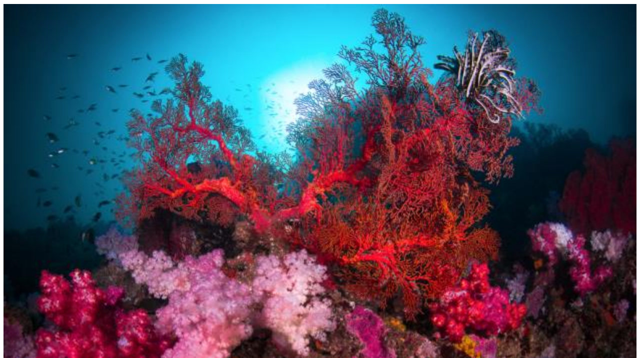
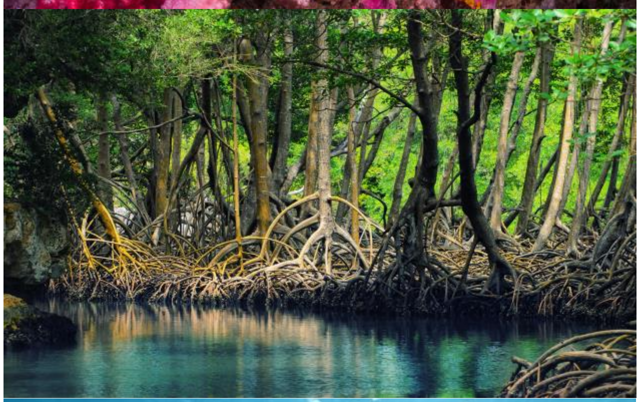


MANAGEMENT CHALLENGES AND STRATEGIES ACROSS CORAL REEFS, MANGROVES, AND SEAGRASS BEDS

ABSTRACT

This paper explores management challenges and current strategies in place to conserve, protect, and restore coral reefs, mangroves, and seagrass beds globally; address vulnerabilities of these systems to anthropogenic and environmental disturbances; and propose adaptive, resilient, and connective management targets to mitigate regional and global pressures while achieving the United Nations Sustainable Development Goals.

Harshitha Sai Viswanathan

SMEA 591: Marine Science in the Coastal Zone

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<u>Guiding Question:</u> *What are the management challenges of this system? How is the system being managed now?*

I. Coral Reef Ecosystems

Coral reefs are biogenic engineered ecosystems alongside tropical coastlines and play a vital role in maintaining species rich biodiversity and productivity. The marine environment in these regions is characterized by shallow, clear, and warm water with low-nutrients and saturated with calcium carbonate minerals (Wilkinson & Buddemeier, 1994). In addition to supporting ecosystem services such as trophic level species diversity and interactions alongside biogeochemical functioning, coral reef ecosystems provide social, economic, and environmental benefits to the lives of coastal and small island communities through food security, protection of coastlines, tourism activities, research & pharmaceutical services, and hold cultural and aesthetic value for more than half a billion people in more than 100 countries (Obura, 2019). As a result of urbanization of the coast, these ecosystems are vulnerable to both anthropogenic and environmental disturbances. A combination of local and globalized pressures has exacerbated the rapid decline in coral reef structures and demands for management responses focused on strategies to mitigate immediate impacts and consequently enhance coral resilience to inevitable changes in the future (McCook, 2009).

A. Management Challenges for Coral Reef Ecosystems

<table>
<tr><th>Environmental Disturbances</th><th>Effects</th><th>Examples</th><th>Management Challenges</th></tr>
<tr><td>Sea level rise</td><td>- Sediment erosion
- Storm inundation
- Ineffective coastal barriers</td><td>Islands of the Indo Pacific experience increased coastal sediment deposits and erosion impacting protective capacities of reefs (Wilkinson, 1994).</td><td rowspan="6">- Lack of collaboration between environmental management sectors
- Species specific approaches rather than ecosystem-based approaches
- Lack of long-term regional monitoring
- Mismanagement of methodologies for data collection (ineffective model projections)
- Unmet need to acquire multiple variables in data collection for a holistic approach
- Prioritization of economic activities
- Political instability (in some regions)
- Lack of an integrated and interconnected management network
- Unregulated management
- Lack of enforcement of regulations</td></tr>
<tr><td>Increasing temperature</td><td>- Bleaching events
- Mortality
- Reduced productivity
- Ecosystem shifts</td><td>Regions of northern Japan have observed coral larvae shifting towards higher latitudes in response to high thermal stress in low latitudes impacting composition of coral communities and coastal economies (Wilkinson, 1994).</td></tr>
<tr><td>Increasing CO_2 emissions</td><td>- Low calcium carbonate saturation
- Competition with marine algae and seagrass beds
- Ocean acidification
- Ineffective coastal barriers
- Ultraviolet radiation</td><td>Baja California, Japan, China, and Southern Australia form the upper and lower latitudinal boundaries of coral reef distributions and carry more CO_2 in cooler waters thereby exacerbating impacts of climate-related stressors (Pendleton, 2016).</td></tr>
<tr><th>Anthropogenic Disturbances</th><th>Effects</th><th>Examples</th></tr>
<tr><td>Unsustainable Fisheries</td><td>- Destructive fishery practices (poison fishing, blast fishing, etc.)
- Overfishing
- Unregulated aquaculture development</td><td>Restaurants in Hongkong use cyanide as a “cost-effective” way of harvesting fisheries. Most endemic species and apex predators are targeted impacting trophic level interactions (Ohman, 2000).</td></tr>
<tr><td>Dredging/Mining/Infrastructure development</td><td>- Eutrophication
- Destruction of reef flats
- Logging</td><td>Regions near the Red Sea and the Arabian Gulf have engaged in non-sustainable oil extraction and desalination activities along the coast whereby untreated brine is released back into the water leading to decreased oxygen</td></tr>
</table>

