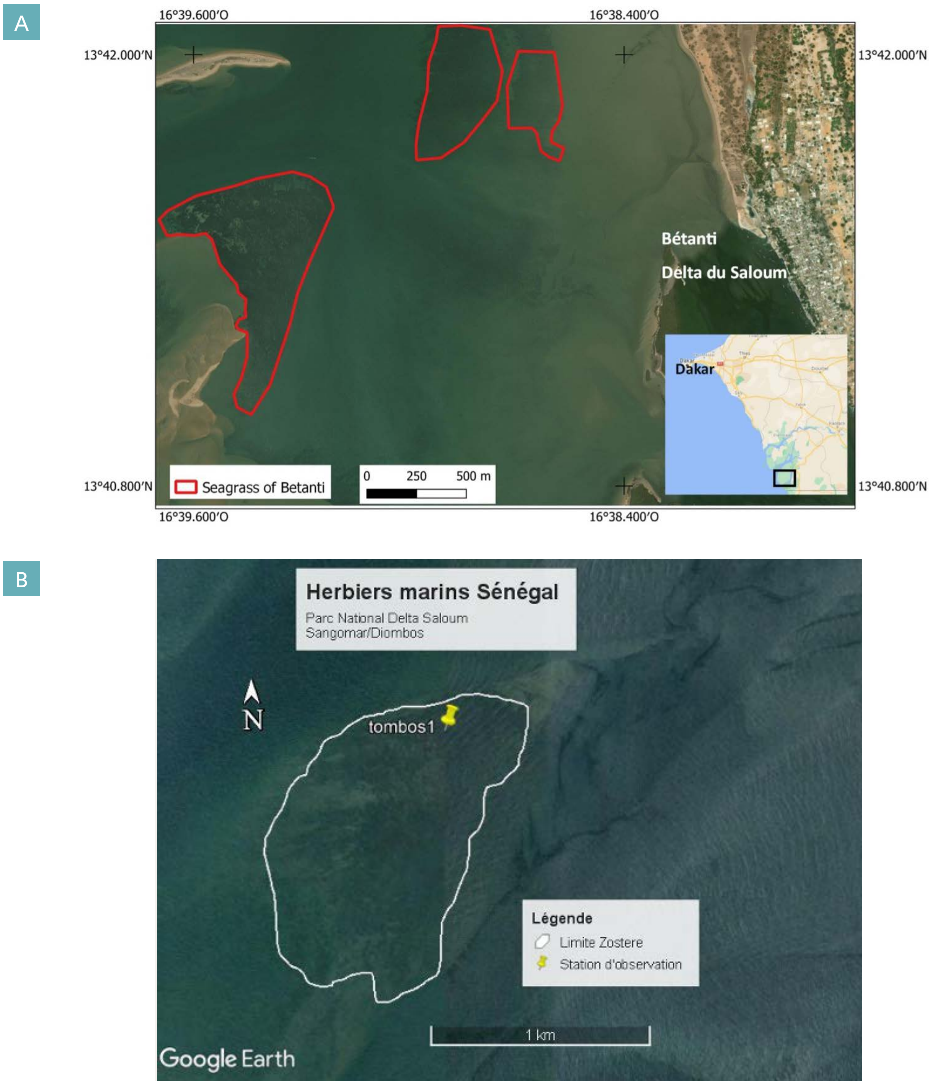

FIGURE 4.3. Examples of distribution maps of seagrass (*Zostera noltei*) meadows where their boundaries were obtained using the perimeter technique in two locations of Delta du Saloum (Senegal): A) Betani and B) Sangomar - Diombos. After the fieldwork, the positions registered with a hand-held GPS were imported into a GIS system or GoogleEarth to obtain the polygons, creating the digital map. **Source:** M.A. Sidi Cheikh.

4.4. SEAGRASS MONITORING METHODS

The monitoring methods presented here are those recommended by SeagrassWatch, the Global Seagrass Observing Network [7]. SeagrassWatch is an initiative that creates a partnership between scientists and citizens to accurately monitor the status and trends in seagrass condition, and it has been expanded to more than 400 sites across 21 countries since its establishment in 1998 (www.seagrass-watch.org).

Once the seagrasses have been mapped (section 4.3), the next step is to design the monitoring protocol, considering that the design must [7]:

• ask appropriate questions and set achievable goals
• collect accurate and precise data that meet the requirements of the users
• report data in an informative manner
• be easy to work through
• use available time and resources efficiently

This section is divided into site selection (where to monitor seagrasses), monitoring design selection (how to set the observation points in the seagrass area), and monitoring procedures (which parameters to record within the observation points).

4.4.1. SITE SELECTION

Once the map of the area to monitor is available, it is necessary to select a site to monitor, a critical step that precedes the implementation of a seagrass monitoring plan. The selected site should meet the following criteria [1]:

1. To be logistically easy and safe to reach and monitor over time,
2. To be less prone to temporal variability or significant anthropogenic impact,
3. To be representative of the particular area in terms of biodiversity and depth range, and
4. To be relatively homogenous, to allow for replicate sampling.

4.4.2. MONITORING DESIGN

4.4.2.1. Spatial design

Based on the distribution of the monitoring points in the seagrass area, we can define five common spatial designs [7]. Here, we present them succinctly, however, they are fully explained in the SeagrassWatch Manual [7].

A) FIXED TRANSECTS SITE. This type of monitoring technique is most useful for monitoring intertidal seagrass meadows. However, it can also be used for subtidal seagrass meadows using SCUBA diving. The goal is to monitor broad changes that may occur within a specific seagrass meadow. The fixed transect consists of three parallel transects, usually perpendicular to the shoreline and at an equal distance from each other (Figure 4.4A). Fixed transects means that the transect is marked from the first monitoring sampling event and will be revisited in the following monitoring events. Thus, it is necessary to

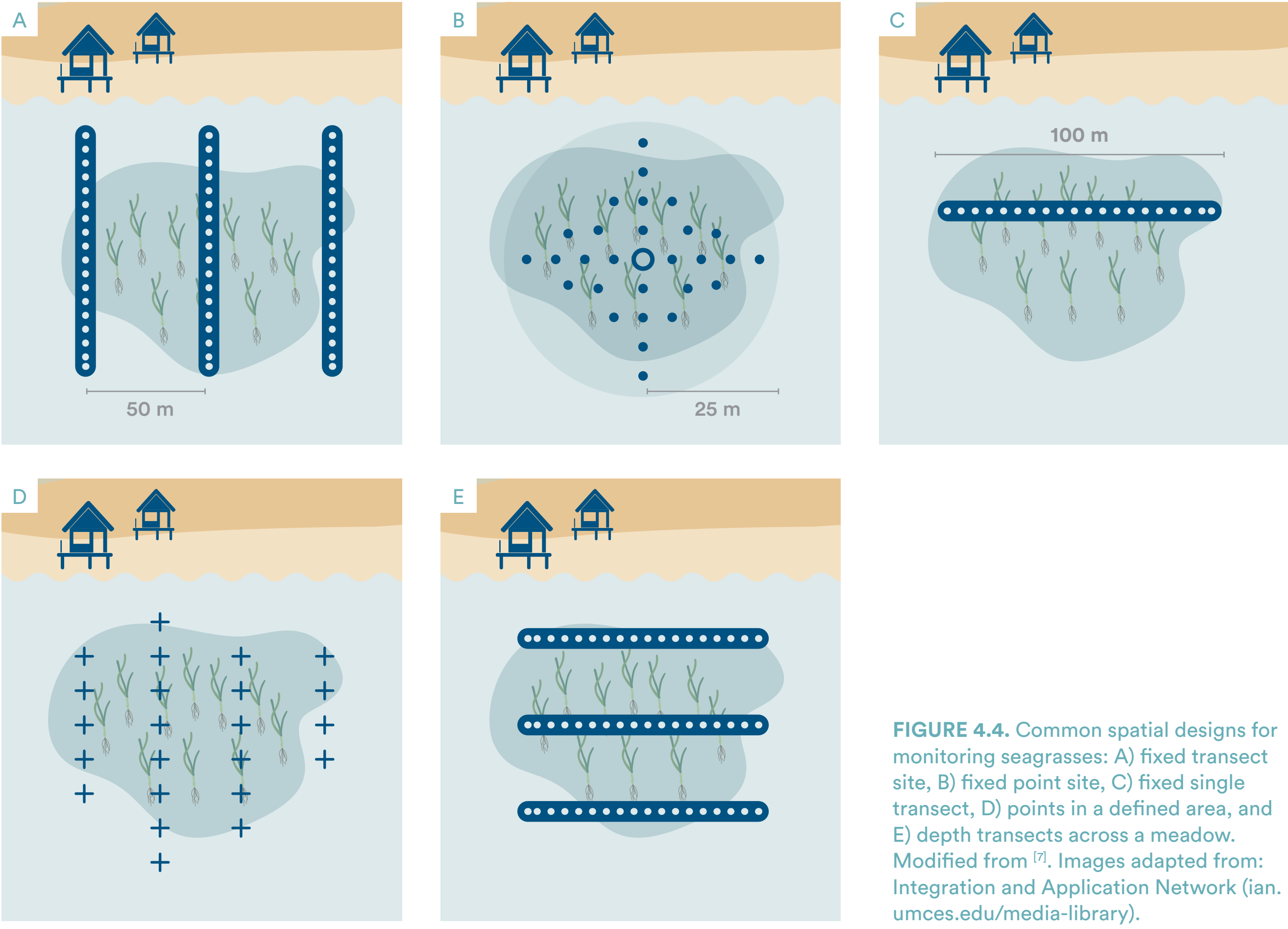

FIGURE 4.4. Common spatial designs for monitoring seagrasses: A) fixed transect site, B) fixed point site, C) fixed single transect, D) points in a defined area, and E) depth transects across a meadow. Modified from [7]. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

mark the start of the transects with a permanent tag in order to find it during the next sampling event, and to know the bearing of the transect (using a compass).

