Chapter 3
Mangroves and Seagrasses

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Abstract Mangroves and seagrass contribute to people's quality of life, taking an important place in the Blue Economy context. Activities such as fishing contribute to the national economies of many developing nations. Carbon sequestration in these systems is considered among the most effective among ecosystem types—even including terrestrial systems—and helps mitigate climate change impacts. Nature-based tourism activities, including in mangrove and seagrass systems, add to the conservation values of these systems, engaging both stakeholders and local communities and generating income through these activities. Biotechnology research and new studies continually reveal the potential of these blue systems for discovery of marine natural products that could be important for medicine, cosmetics, and other products. Despite their importance and potential, mangrove and seagrass systems are under-considered by decision-makers as vulnerable environments, faced by several threats, which has led to decreased areas of these systems. For our future and better exploration of their potential in the blue economy context, mapping Blue Carbon Ecosystems, implementation of restoration programs, and incorporating the

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ecosystem services they provide into financial valuation frameworks need to be urgent priorities all over the world, especially in developing countries.

Keywords Ecosystem services · Ecosystem management · Sustainable Development Goals · Remote sensing techniques

3.1 Introduction

Human communities depend on coastal ecosystems to sustain them, but the continued health of coastal ecosystems depend on their careful use. In these coastal environments, several conflicts are triggered by the multiple uses of natural resources, sometimes conflicting, such as fishing and tourism. Although these activities are often not the most impactful, they are sectors of the blue economy that must be managed appropriately to achieve their potential for sustainable use. Many developing coastal and island nations depend on tourism and fisheries for a significant part of their gross domestic product and public revenues. Coastal tourism is a key component of small island state economies (World Bank 2016) (see also Chap. 6 on Tourism). The impacts of overfishing, coastal development, pollution, and climate change are being felt by coastal communities around the world. However, countries are looking to the ocean as a new frontier for food security, poverty reduction, and economic growth (Patil et al. 2016). The need to balance the economic, social, and environmental dimensions of sustainable development in relation to the ocean is a key component of the blue economy (World Bank 2017).

Protection of coastal ecosystems relates to the United Nations Decade of Ocean Science for Sustainable Development and Agenda 2030 Sustainable Development Goals (SDGs), especially SDG 14 (Life below Water). As noted in Chap. 1, blue economies balance economic, social and environmental benefits, and may require development paradigms other than those historically considered. These triple pillars reflect the SDGs, which are now the primary instruments that frame the international policy context. The unique importance of the ocean, and the challenges it faces, are reflected in SDG 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development,' and the seven targets that underpin it. Other SDGs also have to be considered, such as SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 6 (Clean Water and Sanitation) SDG 13 (Climate Action) and SDG 15 (Life on Land). As key ecosystems that promote a productive ocean, keeping blue carbon ecosystems healthy maintains the quality of life of human populations on the planet.

Although mangroves make up less than 1% of all tropical forests worldwide, they are highly valuable ecosystems, providing an array of essential goods and services which contribute significantly to the livelihoods, well-being, and security of coastal communities (Fig. 3.1). The complex network of mangrove roots can help reduce wave energy, limiting erosion and shielding coastal communities from the destructive forces of tropical storms. Mangrove ecosystems are often an essential source of

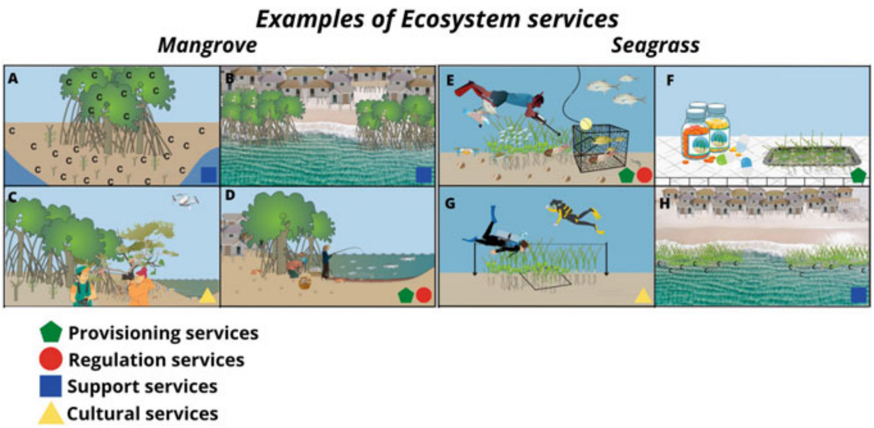

Fig. 3.1 Examples of ecosystem services of mangroves and seagrasses. **a** carbon sequestration and storage; **b** coastal protection; **c** recreation activities; **d** fishing and food provisioning; **e** fisheries; **f** medicine; **g** research and monitoring; **h** carbon sequestration and storage and shoreline protection. Art: Gabriel Henrique Silva @gabriielnk. Diagram symbols are from the Integration and Application Network, University of Maryland Center for Environmental Science (http://ian.umces.edu/imagelibrary/)

seafood for both subsistence consumption and the local and national seafood trade, in addition to providing other materials (e.g., firewood and timber) that support the livelihoods of thousands of coastal communities. Beyond their direct benefits, mangroves also play an important role in global climate regulation. On average, they store around 1000 tons of carbon per hectare in their biomass and underlying soil, making them some of the most carbon-rich ecosystems on the planet. Despite their value, mangrove ecosystems are one of the most threatened on the planet (UNEP 2014).

With the recently increased recognition of the seagrass contribution to people's quality of life (McKenzie et al. 2021), as well as the ecosystem services they provide (Nordlund et al. 2016), seagrasses are also considered, together with mangroves, as fundamental ecosystems in the Blue Economy context (Steven et al. 2019). Seagrasses are submersed marine flowering plants represented by approximately 72 species distributed on estuaries and coastal shores of at least 191 countries, up to a maximum depth of 60 m (Silva et al. 2021). Seagrass meadows are under-mapped, but recent estimates suggest that their cover may range from 160,387 km^2 to 266,562 km^2 worldwide (McKenzie et al. 2020). Although not well represented in management plans and under-considered by authorities, decision-makers and stakeholders, seagrass systems play a significant role in supporting food security as they provide nursery habitat for over 20% of the world's main fisheries (Unsworth et al. 2018). The wide range of ecosystem services they provide may vary among species and bioregions (Nordlund et al. 2016), but are enhanced by their connectivity to other coastal ecosystems like coral reefs and mangroves.

Mangroves and seagrasses are considered vulnerable environments, subject to several threats, such as the loss and fragmentation of vegetation cover and deterioration of the quality of aquatic habitats. Such deterioration is mainly due to development for human use and pollution and changes in hydrodynamics, which has decreased the supply of resources on which many traditional communities and sectors depend directly to survive, such as the communities of artisanal fishers (MMA 2018).

3.2 Role in the Blue Economy

Mangroves and seagrasses contribute to the blue economy in several aspects, in line with SDG 14 (Life Below Water): carbon sequestration and storage, nursery for commercially and socially important fish species, sediment retention and stabilization, port activities viability, among others. Understanding the importance of these systems for small-scale fishers is relevant to several SDGs, especially SDG 14, which includes the aim of promoting small-scale fishers' access to "marine resources and markets (SDG 14.b)". Therefore, effective management of mangrove areas with high fishing intensity should be prioritized (Zu Ermgassen et al. 2020), as well as for seagrass, as degradation of these ecosystems severely affects fisheries (Nordlund et al. 2018).