		and nutrients in coral ecosystems (Kleinhaus, 2020).	- Inefficient land-use management tools - Lack adaptability and resilience - Lack streamlined approaches to mitigate and adapt to local and global stressors - Public unawareness
Sedimentation/Pollution/Waste	- Reduced light attenuation - Tissue necrosis - Secondary impact: fisheries, tourism, economic costs - Bleaching events	Coastlines from Sri Lanka and Maldives in South Asia to the East Africa have experienced exacerbated bleaching events as a result of rapid coastal urbanization and lack of proper waste management (Ohman, 2000).	

B. Current Management Strategies for Coral Reef Ecosystems

Current management initiatives of coral reef systems fall into four major objectives - mitigation, protection, restoration, and adaptation. However, alongside these objectives, research and development (R&D), consultation, and governance must come together to assess socio-economic and environmental tradeoffs in order to establish protocols that are holistic and adaptive in management of coral reef ecosystems and furthermore streamlined across other management priorities such as global stressors of climate change.

Figure 1: *Coral Reefs Management Objectives of Coral Reef Systems (Comte, 2018).*

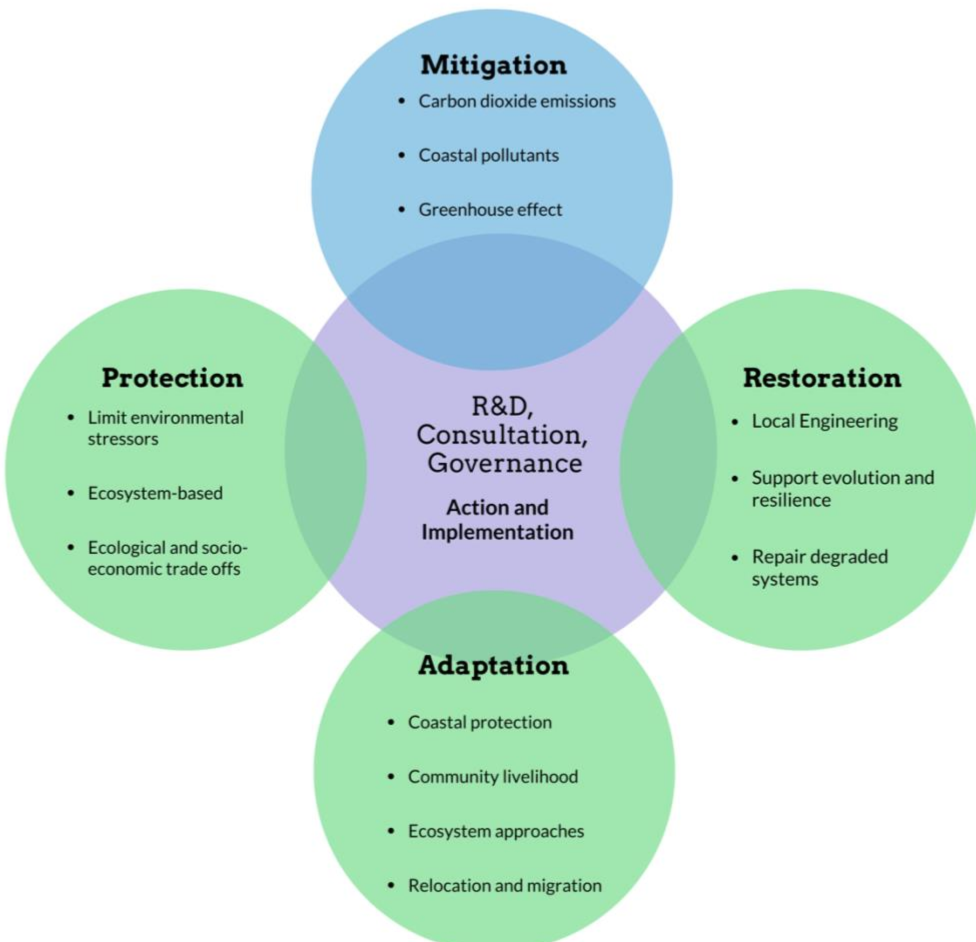


Figure 2: *Current Management Strategies of Coral Reefs.*

II. Mangrove Ecosystems