B) FIXED POINT SITE. This technique is appropriate for both intertidal and subtidal meadows, yet it is not recommended for muddy areas. In its design, the observational points are set around a central point within a certain radius. Quadrats within the monitoring area can be tossed randomly or spread evenly around the central point (Figure 4.4B). As for the previous design, the site has to be marked in the field (usually only the central point is marked) for future reference.

C) FIXED SINGLE TRANSECT. This technique is recommended for subtidal meadows using SCUBA diving. The transect should be longer than 50 m (Figure 4.4C). As for the previous designs, the transect should be permanently marked, if possible (with a surface or subsurface buoy), or alternatively, the GPS coordinates of the starting point should be taken along with the bearing of the transect (measured with an underwater compass).

D) POINTS IN A DEFINED AREA. This design is recommended for subtidal seagrass meadows to be monitored by snorkelling or from a boat with a grab, for areas of a few kilometres such as a bay or an inlet. In this design, there are no permanent markers as in the previous designs, but a set of GPS positions creating a point grid that is revisited (Figure 4.4D). The number of points and the distance between them will depend on the extension of the area and the time and resources available for the monitoring.

E) FIXED DEPTH TRANSECTS ACROSS A MEADOW. This design can be used when both intertidal and subtidal meadows are present in the area, or just subtidal ones. Three transects are laid out parallel to each other and to the coast (Figure 4.4E), with the shallow transect close the upper limit of the meadow (i.e., shoreward edge), the deep transect close to the lower limit of the meadow (i.e., seaward edge) and another transect placed in between the shallow and the deep transects. Transects are normally 50 m in length, and observations are taken at 5 m intervals along each transect. As in other designs, the transects should be permanently marked to revisit them.

4.4.2.1. Temporal design

After selecting the spatial design, it is necessary to define how often the seagrass meadow is going to be monitored. The monitoring frequency will depend on the available resources (equipment, people, and funds) and time. It also depends on the reason behind the monitoring needs, for example, if the reason is the existence of a continuous impact, monitoring should be done more frequently.

Commonly, seagrass monitoring is done once a year, at approximately the same time of the year to avoid seasonal variations. Sometimes, if seasonal variation is desirable to monitor, then the monitoring protocol should be applied every 3 months. If not sure about the frequency, a seagrass specialist should be consulted.

4.4.2.3. Selection of parameters to monitor

As explained in section 4.2, the variety of seagrass parameters to monitor is very high. In addition, monitoring the physico-chemical parameters of the water (for example, temperature, light, nutrients) or sediment (for example grain size) may also be interesting to get a picture of the environmental conditions to which seagrasses are subjected. The selection of the parameters to include in the monitoring plan will depend on the objective of the monitoring, the stressors and impacts present in the area, and the available resources.

The essential and most commonly used parameters in seagrass monitoring programs are structural (Table 4.2), including seagrass species composition, above- and belowground biomass, shoot density, percent cover, canopy height, and algae percent cover. Yet, many other parameters of those listed in Table 4.1 can be included. The inclusion of physiological and biochemical seagrass indicators, as well as physico-chemical parameters in the water (temperature, light, and nutrient concentration) implies the use of specific instrumentation in the laboratory. The selection of the indicators for the monitoring design will then depend on the available resources. If in doubt about the selection of parameters to monitor, a seagrass specialist should be consulted for advice.

Independently of the selected monitoring spatial design, the procedures at each sampling point along the transects or area are the same. This is, once the seagrass variables are selected, they should be measured at each sampling point defined in the monitoring transect or area.

4.4.3. Data quality, storage, organisation, processing, and sharing

Monitoring seagrasses requires time and resources. To make this effort worthwhile, the monitoring data should be collected carefully to ensure a high-quality standard and then stored and organised properly to avoid losing them. If in doubt about the ability to properly acquire and curate the data, then it is preferable to plan a more modest monitoring programme to start with, and then progressively build upon that programme. If this is the case, make sure that the variables that were measured originally will always be measured throughout the duration of the monitoring programme.

Once a decision on an appropriate monitoring programme has been made, make sure to process the data so that information on the seagrass status can be shared with the interested stakeholders. These are some recommendations to attain these objectives:

- Use standardised datasheets for data collection in the field and the laboratory.
- Use standardised guides for seagrass cover percentage.
- Label bags for samples with a unique identifier.
- Check that all the data and information needed is written in the field and laboratory datasheets or notebook and take a picture of the data sheets after finishing the sampling, on the same day that the monitoring was done.
- Write a short report on the tasks performed at each monitoring event, the people involved, problems encountered or any other information that might be helpful in the future.
- Store the data both as the original data hardcopies (printed field and laboratory datasheets and notebooks) and digitally (transfer the data into a datasheet on the computer).
- Save any files generated from the monitoring program in a folder and in an internet Cloud.
- Organise data so it can be easily understood and accessible for a person who has not been involved in the monitoring program. This includes full and abbreviated names of the variables, their units and the methodology used for the measurements.
- Process data to obtain a summary of the results, for example, calculating the mean seagrass biomass (and other parameters), creating the seagrass distribution maps, creating graphs to show the trend of the parameters over time, etc.
- Create an annual report with the activities performed, writing the names of the authors who contributed to its preparation, the funding sources, and the results obtained.
- Monitoring results over time could be published as a scientific article.
- If assistance is needed in any of these steps, contact a seagrass specialist for help.

4.5. STANDARDISED MONITORING PROTOCOL FOR SEAGRASS MEADOWS IN THE RAMPAO MEMBER COUNTRIES

4.5.1. OBJECTIVE AND GENERAL DESCRIPTION

The objective of the RAMPAO seagrass monitoring protocol is to conduct long-term monitoring of seagrass condition in the RAMPAO seagrass sites in order to provide an early warning system of coastal environmental changes for management.

In this section, we recommend a monitoring protocol for intertidal and subtidal seagrass meadows in the RAMPAO member countries. The protocol has been designed considering the human impacts in the area, the characteristics of the seagrass sites, and other issues such as resource availability or access to the sites. This protocol is based on the SeagrassWatch protocol [7], with some adjustments.

The recommended spatial design for intertidal meadows is the method of fixed transects, whereas for subtidal meadows it is the points in a defined area design. In any case, the fixed transect method can also be applied to subtidal meadows that are very shallow (< 50 cm). Table 4.3 shows the spatial design for each pilot site in the RAMPAO member countries. The sampling at each pilot site should be done twice per year, once in the cold or dry season and another in the hot or rainy season, and, if possible, at all the pilot sites. A standardised scientific method is recommended to increase the quality of the data and the comparison of results among pilot sites. The following sections explain the preparation of the monitoring (including the material list) and include, step by step, the procedures to monitor seagrass meadows in the RAMPAO member countries.

TABLE 4.3. Monitoring protocol design for seagrass meadows in the RAMPAO pilot sites.

COUNTRY	PILOT SITE	MEADOW TYPE	SPATIAL DESIGN
Cabo Verde	Gamboa	Subtidal	Fixed points
The Gambia	Bijol Islands	Intertidal/Subtidal	Fixed transects/ points
The Gambia	Tanje, Gunjur, and Kartong	Subtidal	Fixed points
Guinea	Tristao Islands	Subtidal	Fixed points
Guinea Bissau	Unhocomo and Unhocomozinho	Subtidal	Fixed points
Mauritania	National Park Banc d'Arguin	Intertidal/Subtidal	Fixed transects/ points
Mauritania	Baie de l'étoile	Intertidal/Subtidal	Fixed transects/ points
Senegal	Delta du Saloum	Intertidal/Subtidal	Fixed transects/ points
Sierra Leone	Turtle Islands	Subtidal	Fixed points

4.5.2. PRE-MONITORING PREPARATION

The success of a monitoring event relies on detailed planning of the sampling day, with enough time in advance. The planning includes acquiring the resources needed and gathering a team to conduct the sampling. Make sure that the team members have the skills needed for the tasks and that they are trained to conduct the sampling (e.g., if snorkelling is needed, they must know how to swim). These are important issues to consider for a successful monitoring event:

1. **PERMIT.** Taking samples in protected areas may require a legal permit. Request it in advance.

2. **MAKE A TIMETABLE.** Create a document containing: times of departure and arrival back, meeting point, objectives of the day, times for low and high tide, names of the people involved, and the list of the material they need to bring (e.g., water and food, clothes to snorkel, towel, etc.), your telephone number in case someone needs to contact you about doubts and last-minute changes. Several days before the monitoring event, share a copy of the document with all the participants involved. Give a copy of the monitoring plan to someone reliable who will not be in the field, in case of a problem.

3. **BOOK CARS AND BOATS.** Access to the monitoring site may require the use of a car for transportation of the team to the site location, and use of a boat, for sites with subtidal seagrass meadows. Make sure to book the car and boat in advance, including a driver and a skipper if necessary.

4. **SAFETY.** Remember the motto “safety first”. Before the monitoring day, check the weather, tides, time of the day, etc. If during the monitoring activities you do not feel safe, abandon the sampling. Do not put yourself or others at risk. Wear appropriate clothing and footwear. Have a first aid kit with you. Take a mobile phone with you. Specific safety rules must be followed if SCUBA diving.

5. **NECESSARY EQUIPMENT AND MATERIALS.** Check that all the material needed in the field is prepared several days before the monitoring day (lists of materials are given in following sections).

4.5.3. INTERTIDAL SEAGRASS MONITORING PROTOCOL

4.5.3.1. List of material

This list does not contain the personal items that team members should bring. The personal items should include appropriate clothing (that can get wet), footwear, racket shoes (to walk on the intertidal area without getting buried), etc.