3.2.1 Blue Carbon

The carbon market is an instrument to monetize reductions of greenhouse gas (GHG) emissions by providing compensation for each unit of carbon sequestered and/or stored (Perdan and Azapagic 2011). It is based on the concept that the carbon stored in ecosystems can be quantified and traded as credits by buyers (public and private) who need to offset their emissions. Such carbon credits are verified through standards that determine their verification and certification, and establish registration and enforcement systems. The credits are then sold either on the compliance market, in which parties such as national governments or members of industry are obliged to reduce their emissions under a treaty, or on the voluntary market, in which buyers buy credits voluntarily in an effort to be more sustainable (Wylie et al. 2016).

The creation of an international regulatory framework to counter global warming is the core of a market for carbon offsets. The United Nations Framework Convention on Climate Change in 1992 aimed for the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic human-induced interference with the climate system" (Kyoto Protocol 1998). From 1997 onwards, the carbon market expanded considerably with the establishment of the Kyoto Protocol and regional initiatives such as the European Union Emissions Trading Scheme (EU ETS) and the U.S. Regional Greenhouse Gas Initiative (RGGI).

In this context, the term "blue carbon" (BC) refers to the organic carbon that is accumulated by specific coastal wetlands ecosystems (Blue Carbon Ecosystems—BCEs) which, despite their relatively small global extent, are disproportionately important in sequestering carbon dioxide when compared with terrestrial habitats (referred as "green carbon") (McLeod et al. 2011). These BCEs include vegetated environments such as mangroves, tidal marshes, and seagrass meadows, which not only incorporate atmospheric carbon in their living biomass, but also in the substrate enhanced by anoxic and saturated conditions, which prevents the action of bacteria on the organic matter they produce. This carbon originates mainly from plant roots, although woody tissue and leaf litter can also contribute to the carbon deposited in these environments (Lovelock and Reef 2020).The carbon stored in these ecosystems may originate within the BCE ecosystems, when it is gathered from plant biomass debris; or may enter the BCE system from external sources when it is brought through the currents, being deposited in the soil for centuries or millennia (Mateo et al. 2006). Carbon storage is affected not only by vegetation characteristics, but also by biochemical and sedimentary substrate factors such as sedimentation rate and organic matter decomposition.

Numerous studies and research have been conducted in order to quantify the amount of BC sequestered in coastal systems. The most recent estimates (Macreadie et al. 2021) reveal that global distribution of BC is stored in ~36–185 million ha of coastal ecosystems, potentially storing ~8970–32,650 teragrams (Tg). Protecting existing BCE could avoid emissions of 304 (95% confidence interval bounds of 141–466) Tg carbon dioxide equivalent (CO_2e) per year and large-scale restoration could remove an extra 841 (621–1064) Tg CO_2e per year by 2030, equivalent to ~3% (0.5–0.8% from protection and 2.3–2.5% from restoration) of annual global greenhouse gas emissions.

3.2.1.1 Mangroves

Mangrove habitat is among the coastal blue carbon components that provides economically and ecologically significant ecosystem services, including carbon and nutrient sequestration, due to the high primary productivity and efficiency in carbon storage and nutrients in soils. Numerous studies and research have been conducted to quantify the amount of carbon sequestered in mangroves, given the high values involved in the BC market associated with these ecosystems.

However, there are some considerations regarding the concepts and definitions of blue carbon in the form of mangroves. First, the term "carbon sequestration" refers to the process of carbon absorption by these ecosystems, mainly the Net Primary Production (NPP), whose main factors are associated to the type of structure (species, density), nutrient availability and ecological and environmental settings that determine the aboveground biomass accumulation (Alongi 2014). On the other hand, the term "carbon stock" alludes to the total carbon stored in the plant and in the soils underneath the trees, and in the long-lived tissues (e.g., roots and wood) of the plants themselves (Vanderklift et al. 2019). Such carbon stock accumulation is generally associated with more complex long-term processes over tens of thousands of years, and involves not only vegetation characteristics, but also biochemical and sedimentary factors such as sedimentation rate and organic matter decomposition. Thus, the amount of carbon sequestered per unit of mangrove can be highly variable, according to the coastal geomorphological and geological settings that determine aspects of sedimentary processes, nutrient loads and limitations (e.g., the nitrogen-to-phosphorus [N:P] stoichiometric ratio), organic matter decomposition, and, ultimately, C storage in vegetation (Twilley et al. 2018). For example, C sequestration is enhanced in deltaic environments because rivers continuously deposit sediment in mangrove soils, leading to higher C sinking rates (Breithaupt et al. 2012; Cragg et al. 2020). However, fluvial sediments tend to have less organic matter associated, so deltaic mangrove substrates have a relatively low C content by volume. In contrast, in carbonate settings such as in Florida Everglades, Australia, and Caribbean islands, most of the BC volume is associated with the mangrove tree mass, leading to higher C stocks (Breithaupt et al. 2020). But, soils form in deltas more quickly than mangrove trees grow, since rivers are always depositing new sediment (Kusumaningtyasa et al. 2019).

Even taking these uncertainties into account, new estimates show that the global storage of C in mangrove biomass is estimated at 6.4 petagrams (Pg), which equates to only 0.4–7% of terrestrial ecosystem C_{org} stocks, but 17% of total tropical marine C_{org} stocks (Alongi 2020); 70% of this C occurs in equatorial and tropical coastal margins from 0° to 10° N and S latitudes. The average rate of wood production is 12.08 megagrams (Mg) ha^{-1} yr^{-1}, which is equivalent to a global estimate of cumulative sequestration potential of 24.0 ± 3.2 MtC yr^{-1} (million tons—or megatons—of carbon per year) for mangroves (Bertram et al. 2021).

Mangrove BC projects around the world are currently being implemented through a wide range of methodologies and funding mechanisms but, in general, there are two ways to promote the market for BC focused on mangroves, both in voluntary and compliance markets: through incentives for conservation and restoration (Wylie et al. 2016). In the case of conservation, the aim is to prevent the loss of carbon from mangrove ecosystems by maintaining natural geochemical and biophysical processes in order to avoid the loss of this carbon to the atmosphere. Given the alarming loss of mangrove areas—specifically from changes in land use through logging and degradation of areas due to variations in climate regime and sea level—the enhancement of conservation programs can be very important for such environments to maintain existing carbon stores and increase the rate of carbon sequestration.

In restoration programs, on the other hand, there is an effort to replant mangrove forests in areas already deforested or in the process of degradation. These projects, in most cases, are based on local or regional actions and are often associated not only with the recovery of mangrove areas aiming for the BC market, but also focusing on the regeneration and rehabilitation of other ecosystem services such as artisanal fisheries and tourism (see Sect. 2.2).

Conservation programs for mangrove ecosystems using project-based approaches tend to be more effective than restoration programs, considering their implementation, legislation or control actions. In the case of restoration programs, there is a need for high investment for the recovery of areas; moreover, in many cases, the general condition of the region has already been so altered that the planting of new mangrove forests is extremely difficult and not cost-effective. However, both conservation and restoration contribute to climate change adaptation, and therefore restoration offers opportunities to develop market-based mechanisms that take advantage of existing frameworks for carbon offsets (Macreadie et al. 2021).

Mangrove carbon markets are currently constrained by gaps in knowledge on the potential climate mitigation benefits and financial return on investment of mangrove blue carbon projects at national, regional, and global scales (Zeng et al. 2021). There are many technical and methodological difficulties in quantifying the rate of carbon sequestered in soils in reforested areas, which makes it difficult to establish certifications and regulations for accessing the carbon compliance or volunteer markets.