Mangrove forests are salt tolerant (halophytes) ecosystems situated in the intertidal zones of sheltered shores, estuaries, tidal creeks, backwaters, lagoons, marshes, and mudflats of the world's tropics and subtropics predominantly and some temperate coasts (Sandilyan, 2012). The environment is characterized by low wave energy and deposition of fine particles supported by their roots. They possess unique morphological characteristics which include aerial roots, viviparous embryos, rapid canopy production, narrow and densely distributed vessels for nutrient retention, and the ability to balance water and carbon sequestration in highly saline marine environments (Alongi, 2002). They support marine and terrestrial level trophic interactions, provide nursing and breeding sites for marine and terrestrial fauna through microhabitats, and are highly rich in nutrients through sediment accumulation. In addition to ecosystem services, they support coastline communities particularly through fisheries, forest products, pollution abatement, and act as coastal barriers to erosion and natural calamities (Sandilyan, 2012). Their traditional and commercial value is threatened by global natural and anthropogenic disturbances as a result of overexploitation, coastal development, and felling of forests for aquaculture development in order to support urbanization. Hence, the recognition of environmental, social, and economic impacts associated with the decline and degradation of mangroves are essential targets for management, conservation, and restoration efforts.

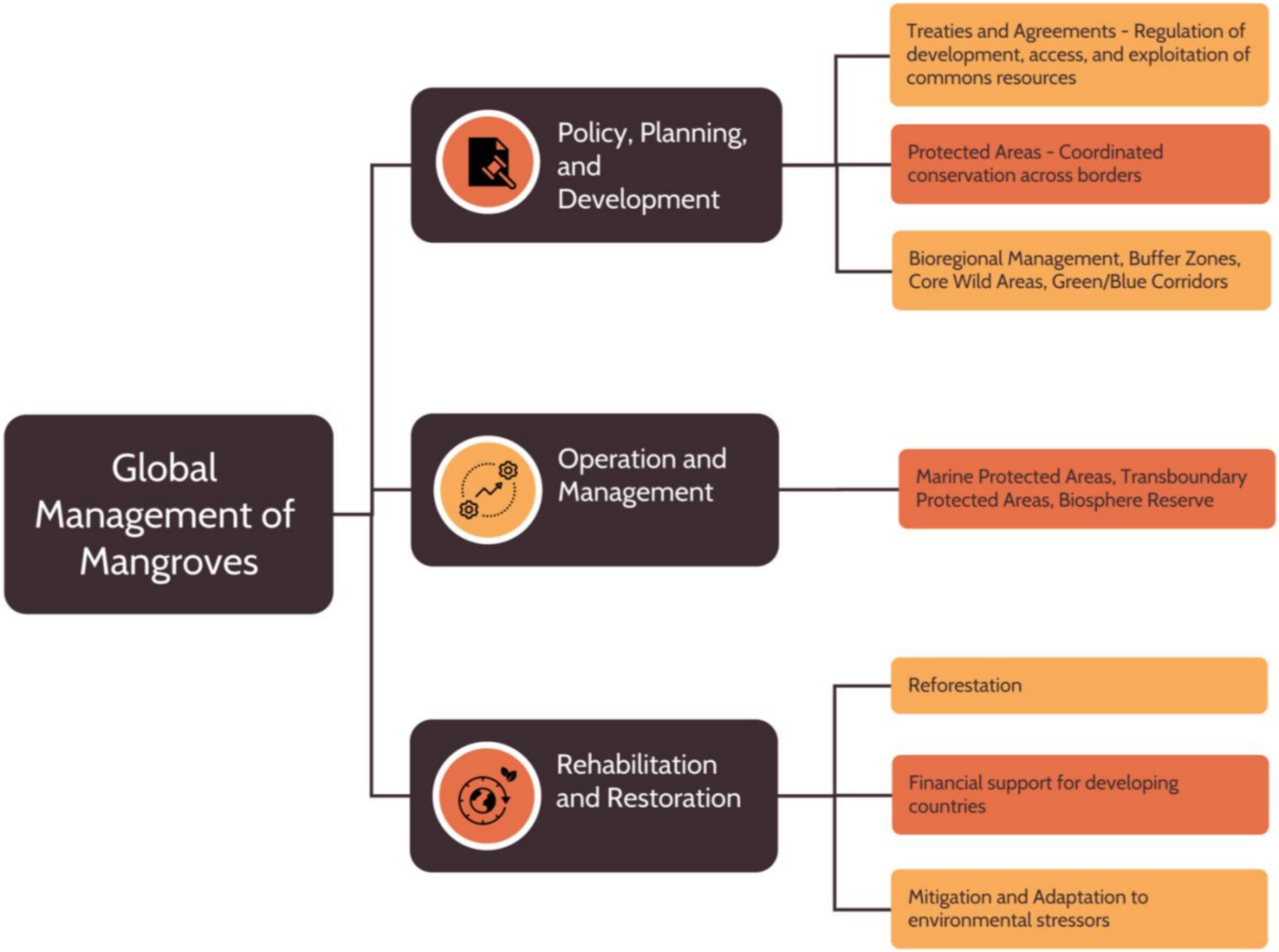
A. Management Challenges for Mangrove Ecosystems