- 1 unit - hand-held GPS
- 3 units - 50 m measuring tapes
- 6 units - 50 cm tent pegs
- 1 unit - compass
- 1 unit - metal or PVC corer (diameter of 10-12 cm)
- 1 unit - quadrat 50x50 cm
- 1 unit - strainer
- 15 units - labelled plastic bags (big size)
- 1 unit - magnifying glass
- 3 units - field datasheets
- 1 unit - clipboard
- 2 units - pencil and rubber
- 1 unit - 30-cm ruler
- 1 unit - quadrat photo-labeller
- 1 unit - waterproof camera with batteries
- 1 unit - percent cover standard sheet
- 3 units - seagrass identification sheets
- 2 units - boxes to transport the material
- 1 unit - cool box to transport the samples
- 1 L of freshwater to rinse waterproof camera in the field

4.5.3.2. Setting the fixed transects

Before setting the fixed transects, the area should ideally have been mapped to know the seagrass distribution, as explained in section 4.3.2. Based on the seagrass distribution map, the selected site for the position of the sampling transects should meet the criteria explained in section 4.4.1.

Once the monitoring site is selected, follow these steps to set the fixed transects in the intertidal meadow (Figure 4.5):

- Select a 50 x 50 m area in the pilot site.
- Push a tent peg into the sediment to mark the start of the transect 2 (central point) and attach one end of the 50-m tape to it (Figure 4.6A).
- Using the compass, run the transect out along the desired bearing (remember, perpendicular to the shore) until you reach 50 m, then mark the end with another tent peg pushed into the sediment.
- Ensure that the tape is as straight as possible between the two tent pegs. Leave the tape in place.
- Go to the start of transect 2 and then mark out transect 1 and 3, which are 25 m to the left and right of transect 2, respectively.
- Leave all the tapes in place with the pegs until the sampling is completed.
- Locate the geographical position for start and end points of each transect with a hand-held GPS, so you can revisit the location in the future. Write down the coordinates (total 6 coordinates, each of them with latitude and longitude) on the fieldwork datasheet.
- If possible, leave permanent marks (e.g., star pickets) at the beginning and end of each transect to easily recognize their position when revisiting the monitoring area in the future.

Important note: sampling is done to the right-hand side of the tape; therefore you should always walk on the left of a transect (starting on the landward side of the transect) to avoid footprints where you will be sampling.

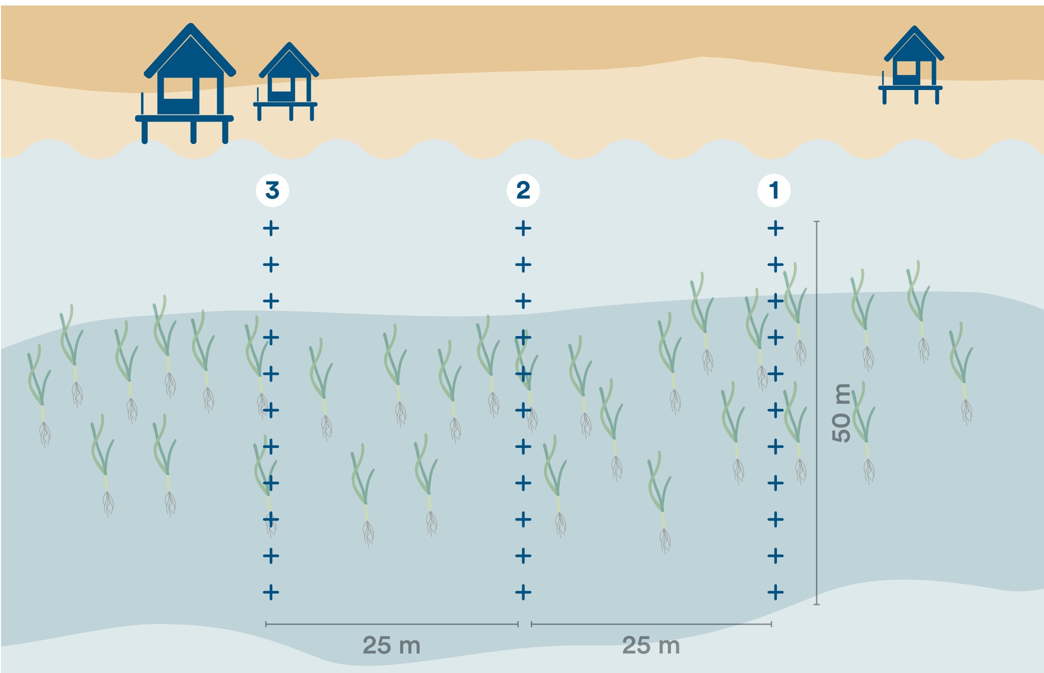

FIGURE 4.5. Diagram showing the setting of the fixed transects (1 to 3) for intertidal seagrass meadows. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

FIGURE 4.6. Pictures showing the monitoring of intertidal seagrass meadows: A) laying a quadrat along the metric tape marking the transect, B) estimating the percentage seagrass cover in the quadrat, C) Taking a picture of the quadrat, D) taking a biomass sample using the corer technique. **Photos by:** ResilienSEA Project (A,B,C), E.A. Serrão (D).

4.5.3.3. Sampling procedures

Once the metric tapes are laid for the three transects, measurements and sampling are done following the steps listed below. The field datasheet to be completed is given in Annex 2.2.

- **Starting point.** Start with transect 1 at the position of the starting mark.

- **Placement of quadrat.** Place a 50x50 quadrat on the 0-m mark. The quadrat is always placed on the right-hand side of the tape (Figure 4.6A).

- **Photograph.** Take a photograph of the quadrat placing the photo quadrat labeller beside the quadrat. This is done before taking any other measurements (Figure 4.6C). The photograph should be taken as vertically as possible, including the quadrat frame and the label. Record that a photo has been taken on the datasheet for that quadrat. Photos should be taken at least at the 5-m, 25-m and 45-m quadrats of each transect.

- **Sediment.** Describe sediment composition at the superficial layer (less than 5 cm deep). Record the texture and any other important comment (presence of shells, etc) in the datasheet:

- gravel (very coarse texture, with some small stones)
- coarse sand (coarse texture, particles loose),
- sand (rough grainy texture, particles clearly distinguishable),
- fine sand (fairly smooth texture with some roughness just detectable, not sticky),
- mud (very sticky, normally dark colour).

• **Seagrass percent cover.** Determine the total seagrass cover within the quadrat (Figure 4.6B) and record the value on the field datasheet.

• **Seagrass species composition.** Identify the species of seagrass within the quadrat and determine the percent contribution of each of them to the total cover, using the seagrass species ID sheet as a guide (Annex 1). Use a magnifying glass to better look at the leaf tip, if necessary. Record the values on the field datasheet. Important note: the composition of all species equals 100% regardless of the total cover (e.g., *Cymodocea nodosa* 70%, *Halodule wrightii* 30%).

• **Canopy height.** Measure the average length of the seagrass shoots. To do so, randomly select 3 to 5 shoots within the quadrat and measure the length from the shoot bottom part (without uprooting) to the leaf tip, ignoring the 20 % of the tallest leaves. Record each length on the field datasheet.

• **Algae percent cover.** Determine the percent cover of non-epiphytic algae in the quadrat, that is, those algae that are growing within the seagrass meadows but that are not attached to them. Use the same approach to estimate the algae cover as for seagrasses (Figure 4.2) and record the value on the field datasheet.

• **Biomass sample.** At positions 5, 25, and 45 m, take a biomass sample using the corer, outside the quadrat (Figure 4.6D). To do so, place the corer on top of the meadow, make sure that the leaves of the shoots inside the corer are also inside, push the corer into the sediment, extract the corer and transfer its contents (seagrass, sediment, and other materials) into the strainer. Wash the material with seawater, far from the transects (to avoid turbidity) and place the clean seagrass shoots into a pre-labelled bag. This should be the last thing to do at those positions. Record that a biomass sample has been taken on the datasheet for that quadrat. Place the samples in the coolbox in dark and cool conditions until the arrival to your institution.

• **Continuation along the transect.** Once you finish with the quadrat at 0 m, continue to the next 5 m mark and repeat the procedure (be aware that pictures and biomass samples are not taken at all of them). Continue along the transect sampling every 5 m until the transect is completed. Then repeat the process along transects 2 and 3.

• **Meadow limits.** After finishing the transects, register the meadow limits. To do so, start at the position 0-m of transect 2 and walk to the right until you reach the limit of the meadow. Locate the geographical position with a hand-held GPS. Do the same to the left of the meadow. Then, reach the lower depth limit, that is the meadow boundary that is further from the shore, and record the position with the GPS. Do the same for the upper meadow limit, that is the meadow boundary closest to the shore. Record the upper and lower meadow limits from the start and end, respectively, of each transect.

Once all the sampling is completed:

• Check that the field datasheet contains all the information required.

- Remove the equipment from the site and double check that nothing is left behind.
- If a waterproof camera was used, rinse it in freshwater immediately.
- Wash the rest of the sampling equipment in seawater at the site, and once you are back at your institution, wash it again with freshwater. Let it dry before storage.
- Store the equipment until the next sampling event.
- Once you are back at your institution, take a picture or scan the field datasheet for digital storage, and enter the data into a datasheet file.
- Process the biomass samples (section 4.5.5.).

4.5.4. SUBTIDAL SEAGRASS MONITORING PROTOCOL

4.5.4.1. List of material

This list does not contain the personal items that team members should bring. The personal items should include appropriate clothing (that can get wet), footwear, goggles and snorkel, etc.