Therefore, one of the most important issues regarding the implementation of large-scale funding programs for conservation and restoration of BC in mangroves is the generation of accurate information about not only the areas of mangrove cover around the world, but also their biophysical characteristics and environmental settings (Howard et al. 2014). Pham et al. (2019) provided a critical overview of the most common mapping and monitoring techniques used for Blue Carbon Ecosystems and found that, in local or regional scales, most of the studies that established quantitative measurements of BC from spectral remote sensing in mangroves were based on regression models from medium-resolution images (e.g., Landsat and Sentinel satellites) and had varying degrees of accuracy depending on the characteristics of the mapped areas, ground truthing and the image processing and classification methodologies (see Pham et al. 2019; Rovai and Twilley 2021; Stankovic et al. 2021, and references within). Thus, the estimated mangrove areas as well as the quantities of BC can vary significantly depending on the precision and accuracy of the techniques used (Fatoyinbo et al. 2018).

3.2.1.2 Seagrasses

Seagrass meadows alter the biogeochemical cycles of nutrients in the coastal zone, significantly contributing to some bacteria groups and reducing human impacts on the coastal ecosystems by absorbing nutrients and other pollutants. They are important systems for carbon cycling, mainly because of their broad distribution in the coastal zones, with high sediment organic content and productivity (Kennedy et al. 2010). Carbon sequestration is considered one of the most relevant ecosystem services provided by seagrass meadows, mitigating global warming (Duarte and Krause-Jansen 2017), but also increasing resilience of coastal environments (Barañano et al. 2018).

Seagrass meadows are one of the main carbon sinks in the ocean, as they store around 20% of the total carbon stored by marine ecosystems and can contain 2–15 times more carbon than terrestrial ecosystems per area, with an export of 30% (approximately 24 Tg year^{-1}) of carbon to the deep sea (Duarte et al. 2005; Kennedy et al. 2010; Fourqurean et al. 2012; Duarte and Krause-Jensen 2017). Several factors may influence the carbon capture and storage in seagrass meadows, including the species composition, growth rates and structural complexity of the plants, landscape (patched or continuous), trophic web imbalance (herbivory, presence of invasive species, extinction of the top predator), environmental interactions (high temperatures, high organic supply, low water motion, low turbidity, low sediment grain size, depth, nutrient availability and geographical location), and other circumstances such as material export, burial rates, anoxic conditions and a low decomposition rate of the sediment that affect the carbon accumulation (Mateo et al. 2006; Duarte and Krause-Jensen 2017).

The carbon accumulated in the seagrass soil is almost always derived from below-ground biomass; carbon originating from leaves has a short residence time in the detrital compartment, although this compartment comprises a short-term sink of organic carbon accumulated after the first year and subject to biological degradation (Mateo et al. 2006). Long-term carbon storage is derived from below-ground tissues, dead and buried in the soil, with material that can be only affected by geochemical processes (Mateo et al. 2006). The first layer of 1 m of the sediment of seagrass meadows can contain about 40 times more carbon than that found in the living biomass, being approximately 74% of the carbon stored below ground (Ganguly et al. 2017).

The importance of seagrass meadows—especially as carbon sinks and thus to climate change mitigation—has been emphasized in recent decades. However, seagrass meadows remain forgotten in global models of the carbon cycle and traditional programs for reduction of greenhouse gas effects (Duarte and Krause-Jensen 2017). Table 3.1 summarizes the values of global cover and C stock and C burial rate of mangroves, seagrasses, and saltmarshes.

Restoring and managing mangrove and seagrass ecosystems for climate change mitigation and adaptation is challenging, but feasible, with the potential to extract an extra 841 Tg CO_2 per year by the year 2030 (Macreadie et al. 2021). However, these systems can provide several additional benefits beyond the issue of the BC itself, including ecosystem services that can benefit the economy at local, regional and national levels.

Table 3.1 Values of global cover, carbon stock and carbon burial rate of coastal Blue Carbon Ecosystems

Ecosystem	Global cover (km^2)	Global C stock ($Mg\ C\ km^{-2}$)	Global C burial rate ($Tg\ C\ yr^{-1}$)
Mangroves	81,485[1]	3.86[2]	23.6[3]
Seagrasses	160,387–266,562[4]	1.08[5]	48–112[6]
Saltmarshes	54,951[7]	2.55[2]	60.4[3]

Legend 1-Hamilton and Casey (2016); 2-IPCC (2014); 3-Duarte et al. (2005); 4-McKenzie et al. (2020); 5-Fourqurean et al. (2012); 6-McLeod et al. (2011); 7-Mcowen et al. (2017)

3.2.2 *Fisheries (See Also Chap. 4)*

Human uses are diverse, in terms of raw material, food, and their relative importance in the blue economy. On a global scale, small-scale fisheries are important in many developing countries, not only by contributions to national economies, but also as a critical source of food and employment in many parts of the world where there are few alternative livelihoods and protein sources. The importance of food security and the association of many fisheries with healthy mangrove forests is obvious at national scales, particularly in Asia, West and Central Africa and in South America (Zu Ermgassen et al. 2020). Similar is the case regarding the importance of seagrass meadows to fishing activities, as they provide an environment for commercial and non-commercial species (but are also important in the food chain of other species in the ecosystem) as nursery areas for growth, feeding and protection (Gillanders 2006).

3.2.2.1 Mangroves

The importance of mangrove areas for fishing activity is well known, as highly productive environments of coastal food chains, hosting a huge range of organisms permanently or temporarily, and often providing especially productive activities for coastal populations, such as fishing communities (Sukardjo 2004; Sulochanan 2013). However, many estimated numbers of fish supported by mangrove systems around the world are unreliable, being generally based on catch delivered to ports, making it difficult to relate catches to specific mangrove areas (Hutchison et al. 2014a, b). Many studies have valued mangroves, but these values are relative, with a huge variation caused by local characteristics, which do not faithfully reflect the importance of these areas for fishing activity. In any case, values expressed in simple catch statistics, in monetary terms or other metrics, are site-specific and are useful in these places where management decisions, conservation actions and fishing activities take place (Hutchison et al. 2014a, b).

Many fisheries occur near mangrove areas, whether fishery products are attached to the roots of vegetation (e.g., mollusks), totally dependent products (e.g., crabs), or products that need the mangrove areas for food, growth or protection (e.g., various fish). The number of fishers associated with mangrove areas was recently estimated at 4.1 million individuals around the world, with the highest number of mangrove fishers found in Indonesia, India, Bangladesh, Myanmar, and Brazil (Zu Ermgassen et al. 2020).

It is observed in Brazil, for example, that a significant number of fishers depend on fishing in mangrove areas. In this coastline of almost 8000 km, there are 14 thousand km^2 of mangroves, which occupy almost the entire coast. Of the total number of fishers in the country, 99% are artisanal and 43% (more than 460,000 fishers) are in the coastal region (Table 3.2). This shows the importance of mangroves in maintaining fishing and fishing communities in this country.