<table>
<tr><th>Environmental Disturbances</th><th>Effects</th><th>Examples</th><th>Management Challenges</th></tr>
<tr><td>Sea level rise</td><td>- Sediment erosion/deposition
- Ineffective coastal barriers</td><td rowspan="2">- Eco physiological characteristics allow mangroves in Australia and New Zealand to withstand increasing CO_2 and warmers waters, however, their latitudinal boundary is suppressed by salt marsh dominance (Macintosh, 2002).</td><td rowspan="6">- Ambiguous policies
- Uncertainty of property rights on the coast
- Governance failure
- Poor land-use planning tools (felling for aquaculture development)
- Lack of implementation and enforcement of regulations
- Public unawareness
- Conflicting interests of various stakeholders
- Community involvement
- Lack of capacity for management
- Unregulated management of other economic and commercial sectors in the coast
- MPA planning without information on environment, site specific, community, physical, and biological characteristics (example buffer zones)
- Well established baseline data with no predictive models
- Lack of connectivity in MPA planning</td></tr>
<tr><td>Increased atmospheric CO_2</td><td>- Rising temperatures
- Increased storm activity/inundation
- Reduced productivity
- Erosion
- Altered salinity</td></tr>
<tr><th>Anthropogenic Disturbances</th><th>Effects</th><th>Examples</th></tr>
<tr><td>Over-exploitation (traditional and commercial)</td><td>- Decline in natural resources
- External pressures (extreme weather events)
- Commercial forestry products, charcoal production</td><td>- Overexploitation of mangroves forests in Bangladesh for timber, bark tannin, animal fodder, native medicines, and food as a result of increasing population (Macintosh, 2002).</td></tr>
<tr><td>Ecosystem conversion</td><td>- Conversion into desalination and salt production facilities, coastal mining, agriculture, and aquaculture etc.
- Deforestation</td><td>- Mangrove forests in Asia have drastically declined due to conversion into rice and aquaculture farming (Macintosh, 2002).</td></tr>
<tr><td>Offsite activities</td><td>- Pollution
- Dredging
- Effluent discharge (industrial/agricultural)
- Logging
- Coastal development</td><td>- Mangrove forests of Brazil have declined as a result of inefficient waste management, industrial effluents, agrochemicals, oil spills etc. (Macintosh, 2002).</td></tr>
</table>

B. Current Management Strategies for Mangrove Ecosystems

Current management initiatives for mangroves at local and national levels fall into 3 objectives of - policy, planning, and development; operation and management; and restoration and rehabilitation through an integrated coastal zone management framework. Compliance between regulatory, institutional, and management groups play an integral role in monitoring and conservation of coastal areas, however, the lack of enforced regulations, poor planning and implementation, and conflicting interests in policy decision making between sectors can lead to continued degradation of mangrove ecosystems unable to recover and adapt to unpredictable changes in the future.

Figure 3: *Current Management Initiatives and Strategies for Mangrove Ecosystems (Macintosh, 2002 & Harty, 2009).*



III. Seagrass Beds

Seagrass are flowering plants of marine and estuarine ecosystems found in all continents except for Antarctica (Duarte, 2008). The marine environment is characterized by a coastal benthic ecosystem in nearshore habitats and life cycle functions that occur while being completely submerged underwater (Björk, 2008). Despite their low diversity (approximately 60 species worldwide) in comparison to other coastal ecosystems (such as coral reefs, mangroves, salt marshes etc.), they have colonized various regions globally with the exception of polar areas (Orth, 2006). These ecosystems exhibit high biodiversity due to their dominant productive capacity and often referred to as "productive biomes" on earth (Duarte, 2002). Seagrass beds provide a range of ecological and commercial benefits through trophic level interactions, coastal and biodiversity protection, reduction of pathogens, carbon sequestration and biogeochemical cycling, and improvements in water quality and stability as a result of unique eco-physiological and morphological adaptations (Unsworth, 2014). In addition, they have had provided traditional and cultural services such as for infrastructure development (roof coverings), provide insulation, medicinal purposes, and used to develop garden fertilizers in dependent coastal communities (Björk, 2008). Despite their multiple benefits, these ecosystems are among the least protected coastal ecosystems (World Seagrass Association, 2020). Recent decline and degradation of seagrass beds as a result of economic development emphasize the need to enforce and streamline management both locally and globally in order to ensure biological conservation and sustainable use.