- 1 unit - hand-held GPS
- 1 unit - sounding line (a line marked with knots of known distance at regular intervals, and a stone or piece of iron attached to one of the ends) or any other depth measurement device (e.g., hand-held depth finder)
- 1 unit - metal or PVC corer (diameter of 15-20 cm)
- 1 unit - mesh bag
- 1 unit - quadrat 50x50 cm
- 15 units - labelled plastic bags
- 1 unit - magnifying glass
- 3 units - field datasheets
- 1 unit - waterproof clipboard
- 2 units - pencil and rubber
- 1 unit - 30-cm ruler
- 1 unit - quadrat photo-labeller
- 1 unit - waterproof camera with batteries
- 1 unit - percent cover standard sheet
- 3 units - seagrass identification sheets
- 2 units - boxes to transport the material
- 1 unit - cool box to transport the samples
- 1 L of freshwater to rinse waterproof camera in the field

The items that are used by the team members that are SCUBA diving or snorkelling should be attached to their bodies, in order not to lose them. The easier way is to use a piece of rope and single or double ended snap clips. It is also useful to attach a small buoy to the item (quadrat, corer, rule, etc.) to find it easily in the water, in case you lose it.

Important note: Make sure that you have the insurance for the certified divers, the pre-checked diving material, and an emergency plan in case of an accident. Follow all the safety rules for SCUBA diving.

4.5.4.2. Setting points in defined area

Before setting the points in the defined area, the area should ideally have been mapped to know the seagrass distribution, as explained in section 4.3.2. Based on the seagrass distribution map, a set of GPS positions are selected on the meadow to be revisited. This method is designed to monitor subtidal seagrass meadows by snorkelling or SCUBA diving.

The selection of the points is done on land. Decisions to take include the distance between them and their number, with a minimum recommendation of 6-9 points (2 x 3 or 3 x 3 grid), separated by 100-150 m, and forming a grid with equidistant points (Figure 4.7). The coordinates of the points should be extracted from a GIS software (or from GoogleEarth). Then, a list with the identification codes of all the points and their coordinates (latitude and longitude) should be printed for navigation purposes, and the positions should be saved in a hand-held GPS to be able to find the points in the field.

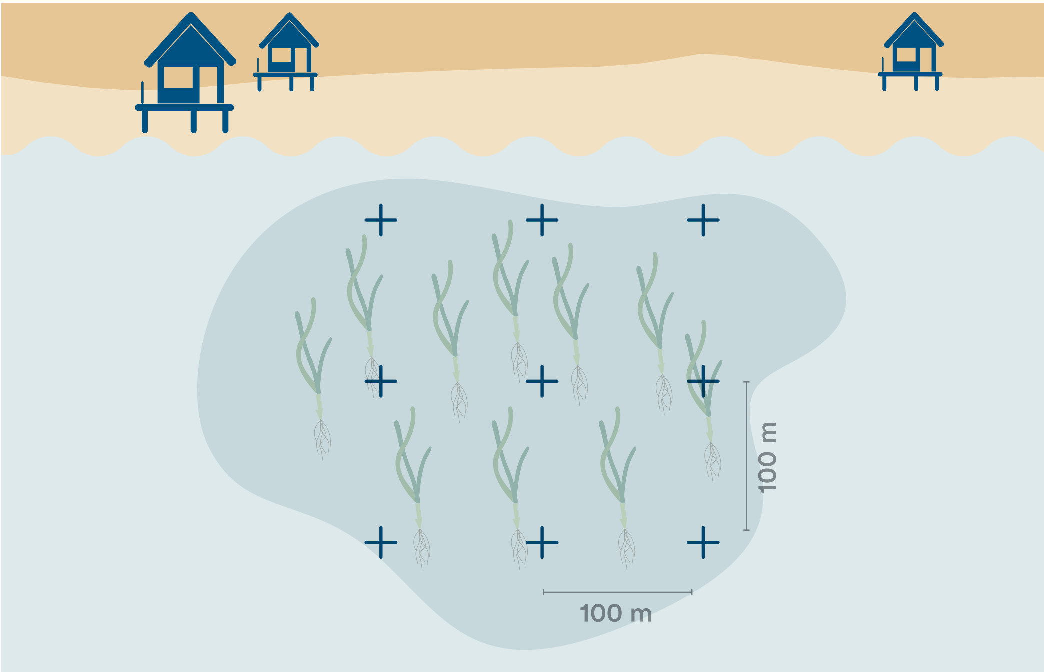

FIGURE 4.7. Diagram showing the setting of points in a defined area for subtidal seagrass meadows. Images adapted from: Integration and Application Network (ian.umces.edu/media-library).

4.5.4.3. **Sampling procedures**

Once you are on board, follow the steps listed below. The field datasheet to be completed is given in Annex 2.3.

• **Positioning.** Locate the position of the first points to visit, using the hand-held GPS. Upon arrival, launch a buoy attached to some weights (2-3 kg) with a rope to mark the point.

• **Water depth.** Note down the time and the depth of the point using a depth measurement device or a sounding line.

• **Descent.** Once at the site, the divers or free divers descend to the seabed with the quadrat.

• **Seagrass percent cover.** The divers place the quadrat on the bottom and estimate total seagrass cover. A total of three quadrats are examined in the nearby area. If SCUBA diving, the three quadrats can be done on the same dive (and the values noted in a waterproof notebook), but for free-divers it can be done over several free-dives. Once at the surface, the divers communicate the percentage values to the team member onboard (to fill in the field datasheet) and check the standardised seagrass cover sheet to confirm the percentages observed.

• **Seagrass species composition.** Identify the species of seagrass within the quadrat and determine the percent contribution of each of them to the total cover, using the seagrass species ID sheet as a guide (Annex 1). Record the values on the field datasheet. Important note: the composition of all species equals 100% regardless of the total cover (e.g., *Cymodocea nodosa* 70%, *Halodule wrightii* 30%).

• **Biomass sample.** During the next dive, the divers leave the quadrat onboard the boat and take the corer and the mesh bag. They descend again and take a biomass sample using the corer. To do so, place the corer on top of the meadow, make sure that the leaves of the shoots inside the corer are also inside, push the corer into the sediment, extract the corer and transfer its contents (seagrass, sediment, and other materials) into the mesh bag. Ascend and transfer the mesh bag to a team member on the boat. They will wash the material with sea water and place the clean seagrass shoots into a pre-labelled bag. This should be the last thing to do at those positions. Record that a biomass sample has been taken on the datasheet for that quadrat. Place the samples in the coolbox in dark and cool conditions until the arrival at your institution. Biomass samples should be taken at every other point, that is, at half of the points, yet evenly distributed across the grid and covering all the depth ranges.

• **Continuation along the grid.** Once you finish at the first point, continue to the next one and repeat the procedure.

• **Meadow limits.** After visiting the points, register the upper and lower meadow limits. To do so, locate the geographical positions of the limits with a hand-held GPS once you reach the limits in both directions (shoreward, i.e., upper limit, and seaward, i.e., lower limit).

Once all the sampling is completed:

- Check that the field datasheet contains all the information required.
- If a waterproof camera was used, rinse it in freshwater immediately.
- Wash the material in the seawater first, and once you are back at your institution, wash it again with freshwater. Let it dry before storage.
- Store the material until the next sampling event.
- Once you are back at your institution, take a picture or scan the field datasheet for digital storage, and enter the data into a datasheet file.
- Process the biomass samples (section 4.5.5.).

4.5.5. PROCEDURES TO OBTAIN BIOMASS AND SHOOT DENSITY FROM THE SAMPLES

Shoot density and biomass are two structural indicators of seagrass meadows. Shoot density is the number of shoots per unit of area (e.g., 240 shoots per square metre) while biomass is the amount of dead or live mass of seagrass tissues per unit of area (e.g., 125 g total alive biomass per square metre). Shoot density is obtained by counting the number of shoots obtained in a sample of known area (in this protocol, the one taken with the corer). To obtain biomass, it is necessary to separate the different seagrass parts, that is, above-ground (leaves) and below-ground (roots and rhizomes) parts. In seagrass meadows, leaf litter (dead leaves, that is, detritus) as well as dead rhizomes and roots in the sediment are often accumulated. Thus, it is necessary to separate the dead and the live seagrass tissues. If more than one species is found in the sample, the biomass fractions must be separated by species, too. Biomass is commonly expressed in units of dry weight, that is, the mass of the sample after having removed the water. For this purpose, the sample is dried in an air-oven at temperatures of 50-60 ºC until constant weight (normally 48-72 hours). If an oven is not available, the fresh weight (that is, the weight of the biomass after blotting it dry with laboratory tissue paper) is also a good estimator.

4.5.5.1. List of material

- Big plastic tray
- Tweezers
- Saltwater (if not available, freshwater is also ok)
- Laboratory tissue paper
- Biomass datasheets (Annex 2.4)
- Pencil and rubber
- Paper bags or envelopes (can be home-made)
- Laboratory oven set at 60 °C (if available)
- Portable battery-operated field balance (precision of at least 0.1 g)
- Box to store the processed samples

4.5.5.2. Procedures

The objective of the biomass sample is to estimate the seagrass biomass (total, above- and belowground, and dead) and the shoot density. If flowers, fruits, or seeds are found in the sample, it should be recorded, too. For this purpose, follow the steps listed below and use the biomass datasheet provided in Annex 2.4.