Table 3.2 Total number of fishers by federation region in Brazil in 2015, including fishers of mangrove and other environments

Federation Region	Total	Artisanal fisheries	Industrial fisheries	Coast	Continent
North	405,718	404,887	831	106,754	298,964
Northeast	513,082	512,626	456	275,974	237,108
Midwest	21.89	21,888	2	0	21.89
Southeast	84,833	83,026	1,807	33,615	51,218
South	62,202	55,444	6,758	47,663	14,539
Total	1,087,725	1,077,871	9,854	464,006	623,719
Percentage		99	1	43	57

Source Ministry of Fisheries and Agriculture's General Fisheries Records of Brazil (RGP) database (Secretariat of Aquaculture and Fisheries/Ministry of Agriculture, Livestock and Supply, Brazil—SAP/MAPA), obtained in March 2016

The fishery products associated with Brazilian mangrove areas are numerous, depending on the geographic area. According to fishing production data from the federation units presented in Freire et al. (2015), in the North and Northeast regions of Brazil, products such as crabs, weakfish, catfish, crevalle jack, southern red snapper, yellowtail snapper, "sururu" mussels, caitipa mojarra, snook and white mullet are closely associated with mangrove areas. In the Southeastern and Southern regions, other species, such as snook, crab-uçá, oysters, white mullet, anchovy, crabs, estuarine shrimp, caitipa mojarra are strongly associated with mangrove areas (Cunha-Lignon and Mendonça 2021).

In mangroves, species of interest to the fishing sector are found at all levels of the food chain, with detritivores such as crabs, shrimp and small fish; filter feeders such as bivalves, planktivorous fish; as well as large consumers such as crabs and fish (Sulochanan 2013; Hutchison et al. 2014a, b). In summary, mangroves are an extremely important environment for the maintenance of fishery resources that are most important for both coastal fishing and fishing activities in deeper waters that exploit resources with a life cycle linked to shallow areas. The maintenance of mangrove areas is essential for the sustainability of fishing that involves both artisanal and industrial participants. Fishing productivity maintains both fishing communities and the entire commercial chain that depends on it, sustaining the cultural diversity of traditional communities, since a multiplicity of traditional fishing gears is used to capture different species of fish and shellfish that use mangrove ecosystems during part or all of their life cycles. Mangrove forest conservation strategies involving local communities are seen as more effective than simply involving top-down state or national government control (Erwiantono 2006). The empowerment of users who are dependent on these environments, and the division of responsibilities, multiply the chances of success in environmental preservation processes, bringing sustainability to the activities and conservation of the environments that maintain these activities.

3.2.2.2 Seagrasses

Seagrass meadows are habitats of commercially important species from small to large vertebrates. Fishes inhabiting seagrass meadows can be permanent (throughout their entire lifecycle), temporal (one phase of their life) or visitors to the meadows with greater or lesser frequency, contributing to energy circulation along the coast (Fig. 3.2). Thus, seagrasses provide food security as a crucial link in the food web for animals and people in both coastal (Duarte et al. 2008) and offshore industrial fisheries (Unsworth et al. 2018). According to Unsworth et al. (2018), this significant role in global fisheries is not formally recognized worldwide. However, it shows high economic importance of seagrasses as they are critical habitat for subsistence and commercial species in addition to recreational and endangered species. Seagrass areas cover between 160,000 and 266,000 km^2 worldwide, being associated with numerous fishing communities (McKenzie et al. 2020).

A variety of fishing gear are used to capture fish in seagrass meadows. Fishing gear used directly on the seagrass meadows varies from the traditional ones (e.g., nets, spears, traps, poisons and narcotics) to local adaptations involving gleaning methods. Even spoons are used in these processes, which usually damage the underground systems of the plants (Musembi et al. 2019; Furkon et al. 2020).

Gill nets are the most used in these areas to capture different fish but, depending on the region of the planet, several other devices can be found that have more significant impacts on the environment, such as explosives and trawling (Veitayaki et al. 1995; Tioti et al. 2021). For example, during trawling, there is displacement over the meadow at low tide, when fishers walk over the meadows at low tide, they leave an extensive trail of destruction behind. Such trawling devices are used in the

Fig. 3.2 Ecosystem connectivity between mangroves and seagrasses and human uses. Art: Gabriel Henrique Silva @gabriielnk. Diagram symbols are from the Integration and Application Network, University of Maryland Center for Environmental Science (http://ian.umces.edu/imagelibrary/)

Pacific region by women fishers (Tioti et al. 2021). Fishing fences or traps (i.e., artisanal structures of wood commonly used by fishing communities in tropical areas to capture fishes when tides recede) are also frequently placed on seagrass meadows, representing another threat by alterations in local hydrodynamics, causing clearings and sand deposition on the meadows (Barros et al. 2016).

Although several different types of fishing equipment and methods target various fishery products, whether fish, crustaceans or molluscs, the activity is carried out by small-scale fishing, developed by communities, which in general are more fragile socio-economically than industrial fisheries. Men, women, and children (usually dominated by women) of coastal and island people around the world have been observed to gather invertebrate species (e.g., clams, sea cucumbers, sea urchins, conch, lobster, shrimp, octopus) during low tides in shallow and intertidal meadows, in Asia, Oceania, Africa and the Americas. In Green Island (Australia), a marine protected area, recreational and commercial fishing is prohibited, but artisanal fishing is allowed for indigenous people (Cullen-Unsworth et al. 2014). This activity is almost always for subsistence, but it can be considered a “backup livelihood” for people when food or money is scarce (Cullen-Unsworth et al. 2014). However, it can be an essential economic activity for villages, with community organizations dedicated to this activity, as in northeastern Brazil (Wojciechowski et al. 2014). But, in general, the environmental impacts of artisanal activities are often low, with fishers (especially women) being concerned with the environment, through an intergenerational transmission of collection techniques taking into account habitat preservation (Cullen-Unsworth et al. 2014; Wojciechowski et al. 2014; Barros et al. 2016).

Other manual collections of fish and shellfish are also conducted in seagrass meadows, such as “flashlight fishing”, where fishers use a flashlight during the night to immobilize and capture shrimp (Santos et al. 2016), mullet and crabs (Comissão Ilha Ativa, personal communication) on the meadows. During low tides, women and children manually collect bivalve species (e.g., *Anomalocardia flexuosa*, *Phacoides pectinatus* and *Tivela mactroides*), which can be both commercialized and serve as a protein source for these traditional people (Barros et al. 2016). To get an idea of how important seagrass can be in maintaining fishery resources, Furkon et al. (2020) related the density of seagrass meadows with abundance indices (catch per unit effort, CPUE) of artisanal fishers in Indonesia, showing a high positive relationship in CPUE increase with the higher density of meadows, with yields from 0.05 to 3 kg person^{-1} hour^{-1}.

It should be noted that the different genders of fishers can influence the impacts on fish resources within areas with seagrass, as men generally use larger equipment than women, causing greater impacts to the environment. For example, when fishers harvest bivalves, men use larger and heavier implements, including construction tools (e.g., shovels and garden rakes) and liquor crates to wash more of the seagrass substrate, with a net production greater than that of women per unit, but women fishers fear that these methods are not sustainable for the species (Wojciechowski et al. 2014). Artisanal fishing activities carried out by women are typically on the edge of the meadows and use larger meshes that minimize damage to the ecosystem, as they avoid clearings in the center of the meadows and capture of juvenile specimens.

However, despite the known rich commercial biodiversity exploited in seagrass meadows as a livelihood for many coastal communities around the world, little or no attention is given by governments to create awareness among stakeholders on ecosystem functioning and the need for correct management. Sector conflict resolution and trade-offs that are necessary for a sustainable blue economy should be considered as several of the practices reported above can damage the meadows and cause seagrass cover loss. The plants need some time to restore their tridimensional structure and substrate to support larval replacement and attract visiting fish species. This review already found some concern of fishers, especially with the correct use of fishing tools, in order to maintain fish stocks and, thus, sustainable use of the ecosystems.