A. Management Challenges of Seagrass beds

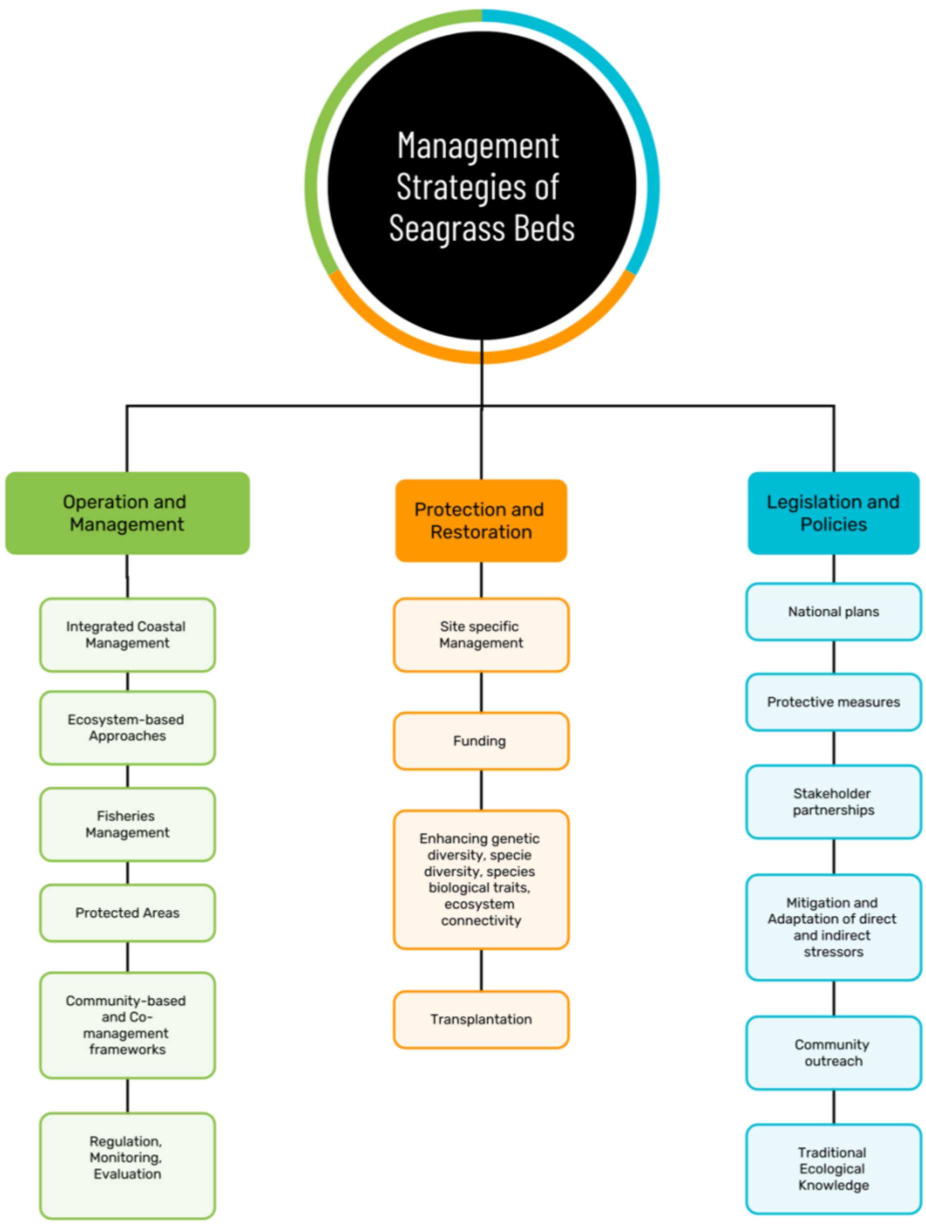
Environmental Disturbances (Indirect Impacts)	Effects	Examples	Management Challenges
Increasing temperature	- Reduced metabolic activity, growth, reproduction - Distribution and abundance - Ecosystem shift	- High temperatures have caused widespread decline of *Amphibolis antarctica* and *Zostera* spp in southern Australia which are accustomed to colder water (Björk, 2008).	- Lack parameters crucial for monitoring systems - Lack international recognition (aesthetic value in comparison to other coastal systems) - Lack implementation of regulations that monitor effluent discharge (point and non-point source) (Global Paper) - Public unawareness - Lack of research and capacity for modeling - Ineffective data collection methods - Inefficient long-term monitoring - Lack of protected area initiatives - Unsustainable fisheries management and other environmental/economic sectors - Inefficient mapping methods of distribution - Lack of input from local ecological knowledge sources and communities - Lack adaptability, resilience, and connectivity in proposing management strategies - Challenges in transplantation for restoration (species diversity)
Increase in CO_2	- Increased photosynthesis - Competitive advantage/disadvantage (depending on other factors in the system) - Ecosystem shift	- Increased production and biomass of epiphytic algae on seagrass leaves causing shading (Björk, 2008).	
Light/UV radiation	- Reduced light attenuation (weather) - Distribution and abundance	- Undesirable for those species that grow in light limited regions	
Extreme Weather (Storms, floods etc.)	- Sediment disturbance - Shading - Reduced productivity	- Seagrasses in Queensland have declined due to sediment and substratum disturbances from flooding and cyclones (Björk, 2008). - Seagrass in the Philippines and Thailand have declined due to sediment loading of silt and clay (Björk, 2008).	
Sea level rise	- Erosion - Sediment hypoxia/anoxia	- Prolonged anoxia increase sulphides in sediments which are poisonous to seagrass bed (Björk, 2008).	
Anthropogenic Stressors (Direct Impact)	**Effects**	**Examples**	
Mechanical damage (shipping, dredging, mining, destructive fishing, recreational activities etc.)	- Impacts on longevity and stability of species and the ecosystem - Recovery dependent on extent of exploitation - Pioneering species more readily impacted but have easier recovery	- Trawling has resulted in losses of seagrass beds along European coasts to the Mediterranean (Borum, 2004).	
Eutrophication	- Outcompeted by macroalgae - Beneficial to species in more well-lit environments - Anoxic environments - Increase in sulphides (poisonous) - Inefficient biogeochemical functioning	- Western Australia has experienced significant losses to seagrass bed as a result of effluent discharge, massive growth of both epiphytic and benthic macroalgae causing shading and decrease in abundance of seagrass beds (Björk, 2008).	
Coastal Development	- Heavy metal pollution (Copper, zinc, petrol chemicals, pesticides, herbicides) - Salinity change - Degradation - Reduced productivity	- Seagrass bed have been degraded by hotel developments as they have been regarded as unattractive, thereby increasing pollution and waste detrimental to the ecosystem (Björk, 2008).	