- Fill in the table at the top part of Annex 2.4, which includes information on the sample ID, the name of the person processing the sample, the date of collection (in the field) and the sample processing date, the area sampled (this is calculated from the diameter of the corer used in the field), the temperature used in the oven to dry the biomass (if applicable), the date when the fresh weight (before the oven) and the dry weight (after the oven) is measured (if applicable), and relevant notes.
- Place your sample on a tray with seawater (if seawater is not available, freshwater is ok, too) (Figure 4.8A).
- Start separating the material, first counting the number of shoots that you find for each species (write the name of the species and the count on the lab datasheet - section A). Dead shoots or shed leaves should not be counted, only the live shoots (i.e., bundle of leaves attached to the rhizome).
- After counting the shoots, separate them by species into live below-ground (roots and rhizomes), live above-ground material (leaves), and dead material (either roots, rhizomes, or leaves) (Figure 4.8A).
- If you find seeds or flowers, record the number on the lab datasheet (section B). Check module 1 to identify the reproductive structures of the seagrass species.
- Once you have counted all the shoots and separated all the material, discard the contents of the tray (animals, etc.).
- Blot dry the seagrass with laboratory paper tissue, making sure that there is no excess water on them.
- Weigh empty labelled paper bags on a balance (Figure 4.8B) and record their labels and weights on the datasheet (section B, columns *Paper bag ID* and *Paper bag empty*, respectively). It is important that the balance is properly levelled. Labels should include the field identification code of the sample (e.g., IW-T1-10m) and the type of tissue (AG: above-ground, BG: below-ground, DM: dead material), and species. For example: IW-T1-10m-AG-CN (this is sample IW-T1-10m, above-ground parts, species *Cymodocea nodosa*).
- Transfer the seagrass tissues to their correspondent paper bags.
- Weigh the bags again on the same balance that was used before (Figure 4.8C). Record the weights on the datasheet (section B, column *Paper bag + fresh weight*). These weights correspond to the fresh weight (FW) plus the weight of the envelope.
- If an oven is available, place the bags with the tissues in it at 60 °C. Bags should be open to allow the water vapour to be released (Figure 4.8D).
- After at least 48 hours, take the paper bags from the oven and weigh them on the same balance that was used before. Record the weights on the datasheet (section B, column *Paper bag + dry weight*). These weights

correspond to the dry weight (DW) plus the weight of the envelope.

- Calculate the DW and FW for the AB, BG and dead biomass as explained in the example on the datasheet.
- Close the paper bags with the samples and store them in a dry place. They might be useful for future works or to confirm the results.
- Take a picture or scan the biomass datasheets for digital storage and enter the data into a datasheet file.

FIGURE 4.8. Pictures showing how a seagrass biomass sample is processed in the laboratory: A) separation of above-ground (leaves) and below-ground (rhizomes and roots) biomass, B) weighing the empty labelled paper bag before putting the biomass inside, C) weighing the paper bag with the biomass inside, D) drying the biomass in the oven. **Photos by:** C.B. de los Santos.

4.5.5.3. Calculations

The estimations of the seagrass biomass and shoot density are obtained from the data recorded on the biomass datasheet and the area of the corers used in the field. It can be calculated either for dry weight (DW) or for fresh weight (FW). These are the formulas:

- Seagrass above-ground biomass estimate (g m^{-2}) = AG biomass / corer area (m^2)
- Seagrass below-ground biomass estimate (g m^{-2}) = AG biomass / corer area (m^2)
- Seagrass dead biomass estimate (g m^{-2}) = Dead biomass / corer area (m^2)
- Seagrass total alive biomass estimate (g m^{-2}) = Total alive biomass / corer area (m^2)
- Seagrass shoot density estimate (shoots m^{-2}) = Number of shoots / corer area (m^2)

1.4. BIBLIOGRAPHY

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ANNEXES

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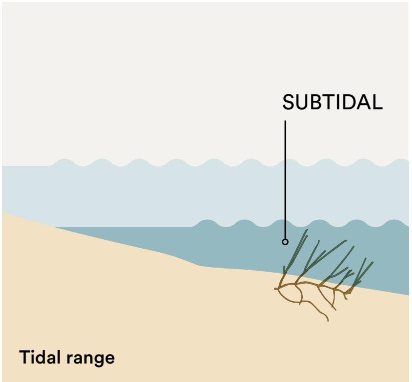
ANNEX 1. SEAGRASS IDENTIFICATION GUIDE

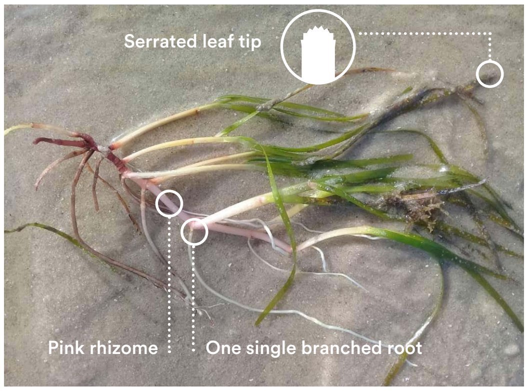
ANNEX 1.1. Summary of morphological features, country of presence, and environment for the 4 seagrass species found in the RAMPAO member countries.

	Cymodocea nodosa	***Zostera noltei***	***Halodule wrightii***	***Ruppia maritima***
Countries	Mauritania, Senegal, The Gambia	Mauritania, Senegal	All countries	Cabo Verde, Mauritania*, Senegal*
Environment	Subtidal	Intertidal	Subtidal	Subtidal
Leaves	3 to 4 leaves per shoot Up to 60 cm long 1.5 to 6.0 mm wide 7-9 veins Rounded serrated leaf tip	2 to 5 leaves per shoot Up to 25 cm long 0.5 to 1.0 mm wide 3 veins Blunt notched leaf tip	2 to 4 leaves per shoot Up to 30 cm long 2.0 to 5.0 mm wide 3 parallel veins Concave leaf tip	Up to 11.5 cm long 0.2 to 0.5 mm wide 1 central vein Acute leaf tip
Rhizomes	> 2 mm thick Pink-brownish	0.5 to 2 mm thick Green-yellow	Thin rhizome White	Thin rhizome Greenish
Roots	1 single root per node Deep roots (up to 35 cm) Strongly branched White	1 to 4 roots per node Shallow roots Non-branched White	3 to 5 roots per node Shallow roots (< 5 cm) Non-branched White with dark point	1 to 2 single roots per node Shallow roots (< 5 cm) Non-branched White
Flowers	Solitary flowers Male flower: pink with a white peduncle	Several flowers on a spear-shaped reproductive shoot	Flowers no longer than 5 mm, positioned on a stem from the leaf sheath, above the sediment	Flowers and fruits on erect branching stem Inflorescence containing 2 flowers
Fruits and seeds	2 lentil-shaped fruits attached to the shoot Seeds buried in the sediment	Seeds 1.5 to 2 mm long, white, and smooth	Fruit 2.0 to 2.5 mm, rounded, olive to tan colour	Seeds 2 to 2.8 mm long, dark brown, pear-shaped

* There are some uncertainties about the presence of *R. maritima* in Senegal and Mauritania.

Cymodocea nodosa





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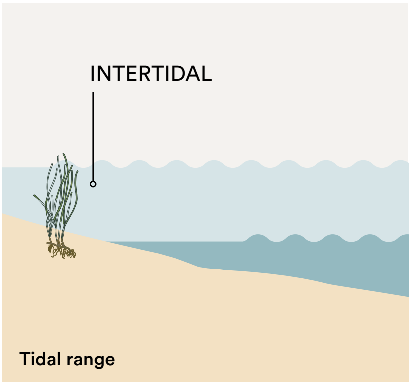
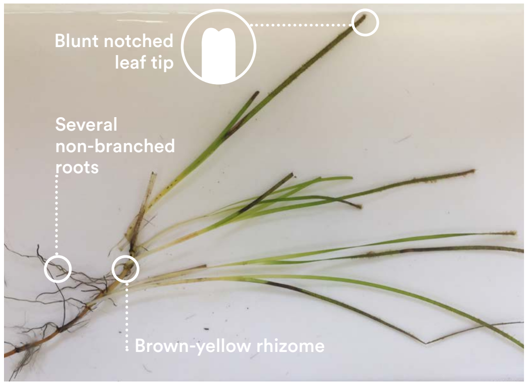
Zostera noltei





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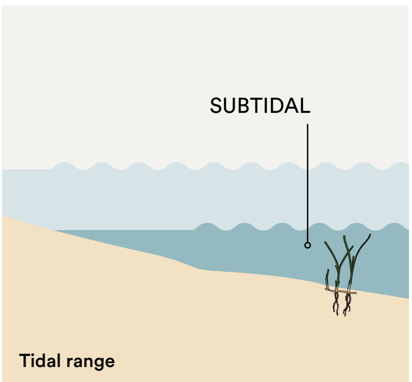
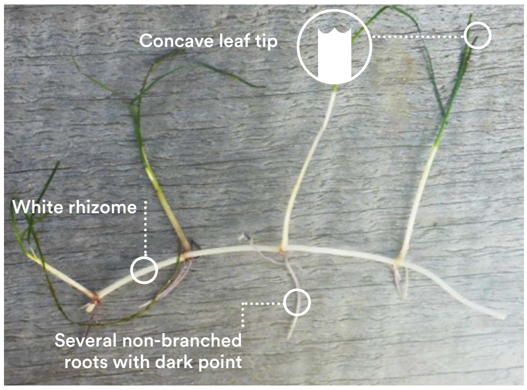
Halodule wrightii





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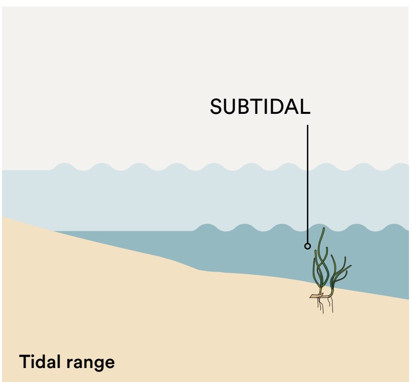
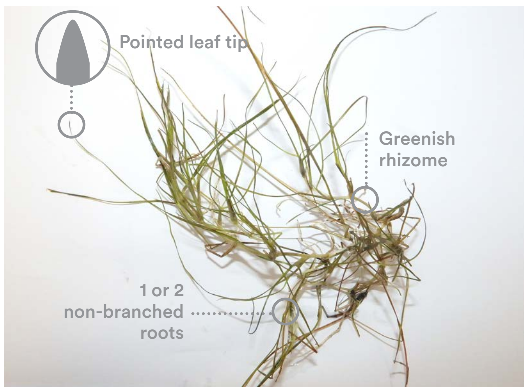
Ruppia maritima





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* There are some uncertainties in the presence of *R. maritima* in Senegal and Mauritania.