3.2.3 Tourism (See Also Chap. 6)

Coastal tourism is one of the most important and obvious activities linked to the blue economy. It includes both direct recreational activities that take place in the ocean, such as snorkeling, sailing, and sports competitions, and the infrastructure involved in the tourism sector, such as accommodation, ports, restaurants, and shopping centers. Although economically important, these activities, if mismanaged, may damage natural systems and reduce their economic and ecologic viability in the long term as pressure on coastal systems causes the deterioration of the main attraction.

3.2.3.1 Mangroves

The use of mangroves as a travel and tourism destination is gaining attention because these areas provide a high-value, low-impact use of these important ecosystems. Ecotourism and recreation in mangrove areas include facilities such as boardwalks, viewing towers and information centers, as well as activities such as boating, fishing, hiking and wildlife watching (Spalding and Parret 2019). Spalding and Parret (2019) identified 93 countries and territories with mangrove attractions, with boating being the most widespread activity, recorded in 82% of English-language sites. Mangrove tourism attracts tens to hundreds of millions of visitors annually and is a multi-billion-dollar industry (Spalding and Parret 2019). These activities can be increased worldwide, especially in protected areas, reinforcing community-based tourism.

Caribbean mangrove ecosystems are displayed as mysterious natural and wild sites and as good places to practice leisure activities and to relax, enjoying the paradisiacal seascapes. Mangrove ecotourism is often accomplished as one-day trips, combining the discovery of natural sceneries and relaxing activities. In Jamaica, Martinique, and Guadeloupe, 62% of local stakeholders use the mangroves directly as the main message for their business (Avau et al. 2011).

Mangrove fauna and flora may enrich coastal tourism experiences. Mangrove nature tourism alternatives can be developed as additional tourism activities for

Indonesian tourist destinations (Kissinger et al. 2020). East Java (Indonesia) still lacks a mangrove tour program, important to deliver the objectives of ecotourism. For the sustainable use of mangrove biodiversity as a tourist attraction, it is essential to know the basic characteristics of mangroves and establish mangrove tourism programs which are able to support conservation of these ecosystems. The incorporation of local wisdom could increase the sustainability of mangrove ecosystems. In Gambia, a boardwalk construction inside an urban mangrove ecosystem received a positive response from local stakeholders. Tourism is one of the major income-generating activities in this area (Satyanarayana et al. 2012). According to Thompson and Rog (2019), charismatic megafauna (tigers, lemurs, trunk monkeys, manatees, dolphins, sea turtles and crocodiles) are underrepresented in research in mangroves, in relation to their benthic invertebrates (crabs, shrimp and bivalves). These flagship species have wide geographic ranges and should be used more to promote mangrove conservation in many regions of the world.

3.2.3.2 Seagrasses

Among the Nature's Contributions to People (NCP), despite the importance of seagrass meadows for a healthy and diverse environment, recreation and tourism are not always considered a direct contribution provided by seagrass ecosystems, but tourism indirectly benefits from services provided by seagrasses, such as biodiversity, water quality and coastal stabilization. Other services provided are fish and shellfish resources used in local cuisines sought by tourists (Ruiz-Frau et al. 2019), food ingredients, handcrafts, fish (Syukur et al. 2019), and seafood supply for hotels in important tourist destinations around the world, such as the Caribbean and the Maldives.

Sighting charismatic megafauna such as green sea turtle, dugongs, and manatees—in addition to ornamental and edible fishes—are also common in many seagrass locations, such as in Florida (USA), Brazil and Australia. In locations where local populations still threaten dugongs (*Dugong dugon*), the monetary gain from local tourism linked with seagrass ecosystems and the animal's conservation is under development, such as in Indonesia. The same efforts have been observed during recent decades in Brazil, where coordinated manatee-related tourism is encouraged, and it is linked with tourism in the nearby systems for diving, for example, near seagrass meadows and coral reefs. This activity could be an interesting starting point to include the appreciation of the habitats of charismatic megafauna, promoting environmental education. Snorkeling, recreational fishing, scuba diving, sea walks, kayaking and wildlife watching in seagrass meadows also offer additional interest to coastal tourist areas (Björk et al. 2008; Cullen-Unsworth et al. 2014). In Lombok Island, Indonesia, tourists reported that they were visiting seagrass meadows in order to fish or observe the plants and associated benthic fauna, such as sea stars, sea cucumbers and sea urchins (Syukur et al. 2019).

Networks such as Seagrass Watch, Seagrass Ecosystem Services Project, Project Seagrass, Save Posidonia Project, Bermuda Seagrass Project and other non-governmental organizations (NGOs) have provided information on seagrass ecosystems, societal engagement and environmental education for national citizens and tourists in some countries around the world. In addition to mapping and monitoring seagrass meadows, national tour operators also include sirenians (dugongs and manatees) and seagrasses as important elements of marine-based tourism, as in Timor-Leste and Fiji (United Nations Environmental Programme 2020). Marine Conservation Agreements (MCAs) among tourism operators, communities, and NGOs produce local economic incentives, which includes income opportunities for people and funds for development of projects of the community in addition to ecosystem improvements (United Nations Environmental Programme 2020). In the eastern Mediterranean Sea, the Save Posidonia Project proposed a sustainable tourism and an action plan to raise funds that will be used exclusively for seagrass conservation, with the main objective of sensitizing nationals, tourists, entrepreneurs and NGOs about seagrass sustainability, by promoting fairs, festivals, conferences and forums (Save Posidonia Project 2021). However, taking into account seagrass distribution around the world, actions as those mentioned above are still very restricted and need to be further expanded.

Also, most of the activities associated with tourism in areas of seagrass meadows have still been indicated as harmful for the meadows' preservation, as they cause physical damage to the plants (e.g., trampling, anchorage, sedimentation, etc.). The intentional removal of the plants by hotels and resorts in order to "clean" the substrate is also a common practice in several parts of the world, but entrepreneurs are starting to be made aware of the importance of preserving the meadows. Several recent studies from around the world have endeavored to highlight the important contributions of seagrasses as a useful tool for ecotourism. Replicating these studies in many other regions is important because of the uniqueness of each location in terms of seagrass diversity and landscape, associated megafauna, lifestyle and needs of the local people, local preservation policies, etc. Furthermore, seagrass ecotourism increases seagrass value and raises awareness among nationals, decision makers and tourists. According to Syukur et al. (2019), ecotourism has been identified as a potential alternative for seagrass conservation, in addition to contributing for livelihood of local communities and environmental preservation.

3.2.4 Blue Biotechnology

In the search for sustainable development for humankind, underexplored marine resources are gaining attention as alternative products. Blue biotechnology is developing fast, especially in the last decade, providing benefits as new protein sources, alternative wastewater treatments, new biofuels, and new forms of pharmaceuticals. Among the benefits of this technology are contributions for marine conservation itself, improving aquatic ecosystems to better cope with climate changes, for example, and enhancing blue carbon sequestration to promote stabilization of ecosystem services. Blue biotechnology follows the same principles as other biotechnologies, such as green ones, but its development still faces numerous challenges, especially to prevent over-harvesting of the systems that are already under stress; therefore, the precepts for bioproduct development should be based on isolating and testing potential products as a basis for further synthetization so as not to provoke pressures of harvesting wild organisms.