Aquaculture	- Eutrophication - Reduced growth - Sediment hypoxia - Invasive species	- Shading and degradation as a result of sulfide poisoning is evident in seagrass beds of Northeast Hainan, China as a result of pond aquaculture effluents (Herbeck, 2014)	

B. Current Management Strategies for Seagrass beds

Current management strategies of seagrass ecosystems globally fall into three main objectives – operation and management, protection and restoration, and legislation.

Figure 4: *Management Strategies for Seagrass Ecosystems (Duarte, 2008).*



IV. Concluding Remarks

The value and strategies for management of coastal ecosystems vary across regions due to differences in socio-economic needs and awareness, effects of anthropogenic stressors such as climate change, and regional pressures. Despite differences in the management and benefits of these systems (Appendix, Table 1), it is evident that mangroves, seagrass beds, and coral reefs are interconnected and interdependent as they support the livelihood of various coastal communities and provide us with numerous benefits and services (Figure 5). Implementation of management, conservation, and restoration that is adaptable, resilient, and supports connectivity will not only provide various environmental benefits but also serves to achieve multiple economic and societal objectives that align with the United Nation's 2030 Sustainable Development Goals (SDGs) (Figure 6) as the coral-mangrove-seagrass complex together is the most biologically diverse and productive systems in the world (UNEP, 2021).