Present

Not present (RAMPAO countries)

ANNEX 1.2. Quick guide to seagrass species identification in the RAMPAO member countries.

ANNEX 2. DATASHEETS

ANNEX 2.1. Field datasheet for seagrass mapping *Example*

Date	15 May 2022	**Time**	12:30
Location	Iwik	**Observers**	Carolina, Sidi, Ester.
Method	Subtidal meadow - snorkelling from shore along a transect of 40 m		

- Seagrass species codes: CN: *Cymodocea nodosa*, HW: *Halodule wrightii*, ZN: *Zostera noltei*, RM: *Ruppia maritima*.
- Sediment types: mud, sand, gravel, shell grit.
- Essential information: point ID, GPS record ID, and seagrass presence.

Point ID	GPS point ID	Water depth (m)	Time	Sediment type	Seagrass presence (yes/no)	Seagrass species	% Seagrass cover	Notes
IW-T1-0m	123	0.5	12:30	Sand	No	-	0 %	-
IW-T1-5m	124	0.8	12:35	Sand	No	-	0 %	-
IW-T1-10m	125	1.0	12:40	Sand-Mud	Yes	CN	25 %	Upper meadow limit. Burrowing marks.
IW-T1-15m	126	1.2	12:45	Sand-Mud	Yes	CN	25 %	Turbid water.
IW-T1-20m	127	1.5	12:50	Sand-Mud	Yes	CN	10 %	Turbid water.
IW-T1-25m	128	2.0	12:55	Sand-Mud	Yes	CN	10 %	Lower meadow limit. Turbid water.
IW-T1-30m	129	2.2	13:00	Sand	No	-	0 %	-
IW-T1-35m	130	2.5	13:05	Sand	No	-	0 %	-
IW-T1-40m	131	3.0	13:19	Sand	No	-	0 %	-

ANNEX 2.2. Field datasheet for seagrass monitoring (method fixed transect) *Example*

Date	15 May 2022			**Observers**	Sidi, Carolina, Ester		
Location	Iwik			**Transect**	Transect 2		
Start time	12:30			**End time**	13:10		
START TRANSECT	**Latitude**	19.88040°	**Longitude**	-16.29444°	**END TRANSECT**	**Latitude**	19.88010°	**Longitude**	-16.29408°

- Seagrass species codes: CN: *Cymodocea nodosa*, HW: *Halodule wrightii*, ZN: *Zostera noltei*, RM: *Ruppia maritima*.

Quadrat	Sediment	Picture taken?	% Seagrass cover	Seagrass spp. and % cover			% Algae cover	Canopy height (cm)	Biomass ID	Notes
				ZN	HW					
1 (0 m)	sand	yes	70	100	0		5	10, 9, 8	S1	Many hermit crabs
2 (5 m)	mud, sand	yes	70	100	0		5	12, 10, 11	-	Gastropods
3 (10 m)	mud	yes	70	100	0		5	13, 13, 10	-	
4 (15 m)	mud	yes	90	100	0		10	14, 15, 12	-	
5 (20 m)	mud	yes	90	100	0		0	16, 17, 14	-	
6 (25 m)	mud	yes	90	100	0		0	17, 16, 16	S2	
7 (30 m)	mud	yes	100	100	0		0	15, 17, 18	-	
8 (35 m)	mud	yes	100	100	0		10	19, 19, 18	-	
9 (40 m)	mud	yes	100	90	10		5	22, 20, 19	-	
10 (45 m)	mud	yes	100	90	10		5	20, 24, 22	-	Sea star
11 (50 m)	mud	yes	90	80	20		0	25, 23, 14	S3	Sea cucumber

Distance from START to UPPER limit (m)	2 m	**Distance from START to LOWER limit (m)**	7 m

ANNEX 2.3. Field datasheet for seagrass monitoring (setting points in a defined area) Example

Date	15 May 2022			**Observers**	Sidi, Carolina, Ester		
Location	Iwik			**Method**	Snorkelling, quadrat, biomass 1 in 3 points		
Start time	12:40			**End time**	14:30		
LOW TIDE	**Time**	11:30	**Height (m)** 0.5	**HIGH TIDE**	**Time**	17:40	**Height (m)** 1.5

* Seagrass species codes: CN: Cymodocea nodosa, HW: Halodule wrightii, ZN: Zostera noltei, RM: Ruppia maritima.

Point ID	Water depth (m)	Time	Latitude (°)	Longitude (°)	% Seagrass cover	Seagrass species			Biomass ID	Notes
						CN	HW			
IW-1	1.0	12:40	19.898426°	-16.278200°	40	90	10		S4	Many green algae.
IW-2	1.0	12:50	19.897420°	-16.278997°	40	90	10		-	
IW-3	1.2	13:00	19.896247°	-16.280049°	50	100	0		-	
IW-4	2.4	13:10	19.897486°	-16.277102°	30	100	0		S5	
IW-5	2.5	13:20	19.896677°	-16.278033°	20	100	0		-	
IW-6	2.3	13:30	19.895463°	-16.279066°	30	100	0		-	
IW-7	3.0	13:40	19.896547°	-16.276031°	10	100	0		S6	
IW-8	3.1	13:50	19.895800°	-16.276840°	0	100	0		-	Turbid water, seagrass not seen.
IW-9	3.4	14:00	19.894860°	-16.277868°	5	100	0		-	Just a few shoots.

Position UPPER limit (°)	19.898426° -16.278200°	**Position LOWER limit (°)**	19.894860° -16.277868°

ANNEX 2.4. Laboratory datasheet for seagrass biomass (two sections A and B) Example

Sample ID	IW-T1-10m	**Person**	Sidi
Collection date	15 May 2022	**Date processing**	15 May 2022
Area sampled (m²)	20 cm diameter > 0.0314 m2	**Oven temperature (°C)**	60 °C
Date fresh weight	15 May 2022	**Date dry weight**	17 May 2022
Notes	Samples were stored after weighing the dry weight in box number #4.		

SECTION A - SEAGRASS SHOOT COUNTING

Mark one cell for each shoot you count for each species, then calculate the total number (each line has 50 cells).

COUNTING

Species 1	*Cymodocea nodosa*
Species 2	*Halodule wrightii*

CALCULATIONS

	Total number of shoots	Sample area (m²)	Shoot density (shoots m⁻²)	Notes
Species 1	12	0.0314	12 / 0.0314 = 350	Many leaves detached from shoots
Species 2	16	0.0314	16 / 0.0314 = 509	-
All species	12 + 16 = 28	0.0314	28 / 0.0314 = 891	-

SECTION B - SEAGRASS BIOMASS AND REPRODUCTIVE STRUCTURES

Enter the weights for each item, then calculate the total, aboveground (leaves), belowground (rhizomes and roots), and dead seagrass biomass.
If more than one species is found in the sample, fill in one datasheet for each of them.

Species	*Cymodocea nodosa*

WEIGHTS

	Paper bag ID	Paper bag empty (g)	Paper bag + fresh weight (g)	Paper bag + dry weight (g)	Notes
Above-ground biomass	IW-T1-10m-AG	5.2	11.7	9.0	-
Below-ground biomass	IW-T1-10m-BG	5.5	13.3	10.1	-
Total dead biomass	IW-T1-10m-DM	5.3	9.8	6.5	-

CALCULATIONS

	Fresh weight (g)	Dry weight (g)	Sampled area (m²)	Fresh weight biomass (g FW m⁻²)	Dry weight biomass (g DW m⁻²)
Above-ground biomass	11.7 – 5.2 = 6.5	9.0 – 5.2 = 3.8	0.0314	6.5 / 0.0314 = 205.7	3.8 / 0.0314 = 121.0
Below-ground biomass	13.3 – 5.5 = 7.8	10.1 – 5.5 = 4.6	0.0314	7.8 / 0.0314 = 249.0	4.6 / 0.0314 = 146.5
Total biomass	6.5 + 7.8 = 14.3	3.8 + 4.6 = 8.4	0.0314	14.3 / 0.0314 = 454.8	8.4 / 0.0314 = 267.5
Total dead biomass	9.8 – 5.3 = 4.5	6.5 – 5.3 = 1.2	0.0314	4.5 / 0.0314 = 143.3	1.2 / 0.0314 = 38.2

REPRODUCTIVE STRUCTURES

	Number	Notes
Seeds or fruits	0	-
Flowers	1	Male flower of *Cymodocea nodosa*!

ANNEX 2.1. Field datasheet for seagrass mapping

Date		**Time**	
Location		**Observers**	
Method			

- Seagrass species codes: CN: *Cymodocea nodosa*, HW: *Halodule wrightii*, ZN: *Zostera noltei*, RM: *Ruppia maritima*.
- Sediment types: mud, sand, gravel, shell grit.
- Essential information: point ID, GPS record ID, and seagrass presence.

Point ID	GPS point ID	Water depth (m)	Time	Sediment type	Seagrass presence (yes/no)	Seagrass species	% Seagrass cover	Notes

ANNEX 2.2. Field datasheet for seagrass monitoring (method fixed transect)

Date					**Observers**				
Location					**Transect**				
Start time					**End time**				
START TRANSECT	**Latitude**		**Longitude**		**END TRANSECT**	**Latitude**		**Longitude**	

- Seagrass species codes: CN: *Cymodocea nodosa*, HW: *Halodule wrightii*, ZN: *Zostera noltei*, RM: *Ruppia maritima*.