3.2.4.1 Mangroves

Beyond ecosystem services and carbon storage capacity, mangroves have been widely used as a source of basic resources for local communities and, increasingly, in the use of bioproducts and raw materials for the development of pharmaceuticals and substances with potential biological properties. Historically, the exploitation of mangroves has been more linked to destructive processes such as logging for domestic and commercial uses and land clearing for agriculture and urban expansion, as well as artisanal processes such as harvesting, fishing, and mariculture. In recent years, however, interest in products of pharmacological and industrial interest has been increasing, although research on bioproducts associated with wood and mangrove endophytic organisms is still in the beginning phases. Wu et al. (2008) and Patra et al. (2020) have reviewed the various studies on the utilization of mangrove bioproducts from around the world. There are more than 350 metabolites described in mangroves and more than 200 of them are unique to species of these environments including phenols, alkaloids and terpenoids that are produced by plants and endophytic organisms, which have medicinal benefits such as antidiabetic, antifungal, antimicrobial, anticancer and antioxidant capabilities, in addition to industrial products such as biofertilizers and pigments.

Although this high potential for the exploitation and use of bioproducts is well known to science and industry, little research has yet reached the advanced stages of clinical trials beyond in vitro analyses. As some examples, *Rhizophora racemosa* has clinical use in the treatment of type 2 diabetes (Tsabang et al. 2016), and extracts from *Excoecaria agallocha* plants have anticancer, anti-HIV, and antiviral potential. *Bruguiera sexangula* is used in the treatment of cancer, and extracts of *Avicennia marina* have been exploited for their anticoagulant activities (Gajula et al. 2020). The use of these bioproducts may be one of the greatest added values to the preservation of mangroves, since in most cases, they can be exploited in a sustainable way without destroying mangrove forests; however, more research and information is still needed about the real value of these bioproducts and how they can be used, either by local communities or industry.

3.2.4.2 Seagrasses

Blue biotechnology is a growing field for seagrass. Several metabolites with multiple bioactivities have been reported for these plants, varying from antioxidant, antibacterial, anti-larval, antiviral (including anti-HIV) and cytotoxicity against cancer cell lines (Kim et al. 2021). Antibacterial activity for potential disease control has been tested in *Halophila* and *Cymodocea* species (Kannan et al. 2010; Yuvaraj et al. 2012). The seagrass *Syringodium isoetifolium* was proved to have larvicidal potential against the mosquito *Aedes aegypti*, which transmits the tropical disease dengue fever (Ali et al. 2012); the associated microbiome on the roots of this species has potential use as an antibacterial agent (Ravikumar et al. 2012).

At least 10 of the 72 recognized seagrass species were reported as having ethnopharmacological properties by a local population in India (Newmaster et al. 2011); these authors pointed out a medical potential that is not yet well explored. For example, *Enhalus acoroides* rhizome, and sometimes roots, can be processed to produce juices that can be consumed raw to treat seasickness, ease indigestion, treat hangovers and even mental disorders and low blood pressure. Paste from leaves of different species is used to treat wounds and skin diseases. *Halophila* species can be toasted with oil and consumed to treat iron deficiency. For malaria and fever treatment, it can be used as vapors for inhalation therapy.

Seagrass nutritional composition may also have the potential for the development of functional food ingredients. The direct consumption of seeds is common by people in areas where *Enhalus acoroides* is distributed and fed to goats and sheep in India. Their caloric value is similar to plants of terrestrial origin and is reported to have aphrodisiac and contraceptive properties (Montaño et al. 1999). The efficacy of *E. acoroides* seeds to HIV-AIDS patients was tested, indicating potential in increasing the number of T-CD4 cells for patients who consumed seeds (Nindatu et al. 2018), showing the potential seagrass may have for this therapy.

Species such as *Halophila* are directly consumed in salads; *Enhalus* flour is used for baking cookies, and seagrass is also used as tea. However, human consumption took another step as a Spanish three-star Michelin chef brought *Zostera marina* seeds to the spotlight. The Aponiente Marine Project[1] cultivates seagrasses in a low-cost and environmentally friendly way. They present the marine grains as a "superfood" for the unique nutritional qualities the seeds have as gluten-free, high in omega 6 and 9 fatty acids, and containing 50% more protein than rice per grain. Since 2017, they have been cultivating seagrass as crops for their use, restoring the seagrass meadows of the area and improving social systems to generate jobs.

The energy potential of seagrass harvest as a biofuel is also an essential part of its blue economy interest. For seagrass, biofuel studies were initiated with seeds, but increasing the production capacity of seagrass seeds and developing culturing and harvesting skills are among the further activities needed to pursue this use. Studies to contribute to the marine fermentation industry to develop alcoholic beverage and food

[1] https://www.cerealmarino.com/wp-content/uploads/2021/01/APONIENTE_CEREAL-MARINO_DOSSIER-DE-PRENSA_ENG.pdf.

products may be possible from seagrass seeds (Uchida et al. 2014). Another potential of seagrass biofuel potential being tested is as a substrate for ethanol production; as a low-cost and eco-friendly bio-adsorbent material for effective synthetic dye removal from the aquatic environment; and phosphate removal from synthetic and natural wastewater in a circular economy concept. Green fertilizer for gardens is also frequently mentioned, as is the use as roof covering and filling, and building material for many species in different countries.

3.3 Threats

Natural and anthropogenic impacts have been observed in BC environments around the world. Coastal ecosystems have rapidly declined in recent decades, evidencing the losses of their recognized goods and services. In review, Lovelock and Reef (2020) pointed out the main threats of climate changes, which can vary according to factors such as sensitivity, exposure, adaptive capacity and global distribution of each ecosystem. Mangroves and saltmarshes are highly affected by droughts and storm events (and saltmarshes are also exposed to mangrove encroachment), in addition to hydrodynamic changes related to the ocean changes. Seagrasses are affected by marine heat waves at the lower limit of the latitudinal distribution of the species, resulting in degradation, loss and change of the ecosystems, among other consequences. It is worth mentioning that a very important threat factor is also urban and industrial development and, in recent decades, aquaculture expansion in these extremely fragile environments.

The effects of climate changes on blue carbon ecosystems can be even more intensified, together with harmful human actions, accelerating losses of these ecosystems. Hence, BC ecosystems can contribute to global climate regulation in the face of climate changes, while at the same time they have also been threatened by these environmental changes, human actions, or both. It has been estimated that 67% of total mangrove forests, 35% of tidal marshes and 29% of seagrass beds have been lost from their historical maximum levels. If the rates of decline continue, around 30–40% of tidal marshes and seagrasses will be lost and nearly all unprotected mangrove areas could be lost in the next 100 years (Pendleton et al. 2012). Losses of these vegetated environments in coastal areas have caused significant carbon dioxide emission by disturbing and releasing the carbon previously trapped in biomass and sediments. Conversely, the expansion of blue carbon ecosystems can contribute to carbon sequestration, reducing the consequences of the effects of climate change, but this balance still needs to be further understood.

3.3.1 Mangroves

Mangroves are being destroyed at rates 3–5 times greater than average rates of forest loss and over a quarter of the original global mangrove cover has already disappeared. These losses are driven by land conversion for aquaculture and agriculture, coastal development, pollution and over-exploitation of mangrove resources, as well as the impacts of climate change (Gilman et al. 2008; Mitra 2013). As mangrove forests become smaller and more fragmented, important ecosystem goods and services will be diminished or lost, with high ecological and economic importance, making them susceptible to additional pressures from human activities. The consequences of further mangrove degradation will be particularly severe for the well-being of coastal communities in developing countries, especially where people rely heavily on mangrove goods and services for their daily subsistence and livelihoods. However, the future of mangroves does not have to be bleak, with greater recognition of the importance of mangrove ecosystems for biodiversity and human well-being and global efforts aiming to conserve, manage and restore these ecosystems (UNEP 2014).

