

# Management Strategies to Mitigate Anthropogenic Impacts in Estuarine and Coastal Marine Environments: A Review

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## Abstract

A wide range of anthropogenic activities impacts estuarine and coastal marine environments including interactive climate and non-climatic drivers of change that can significantly degrade biotic communities and habitats. Many of these environments are in decline due to changes in ecosystem structure and function resulting from multiple stressor effects. In addition, inadequate governance has supported a patchwork of single issues or sectoral approaches rather than integrated management of multiple human uses and activities to maintain healthy, productive, resilient, and sustainable ecosystems and the provision of goods and services. Ecosystem-based marine spatial planning is a viable framework for a more effective governance structure and management of these vital coastal environments. An important component of this approach is a holistic effort to assess the environmental, economic, and societal impacts of anthropogenic activities. Thus, a multidisciplinary integrated approach is preferred that links ecological, physical, and socio-economic systems, increasing the protection of resources and societal benefits. For degraded estuarine and coastal marine ecosystems, restoration and rehabilitation initiatives are important intervention strategies used to reverse the loss of habitats and biotic resources and to support management programs. Marine Protected Areas (MPAs) are an integral element of marine management plans to conserve and sustain estuarine and coastal marine environments by protecting threatened ecosystems and their resources from anthropogenic activities. National and international regulatory frameworks and directives are also in place to protect and conserve these environments.

## Keywords

Estuaries, Coastal Marine Environments, Anthropogenic Activities, Drivers of Change, Ecosystem-Based Management, Marine Protected Areas,

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## 1. Introduction

Estuaries and coastal marine waters are among the most productive environments in the world. Yet, they are often the most heavily impacted by anthropogenic activities. Despite their susceptibility to anthropogenic degradation, these environments support numerous species of organisms and habitats of ecological importance, while also providing vital goods and services to society. Estuaries alone cover more than 400,000 km of the global coastline with an estimated surface area of  $1.1 \times 10^6$  km<sup>2</sup> [1] [2]. They form transitional environments between terrestrials, rivers, and open ocean systems and thus are vulnerable to an array of anthropogenic impacts because coastal lands nearby are often highly developed and densely populated, with human activities greatly affecting ecosystems along the watershed, river, estuary, and coastal ocean continuum [3] [4]. The protection and maintenance of estuarine and coastal marine environments require integrated ecosystem management that considers the connectivity of land, estuary, and ocean components [5].

Four classes of anthropogenic drivers are potentially threatening estuarine and coastal marine environments, notably industrialization and urbanization, habitat degradation, increasing use of resources and space, and climate change [2] [6] [7]. They are particularly problematic when acting synergistically with other drivers of change to impact the structure and functioning of these environments and to reduce ecosystem goods and services. The net effect is decreasing resistance and resilience of ecosystems, as well as a reduction of their sustainable use due to climate change and non-climatic anthropogenic factors [7].

This article reviews the management strategies and legislative frameworks that address anthropogenic drivers of change and impacts in estuarine and coastal marine environments and which serve as vehicles for ecosystem protection and conservation. Day *et al.* [8] convey that most, if not all, coastal systems have serious environmental problems due to multiple stressors that require management intervention. Although no general administrative plan targets and successfully remediates all problems existing in estuarine and coastal marine environments, management measures exist to mitigate serious impacts in an effort to promote and sustain healthy ecosystems.

The main objective of the article is to synthesize the aforementioned management strategies and legislative frameworks, examining other published works on the subject such as the comprehensive treatments of Elliott [5], Kennish and Elliott [6], Defeo and Elliott [7], and others. To this end, the general structure of the article consists of several key components that follow: types of anthropogenic impacts, management strategies, management frameworks, remediating damaged coastal environments, and regulatory frameworks. As noted by Elliott *et al.* [5], the degradation of biotic communities and habitats in natural systems due to

anthropogenic impacts requires effective management measures for successful restoration and mitigation, while concurrently sustaining goods and services.