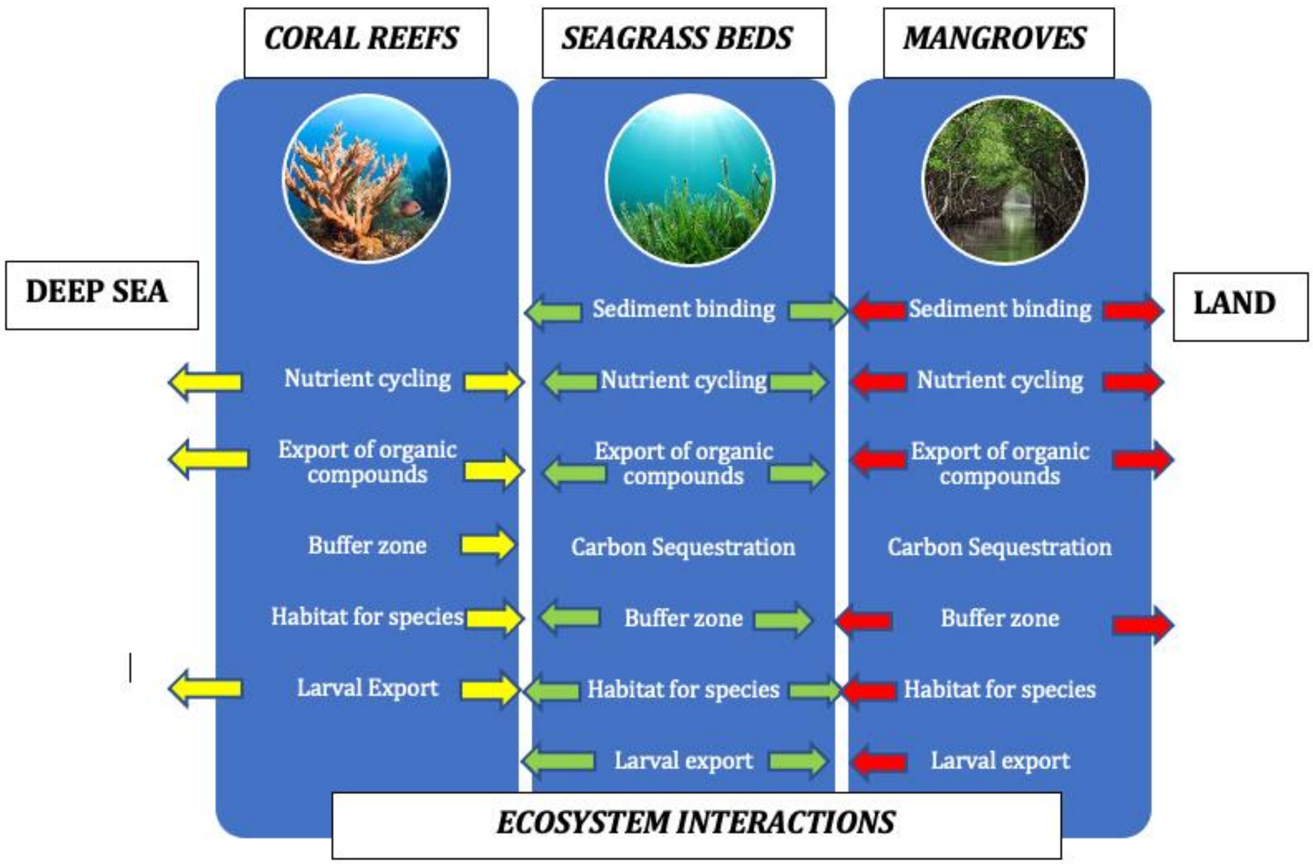
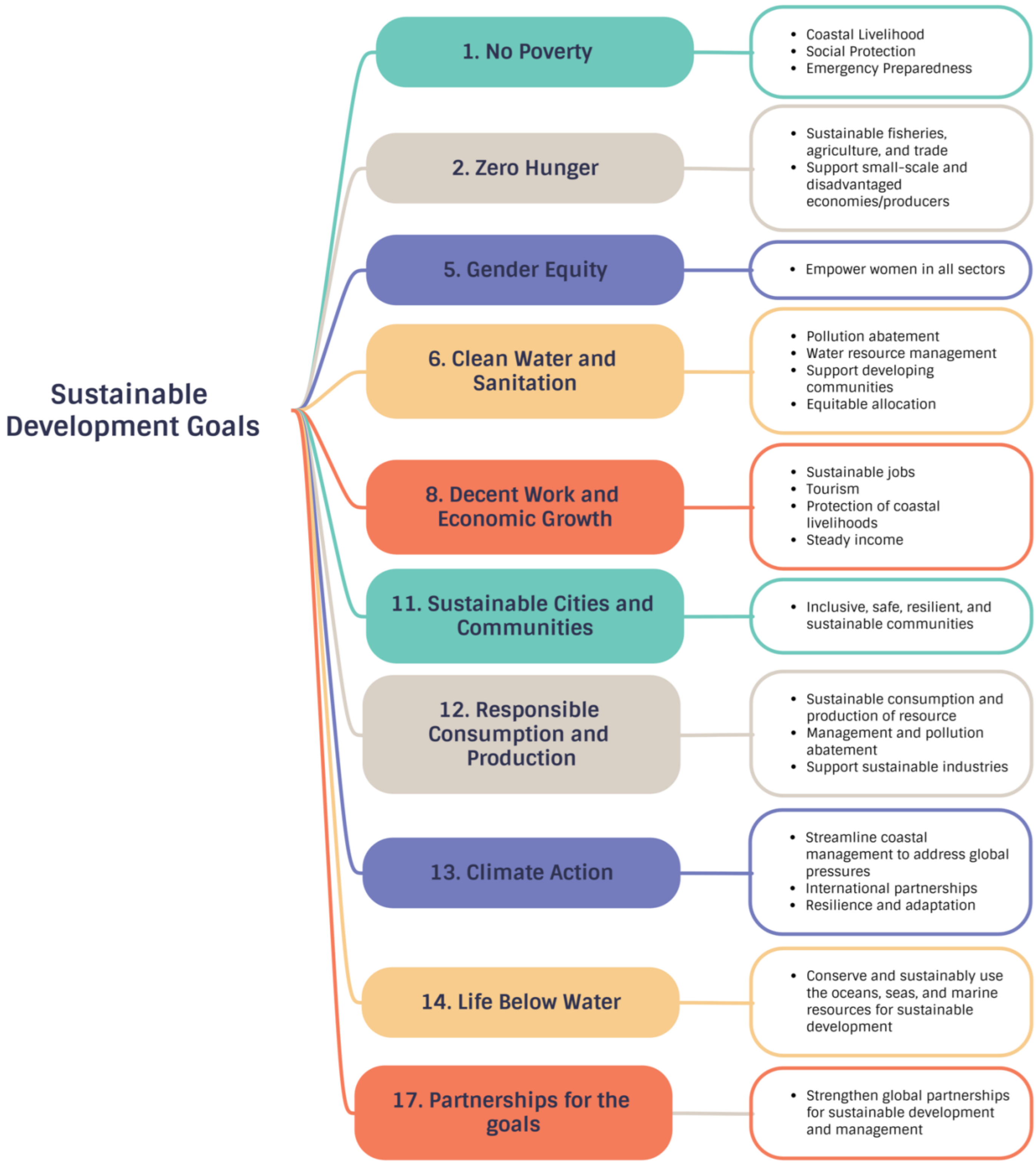