To date, relative sea-level rise has likely been a smaller threat to mangroves than non-climate related anthropogenic stressors, outlined above, which have likely accounted for most of the estimated global average annual rate of mangrove loss of 1–2%, with losses during the last quarter century ranging between 35 and 86% (Valiela et al. 2001; Duke et al. 2007; Gilman et al. 2008; FAO 2010). In Brazil, for example, actions such as sewage and solid waste dumping, real estate speculation, deforestation and shrimp farming have been identified as important threats to these ecosystems (Costa and Pegado 2016; Silva et al. 2017; Celeri et al. 2019; Lacerda et al. 2021). However, relative sea-level rise may constitute a substantial proportion of predicted future losses. Biotic factors related to the physiology, development and distribution of mangroves may be the most vulnerable to changes in sea level and may affect mangrove ecosystems in the short term (Richieri 2006). However, the patterns of mangrove responses to sea level rise depend on local geographic characteristics and conditions in adjacent areas, in addition to rates of sea-level rise (Bezerra 2014).

3.3.2 Seagrasses

Assessing current distribution and trends of seagrass meadows is critical. The loss of seagrass areas increased from 0.9% (Duarte et al. 2005) to 7% annually since 1990 (Waycott et al. 2009). However, many areas are still being mapped and registered. Large stocks of blue carbon may be lost as seagrass meadows are being destroyed (Lovelock and Reef 2020).

Rapid population growth, urbanization, destructive fishing practices and overexploitation using fishing gear and fish fences, in addition to physical damage with algae cultivation on seagrasses, are indicated as some threats to seagrass around the world. Seaweed cultivation commonly occurs on seagrass meadows of Indonesia and Tanzania, but this activity can generate severe damage to the plants by removal of leaves and roots, causing clearings (Cullen-Unsworth et al. 2014). Other potential impacts, like oil spills, can also be a threat to these systems, both in the contamination itself and the cleaning process (Magalhães et al. 2021).

Tourism can be either a positive or negative factor for seagrasses as a blue economy resource. The positive impacts of tourism relate to seagrass meadows as locations for ecotourism. Negative consequences occur with the removal of seagrass to make way for tourists to access the water (Zuidema et al. 2011). In addition, activities such as permanent boat moorings, extensive anchor use, and diving have been considered unfavorable for seagrass meadows, possibly contributing to the seagrass loss worldwide (Cullen-Unsworth et al. 2014). Damage from anchors linked to tourism also occurs in seagrass meadows in sheltered locations and in small commercial fishing harbors, where small to medium-sized vessels anchor. Other recreational activities, such as kayaking, swimming, diving and recreational collection of shrimps are tourism-related sources of damage to seagrass meadows.

Climate-related threats involve acidification, increasing frequency of extreme events, and sea levels and temperatures rising. As reviewed by Connolly et al. (2020), the accuracy of the global change effect predictions is still limited as the global models may not be appropriate for seagrass biology and long-term studies are still necessary to address variations due to seagrass species and different effects at different latitudes. Massive losses have been reported to be linked to marine heatwaves events in Australia, cyclones in Mozambique, run-off from degraded lands, among others. We recommend that management goals should focus on local threats as preservation locally may make these meadows less susceptible to extreme events.

The impacts on seagrasses have local consequences, such as the reduction of fauna, which is often the main means of survival for fishing communities, which depend on intact ecosystems. The value of seagrass ecological services has been estimated at $1.9 trillion per year in the form of nutrient cycling and increased productivity of coral reef fish, and as a habitat for thousands of fish, birds, and invertebrate species (Waycott et al. 2009).

3.4 Outlook and Potential Challenges

As the potentials of blue economy coastal systems are still being truly understood, they are under threat. Alternatives for mapping, restoring, valuing the services, and managing and engaging society, are essential in order to protect the future of the sustainable economy we expect to achieve. Only by raising the awareness of these systems' service values can they be recognized and properly included in the blue economy (Fig. 3.2). Science and technology have an important role to play in these blue economy activities.

3.4.1 Mapping

Locating and estimating areas of mangrove and seagrass meadows are very important to develop proper management of these ecosystems. Recent efforts have been made to create models of global mangrove and seagrass services and BC estimation, with standardized methodologies using climate proxies, multi-source remote sensing data and surface observations. For example, Hutchison et al. (2014a, b) developed a climate-based model for estimating potential mangrove above-ground biomass (AGB) linked to global data based on models from the literature. Hu et al. (2020) produced a global mangrove forest above-ground biomass map at 250-m resolution by combining ground inventory data, spaceborne LiDAR, optical imagery, climate surfaces, and topographic data with a machine-learning method. Simard et al. (2019) released a 30-m resolution dataset of global distribution, biomass, and canopy height of mangrove-forested wetlands based on remotely sensed and in situ field measurement (region-specific allometric models). Many of these products can serve as a basis for generic blue carbon estimates. They are publicly available in digital formats and ready to be used in GIS tools (see map in Fig. 3.3).

To map seagrass meadows, the use of several methods has been mentioned in the literature, such as aerial photographs, multi-beam sonar, acoustic telemetry, satellite images and remote sensing. A recent study suggested a hierarchical mapping approach that includes combining eco-geomorphological principles and hierarchical object-based analysis to create maps that should be validated with field observations (McKenzie et al. 2021). We note that the priority is to centralize all the data already available in a global GIS clearinghouse, such as the World Conservation and Monitoring Center. Such datasets are highly suitable for determining generic BC and ecosystem service strategies and market application policies, but they may

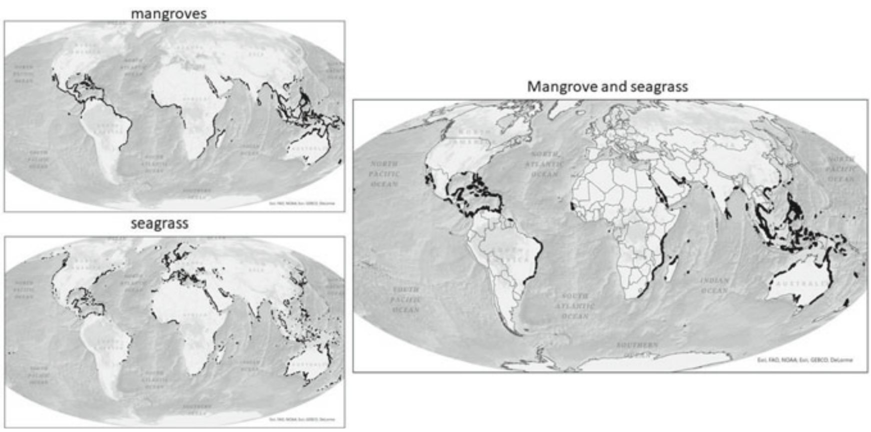

Fig. 3.3 Mangrove and seagrass global distribution maps (and overlapping areas): Several data on global ecosystem distributions are available as georeferenced files as in the case of UNEP (2020) and Bunting et al. (2018)

have discrepancies that can lead to uncertainties and inaccuracies, especially when detailed analysis is needed. These limitations indicate the importance of developing work at higher resolutions to complement these data with local analyses (and improve training data in the case of machine-learning models).

Although the specific methods used to derive habitat maps vary considerably, studies can generally be categorized into one of three overarching strategies: (1) abiotic surrogate mapping; (2) assemble first, predict later (unsupervised classification); and (3) predict first, assemble later (supervised classification). While there is still no widely accepted agreement on the best way to produce benthic habitat maps, all three strategies provide valuable map resources to support management objectives (Brown et al. 2011).