Quadrat	**Sediment**	**Picture taken?**	**% Seagrass cover**	**Seagrass spp. and % cover**			**% Algae cover**	**Canopy height (cm)**	**Biomass ID**	**Notes**
1 (0 m)										
2 (5 m)										
3 (10 m)										
4 (15 m)										
5 (20 m)										
6 (25 m)										
7 (30 m)										
8 (35 m)										
9 (40 m)										
10 (45 m)										
11 (50 m)										

Distance from START to UPPER limit (m)		**Distance from START to LOWER limit (m)**	

ANNEX 2.3. Field datasheet for seagrass monitoring (setting points in a defined area)

Date				Observers			
Location				Method			
Start time				End time			
LOW TIDE	Time		Height (m)	HIGH TIDE	Time		Height (m)

- Seagrass species codes: CN: *Cymodocea nodosa*, HW: *Halodule wrightii*, ZN: *Zostera noltei*, RM: *Ruppia maritima*.

Point ID	Water depth (m)	Time	Latitude (°)	Longitude (°)	% Seagrass cover	Seagrass spp. and % cover			Seagrass species	Biomass ID	Notes

Position UPPER limit (°)		Position LOWER limit (°)	

ANNEX 2.4. Laboratory datasheet for seagrass biomass (two sections A and B)

Sample ID		**Person**	
Collection date		**Date processing**	
Area sampled (m²)		**Oven temperature (°C)**	
Date fresh weight		**Date dry weight**	
Notes			

SECTION A - SEAGRASS SHOOT COUNTING
Mark one cell for each shoot you count for each species, then calculate the total number (each line has 50 cells).

COUNTING

Species 1																																																	
Species 2																																																	

CALCULATIONS

	Total number of shoots	Sample area (m²)	Shoot density (shoots m⁻²)	Notes
Species 1				
Species 2				
All species				

ANNEX 2.4. Laboratory datasheet for seagrass biomass (two sections A and B)

SECTION B - SEAGRASS BIOMASS AND REPRODUCTIVE STRUCTURES

Enter the weights for each item, then calculate the total, aboveground (leaves), belowground (rhizomes and roots), and dead seagrass biomass.
If more than one species is found in the sample, fill in one datasheet for each of them.

Species	

WEIGHTS

	Paper bag ID	Paper bag empty (g)	Paper bag + fresh weight (g)	Paper bag + dry weight (g)	Notes
Above-ground biomass					
Below-ground biomass					
Total dead biomass					

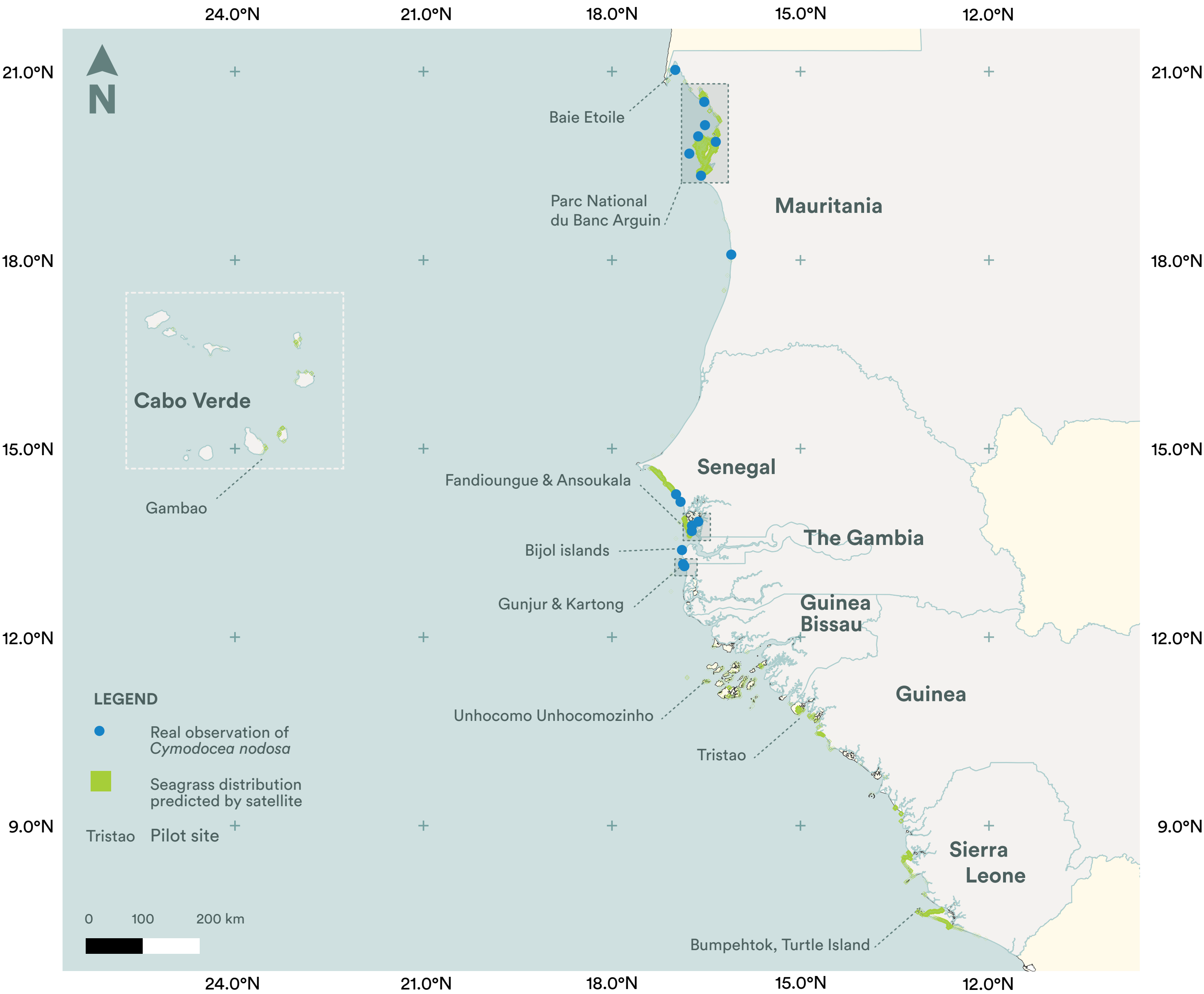
CALCULATIONS

	Fresh weight (g)	Dry weight (g)	Sampled area (m^2)	Fresh weight biomass (g FW m^{-2})	Dry weight biomass (g DW m^{-2})
Above-ground biomass					
Below-ground biomass					
Total biomass					
Total dead biomass					