Figure 5: *Ecosystem Services Interactions between Coral Reefs, Mangroves, and Seagrass beds (Earp, 2018).*

Hence, the conservation and restoration of these natural systems will not only allow developing and developed countries achieve indicators associated with 10 SDGs but strengthen local economies to value these systems efficiently and equitably through stakeholder partnerships while meeting global coastal management targets.

Figure 6: *Sustainable Development Goals achieved by Corals, Mangroves, and Seagrass beds (World Seagrass Association, 2020 & United Nations Sustainable Development, 2021).*



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VI. Appendix

Table 1: *Similarities and Differences in Management targets of coral reefs, mangroves, and seagrass beds.*

Management Criteria	***Similarities***	***Differences***
Ecosystem services	- Trophic level interactions - Species richness - Support biogeochemical functioning - Coastline protection	**Seagrass beds** - Rich nutrient availability - Pollution abatement - Reduction of pathogens - Carbon sequestration - Water quality and stability **Coral Reefs** - Low nutrient availability **Mangroves** - Support marine and terrestrial level interactions - Rich nutrient availability - Establish microhabitats - Forestry products - Pollution abatement - Reduction of pathogens - Carbon sequestration - Water quality and stability
Economic benefits	- Food security - Pharmaceutical services - Cultural and traditional values - Resources	**Coral reefs** - Greater tourism benefits in comparison to mangroves and seagrass beds
Stressors	- Environmental: Effects of climate change - Anthropogenic: Direct and Indirect impacts	**Seagrass beds** - Aquaculture development **Mangroves** - Overexploitation - Ecosystem conversion - Aquaculture development
Management challenges	- Lack of collaboration between environmental, management, and legislative groups - Lack ecosystem-based approaches - Lack long term sustainability initiatives - Lack efficient monitoring techniques for various biological and physical factors - Lack holistic management approaches - Economic environmental trade off - Unregulated management - Lack enforcement of regulations - Inefficient land-use management tools - Inefficient adaptive management of systems - Need for streamlines approaches to other environmental vulnerabilities - Public unawareness - Ambiguous policies - Lack capacity - Lack predictive models - Lack connectivity - Funding	**Seagrass beds** - Lack legislative framework for management, interconnected governance network - Exhibit resilience through dynamic responses to stressors - Lack of research - Lack predictive models - Reduced protected area initiatives in comparison to corals and mangroves - Inefficient global mapping **Coral reefs** - Political instability in some regions over others - Lack adaptability and resilience management **Mangroves** - Exhibit resilience through dynamic responses to stressors - Uncertainty of property rights - Well established baseline data with no predictive models
Current Management	- Mangroves and coral reefs are recognized through international partnerships - Protective and restorative measures - Protected areas - Integrated coastal management - Prioritization of monitoring techniques - Community outreach - Sustainable fisheries management	**Seagrass beds** - Lack international representation - Process of developing legislative framework - Operational management criteria **Coral reefs** - Mitigation and adaptation initiatives in place

	- Stakeholder communication - Ecological and economic assessment	- Established as ecosystem engineers **Mangroves** - Policy, planning, development criteria - Operational management criteria
Knowledge systems	- Scientific, legislative, environmental, management, policy	**Seagrass beds** - Lack scientific research - Environmental, management, and policy frameworks in place - Emphasizes use of traditional ecological knowledge for management development