3.4.2 Conservation

The United Nations Decade on Ecosystem Restoration (2021–2030) aims to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean. The UN Decade proposes a strategy with ten actions, such as empowering a global movement, investing in research, building up capacity, and stimulating youth participation, among others.

Responding to Sustainable Development Goals (SDGs), restoration projects can help to end poverty in all its forms everywhere (SDG 1), end hunger, achieve food security and improved nutrition (SDG 2), ensure availability and sustainable management of water and sanitation for all (SDG 6) and take urgent action to combat climate change and its impacts (SDG 13).[2]

Increasing recognition of the importance of mangrove ecosystems for both biodiversity and human well-being is driving efforts around the world to conserve, better manage and restore these ecosystems. Many of these have been successful at local scales, often supported by national policies that recognize the significant long-term benefits of mangroves over short-term financial gains (UNEP 2014).

Restoration projects of seagrasses and mangrove areas will mitigate climate change, safeguard biodiversity and increase food security. Although much effort is needed and decline is still going on, different projects are gaining space with restoration programs such as “Project Seagrasses: making waves to save our seas”[3] that proposes to restore 30 km^2 of seagrasses in the UK. The project from Wetlands International “To plant or not to Plant?”[4] proposes to use best practice in mangrove restoration, considering biophysical (hydrological flows) and socio-economic conditions, empowering communities, engaging local government, and ensuring that local actions are strengthened by policies and planning.

[2] https://www.decadeonrestoration.org/.

[3] https://www.projectseagrass.org/.

[4] https://www.wetlands.org/publications/mangrove-restoration-to-plant-or-not-to-plant/.

Rehabilitation projects are planned, conceived, executed, and managed by people with diverse backgrounds and different scientific and socio-political agendas. These projects need to be responsive to various stakeholders and actors who have different values. In general, the projects are influenced by laws that span local and international scales and must be able to adapt and evolve geomorphologically and socioeconomically over decades to centuries in the context of a rapidly changing climate (Ellison et al. 2020).

Natural regeneration gained worldwide relevance with the "Ecological Restoration of Mangroves" approach, which emphasizes the management of hydrology and topography (Lewis 2005). Subsequently, local human communities and other social actors have been included in the process as a central element in the planning and implementation of actions, with the approach of "Community Based Ecological Mangrove Restoration" (CBEMR) (Brown et al. 2014), in which women have been considered having fundamental roles in mangrove restoration projects.[5] Restoration projects have to consider some important context. It is necessary to avoid planting in areas where the local community is not involved, and avoiding mono-species planting, leading to mangroves with low resilience and planting in places that are too exposed to erosion processes, among others.

3.4.3 Awareness (Perceptions) and Citizen Science

Historically, mangrove forests have been cast in a negative light due to their (often perceived) ecosystem disservices (Friess et al. 2020a), such as being habitats for dangerous animals (like crocodiles, tigers, and snakes) and insects (like mosquitoes and sandflies) that act as vectors for disease. Dahdouh-Guebas et al. (2020a, b) highlighted the dangers of recurrent public misperceptions about mangroves and how they can be countered. Mangrove conservation has recently shifted from a pessimistic to a more optimistic trajectory. Management and governance success stories have helped to protect mangroves and build upon international interest in sustainable blue economies. Conservation Optimism is an emerging paradigm that can unite stakeholders and the public and increase their engagement with conservation and inspire local action. Capitalizing on successes in one ecosystem and transferring this knowledge can help us limit broader environmental degradation, making mangroves an important and positive case study for the Conservation Optimism movement (Friess et al. 2020b). Promoting positive perceptions by highlighting the valuable functions, goods and services and the long-term economic and social benefits that these endangered ecosystems provide will ultimately underpin successful conservation (Bennett 2016).

Unlike mangrove forests, seagrass meadows are not always seen with a negative point of view since they can really be "invisible" for the general public and the stakeholders due to their submersed nature in most of their distribution areas. Raising

[5] https://www.iucn.org/news/forests/201707/gender-equity-key-mangrove-restoration.

public awareness and communicating the seagrass contribution to human livelihoods and well-being, as well as the consequences of their loss, are key for any development towards a sustainable blue economy involving them.

Involving the public without formal scientific background in scientific studies—citizen science—is one of practices that has been working to both achieve conservation and gather data on a large spatial scale and long time scales. Jones et al. (2018) listed seagrass projects using citizen science around the world, but point out that only two of them are real examples of programs that cover a wide spatial scale involving a large number of participants: Seagrass-Watch and SeagrassSpotter. The use of technology seems to be essential for this kind of research (Dalby et al. 2021) but, even so, citizen participation as a tool in science for coastal ecosystems may be limited by intertidal access.

Highlighting the role of indigenous/traditional communities is fundamental to understanding seagrass potential, but also for the effectiveness of any protection or intervention, and even to coping with global changes. A good way to involve communities is to incentivize the people who work daily on the meadows, increasing their awareness of the importance of the conservation of these marine environments; communities are also able to perceive threats to the ecosystems and propose alternatives to mitigate anthropogenic pressures (Nordlund et al. 2018; McKenzie et al. 2021).

3.4.4 Marine Protected Area and Legislation

Mangroves need to be appreciated for the valuable socio-economic and ecological resources they provide, and to be conserved and managed sustainably. This requires a commitment by governments to make policy decisions and enforce existing protective measures to curb widespread losses from human activities.

In several parts of the world, mangroves and seagrasses are protected by law, being areas of strict protection. But even with such protections, these systems are being destroyed, mainly due to the expansion of urban areas, as well as large enterprises, such as ports and aquaculture. In Brazil, where there is vast environmental protection legislation, any intervention on these areas is only considered in exceptional cases, requiring a technical and legal assessment for intervention purposes in these specially protected areas.

3.4.5 *Valuation*

Although in some cultures, people strongly identify with seagrass meadows because they provide food security, livelihood, and spiritual fulfillment, valuing seagrass services is one of the most significant challenges in seagrass conservation. Monetizing goods and services derived from seagrass meadows may be essential to represent the ecosystem in management and policy decisions. Together with macroalgae banks, economical services of seagrass meadows were estimated to amount to US$29,000 ha^{-1} yr^{-1}, a value 27 times greater than the average of marine ecosystems as a whole and 7–23 times greater than terrestrial ecosystems, being almost 6 times most productive than tropical forests, making seagrass meadows one of the most valuable biomes on Earth (Costanza et al. 1997, 2014; Björk et al. 2008). For mangrove forests, the calculated value, together with tidal marshes, is even higher, around US$194,000 ha^{-1} yr^{-1} (Costanza et al. 2014).

3.5 Summary

This chapter serves as a call to action to decision makers and highlights the unique range of values of mangroves to people around the world. It aims to provide a science-based synthesis of the different types of goods and services provided by mangroves and the associated risks in losing these services in the face of ongoing global habitat loss and degradation. Mangrove and seagrass ecosystems have enormous potential as components of blue economies, but these systems are in danger. The growing human occupation in coastal areas around the world brings great pressure, with reduction and fragmentation of these ecosystems. Measures for the conservation and protection of mangroves and seagrasses have increased and involved communities worldwide. We are still learning to value these systems and to promote their ecosystem services more effectively; improving the mapping of seagrass and mangrove ecosystems is critical. In addition, it is essential to involve stakeholders and local communities at all stages of the process. We need to increase knowledge about these ecosystems, to protect and restore them, and in this way, we can fully exploit them in a sustainable way and achieve the goals of the Blue Economy, promoting alternative economic improvements for coastal populations and consequently increasing the quality of human life.

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