## 2. Types of Anthropogenic Impacts

Kennish [9] has reviewed the numerous anthropogenic drivers of change that impact estuarine and coastal marine environments, organizing them into 12 categories: 1) habitat loss and degradation (e.g. lagoon construction, shoreline hardening, and land reclamation); 2) enrichment (e.g. nutrients, organic carbon, and thermal loading); 3) sewage and pathogenic inputs; 4) chemical contaminants; 5) human-induced sediment/particulate inputs; 6) human-altered hydrological regimes; 7) dredging and dredged-material disposal; 8) invasive/introduced species; 9) overfishing and intensive aquaculture; 10) coastal subsidence; 11) floatables/plastics/debris; and 12) climate change. Transportation and shipping, renewable and non-renewable energy generation, agriculture, and coastal infrastructure may be added to this list [10]. These drivers of change can be organized further into physical, chemical, and biotic factors that often affect the ecological integrity, sustainability, and ecosystem services of these environments, or can be divided into four major categories depending on whether they compromise water quality, alter biotic communities, degrade habitat, or are linked to climate change (Table 1). Nutrient enrichment, organic carbon loading, chemical contaminants, and pathogens are examples of drivers that impact water quality. Overfishing, introduced/invasive species, and human-altered hydrological regimes are drivers that also adversely affect biotic communities. Dredging and dredged-material disposal, hardened shorelines and other structural modifications, and wetlands reclamation are drivers that directly degrade habitats.

An array of pollutants—some highly toxic to organisms—accumulate in estuarine and coastal marine environments (see detailed discussion below); most of these pollutants (>80%) are derived from land-based sources [11]. Over the past 50 years, in particular, climate change interacting with pollutants and other local, non-climatic drivers of change has accentuated these impacts, strongly affecting coastal ecosystems at all levels of biological organization [12]. As Landrigan *et al.* [11] note, marine pollution is an escalating global problem poorly controlled by most countries. However, management strategies are being applied that can reduce or eliminate these stressors, such as acute decreases in greenhouse gas emissions, improved regulation of chemical contaminants, and mitigation of coastal habitat loss and alteration.

Climate change increases vulnerability and decreases resilience of estuarine and coastal marine environments [2] [3] [4]. Doney *et al.* [13] showed that climate change-mediated shifts in temperature, precipitation, water circulation, stratification, nutrient input, oxygen content, pH (ocean acidification), and sea level rise have wide-ranging effects on estuarine and marine organisms, including altered distribution and abundance, reduced biodiversity and biotic production,

**Table 1.** Major anthropogenic drivers of change in estuaries. Modified from Kennish (2021).

<b>Drivers</b>	
Category 1	(Degrade Water Quality) Nutrient Enrichment/Eutrophication Organic Carbon and Thermal Loading Biogeochemical Alteration Chemical Contaminants Sewage Inputs Pathogens
Category 2	(Alter Habitat) Watershed Development/Coastal Infrastructure Watershed Impervious Cover Sediment/Particulate Inputs Dredging and Dredged-Material Disposal Shoreline Hardening Lagoon Construction Land Reclamation and Impoundments Coastal Subsidence
Category 3	(Impact Biotic Communities) Human-altered Hydrological Regimes Overfishing Intensive Aquaculture and Agriculture Invasive/Introduced Species Floatables/Plastics/Debris Renewable and Non-renewable Energy Generation
Category 4	(Link to Climate Change) Climate Change Drivers CO <sub>2</sub> , CH <sub>4</sub> , NO <sub>2</sub> , Chlorofluorocarbons, (Greenhouse Gases) Warming Temperatures Precipitation and Land Runoff Extreme Events Hurricanes and Other Major Storms Storm Surges Tornadoes Droughts

habitat loss, and other adverse fluxes. Many organisms exhibit physiological intolerances to changing environmental conditions and variable species interactions resulting in major population-level shifts. Accumulating databases and models indicate marked changes in demography, abundance, distribution, and phenology of species with escalating climate change. Prevailing trends in species responses, largely driven by increasing temperature, include shifts in geographic distribution to higher latitudes and deeper waters [14]. Warming waters in estuaries account for observed poleward range shifts of organisms from estuary to estuary [15]. Other biotic responses to climate change projected in many estua-

rine waterbodies include an increase in invasive species, harmful algal blooms (HABs), and pathogens [4].