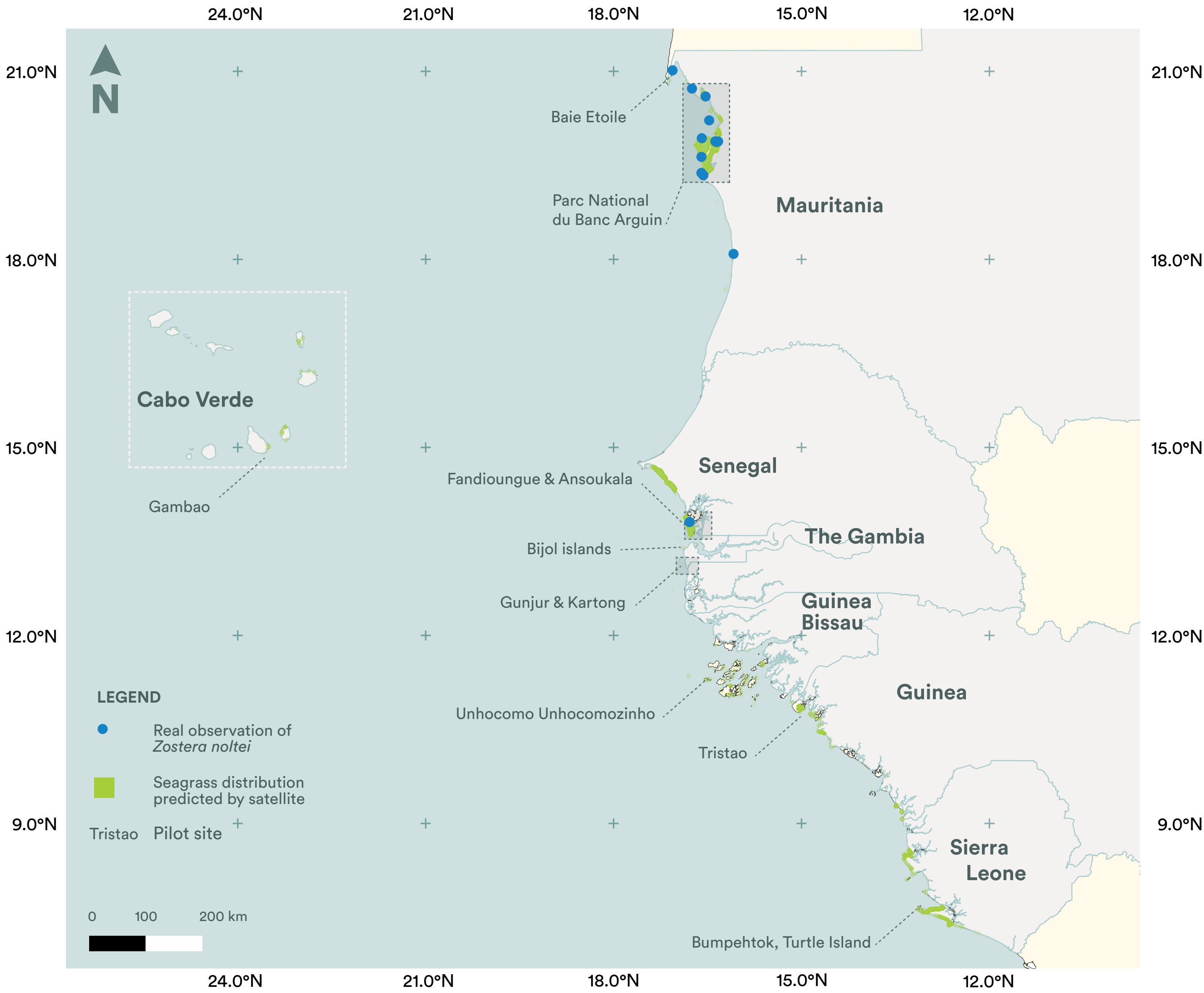
REPRODUCTIVE STRUCTURES

	Number	Notes
Seeds or fruits		
Flowers		

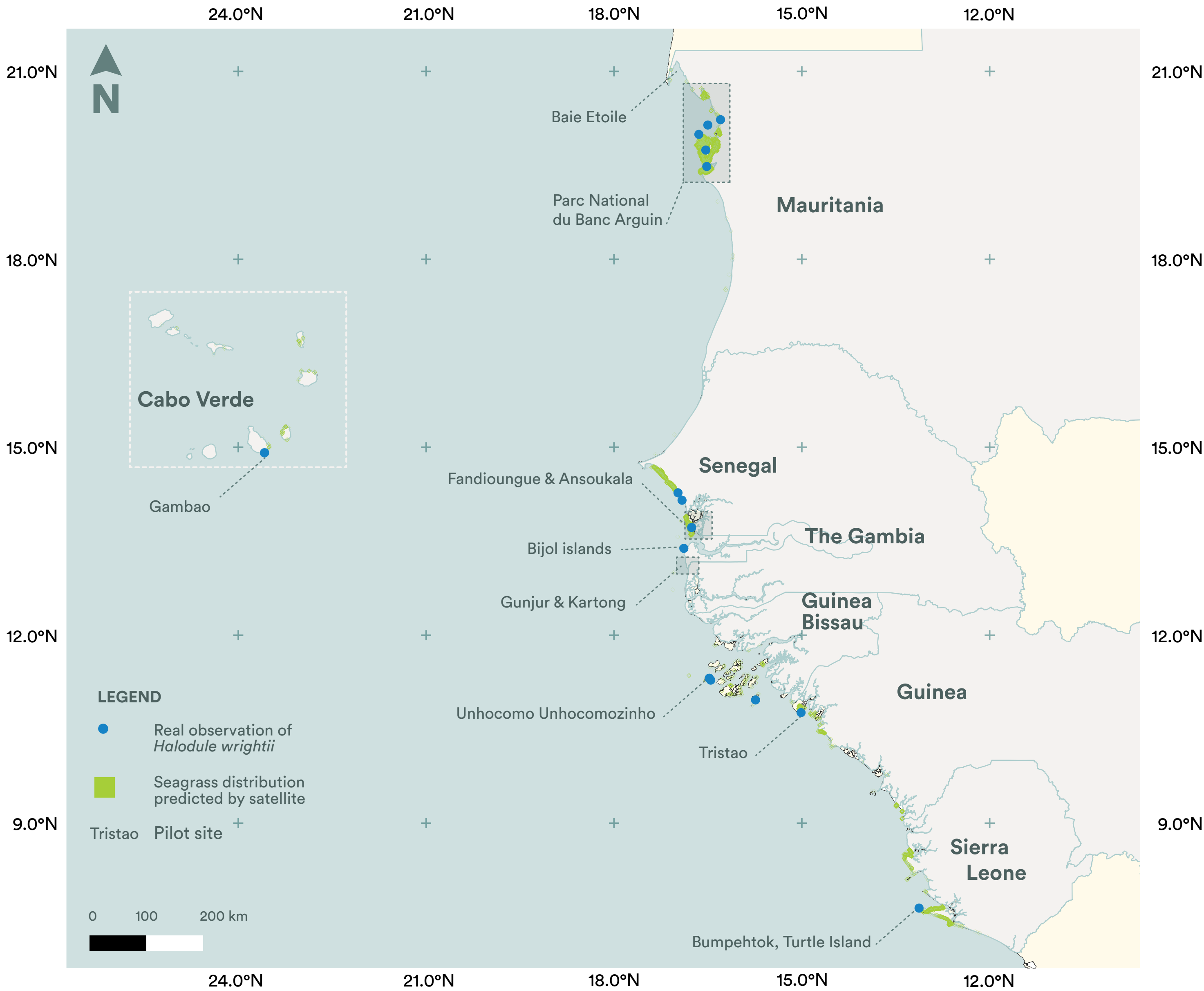
ANNEX 3. SEAGRASS DISTRIBUTION MAPS IN THE RAMPAO MEMBER COUNTRIES



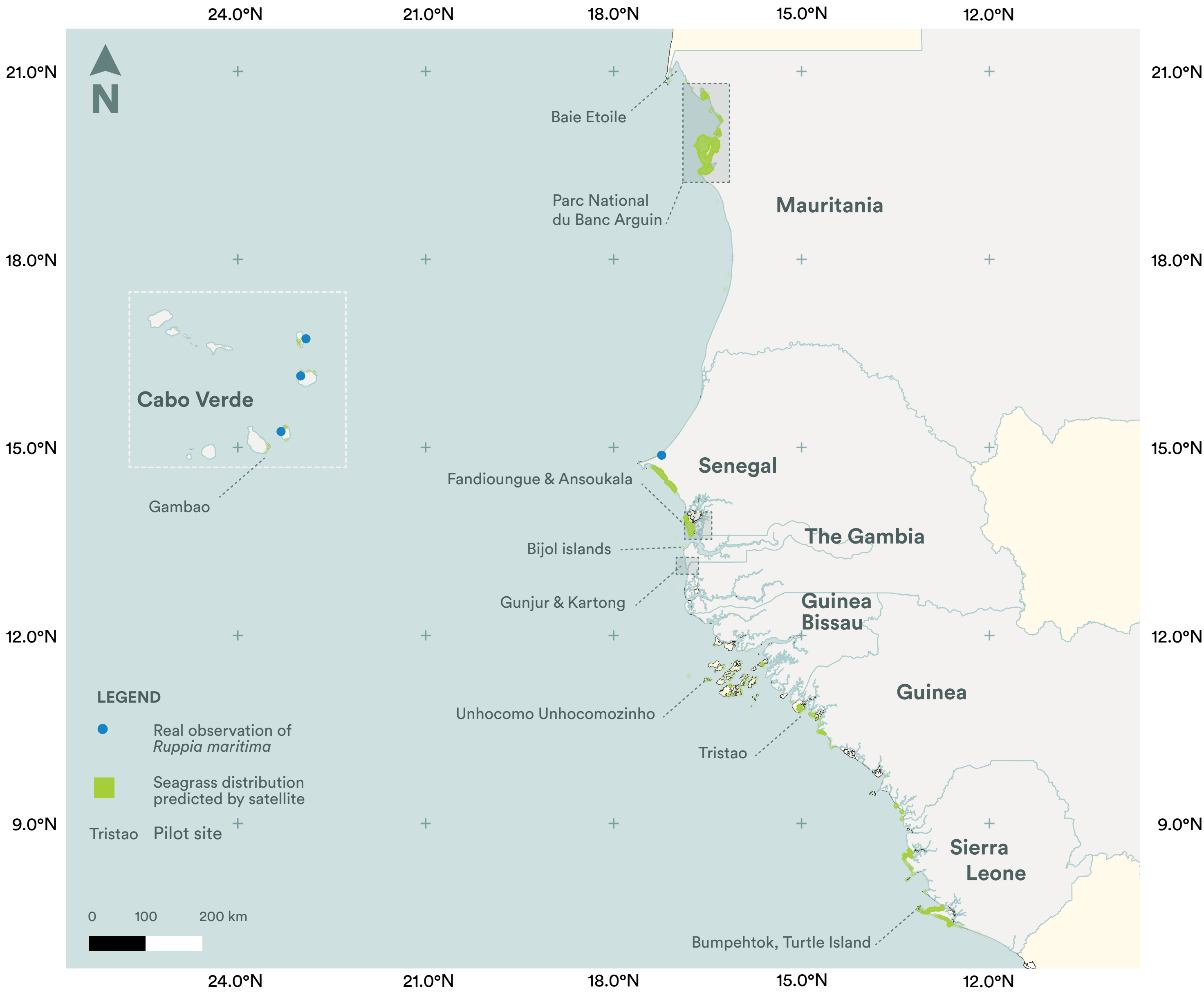
ANNEX 3.1. *Cymodocea nodosa* distribution in the RAMPAO member countries.



ANNEX 3.2. *Zostera noltei* distribution in the RAMPAO member countries.



ANNEX 3.3. *Halodule wrightii* distribution in the RAMPAO member countries.



ANNEX 3.4. *Ruppia maritima* distribution in the RAMPAO member countries.

TRAINING MANUAL FOR

SEAGRASS

MONITORING AND MANAGEMENT IN THE RAMPAO MEMBER COUNTRIES

This training manual aims to improve knowledge, raise awareness, and provide appropriate working tools to managers and other users of MPAs in the RAMPAO network for the protection and conservation of seagrass habitats. Its preparation used a participatory approach, through consultation with MPA managers and other conservation stakeholders from seven RAMPAO member countries (Cabo Verde, The Gambia, Guinea, Guinea Bissau, Mauritania, Senegal and Sierra Leone), with the aim of identifying their capacity building needs and gaining a better understanding of the threats facing seagrass beds in West Africa.

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