### 3. Management Strategies

A primary goal of estuarine and coastal marine ecosystem management is to protect biotic communities and habitats from adverse effects of human activities and natural events, including changes that pose a threat to ecosystem structure, functioning, and sustainability [5] [10] [16]. As such, it is not only important to examine the structure of an ecosystem (*i.e.* species richness, abundance, biomass, density, etc.) but also its functioning (*i.e.* rate processes) and the effects of activities on human uses of estuarine and marine waters. In addition, it is necessary to assess and maintain the natural hydrodynamics, sedimentology, geomorphology and other characteristics of an ecosystem.

Ecohydrology and ecoengineering are important tools used in estuarine management to address altered or damaged habitats and biotic communities and to improve ecosystem conditions. Restoration and rehabilitation are also vital in returning impacted ecosystems to an improved condition. Successful estuarine restoration projects require both effective science and societal components. In fact, development and implementation of ecological restoration projects are processes involving the interaction of multiple actors. Such projects are successful when they lead to the recovery and increased resiliency of degraded ecosystems [17].

#### 3.1. Ecosystem-Based Management

An objective of estuarine and marine environmental management is also to ensure the maintenance of ecosystem goods and services beneficial to society [18] [19]. An ecosystem-based management approach is a holistic strategy that considers the entire ecosystem, including human activities and other societal components [5] [20] [21] [22]. It examines an array of interactions occurring in an ecosystem rather than focusing on a single element (e.g. species, microbes, or ecosystem services). As defined by the Secretariat of the Convention on Biological Diversity [23], “The ecosystem approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way”. The goal of this approach is to maintain the ecosystem in a healthy, productive, and resilient condition, while providing goods and services for human use and enhancing sustainability of resources [21] [22]. A focus is to balance the intensity of human activities with the ability of estuarine and marine environments to provide ecosystem services. A need exists for governance to support integrated coastal management [20].

In a systematic review of 151 peer-reviewed papers on governance and land-sea connections, Pittman and Armitage [24] found that ecosystem-based management is the main management approach used to address land-sea interactions. Far fewer alternative management approaches are presented in the published li-

terature that address science-policy integration, interactions between ecosystem components, as well as cross system threats (e.g. climate change). Because of the complexity of estuarine and coastal marine environments, ecosystem-based management must consider ecosystems along the watershed, river, estuary, and coastal ocean continuum.

### 3.2. Management Frameworks

Elliott *et al.* ([5], p. 709) noted that estuarine environmental management, “revolves around a framework questioning what are the uses for the estuary, what does society do in the estuary, what are the mechanisms whereby impacts are created, and what we do about those impacts”. The goal of estuarine management, therefore, is to determine the threats to an estuary, its watershed, coastal marine areas, and their habitats and biotic communities. Successful and sustainable management of these environments should then follow the 10-tenets described by Elliott [19] that include all facets and players in a system. That is, the management actions should be: ecologically sustainable, technologically feasible, economically viable, socially desirable/tolerable, legally permissible, administratively achievable, politically expedient, ethically defensible, culturally inclusive, and effectively communicable.

The interactions between ecological structure and functioning, physico-chemical processes, and socio-economic systems account for the complexity of managing estuarine and coastal marine environments [16]. Hence, effective integrated ecosystem management of these environments should consider the application of a holistic problem-structuring framework such as a Drivers-Activities-Pressures-State Change-Impacts-Responses approach. This linked framework approach is an effective and accurate way to assess the causes, consequences, and responses of change in natural coastal ecosystems affected by anthropogenic activities. Also significant in this management approach is an understanding by policymakers, managers, and stakeholders of the links between environmental condition and society as well as the distribution and intensity of human activities [16] [25].

Elliott *et al.* [16] and Elliott [26] conveyed that underlying effective marine management is the aforementioned holistic unifying framework that constitutes a constructive integrated process designed to protect and conserve natural ecosystems. Essentially, drivers of basic human needs lead to Pressures of State changes on ecosystems causing Impacts (on human welfare) requiring Responses (as measures) to remediate. Elliott *et al.* [16] provide a detailed explanation of this framework, which links natural and social systems, creating an ecosystem approach for managing estuarine and marine environments to protect and maintain natural systems while supporting ecosystem services that yield societal goods and benefits [26]. This interlinked framework also reflects management of ecosystems along the watershed, river, estuary, coastal ocean continuum encompassing components of ecosystem structure and functioning, ecosystem

services, and societal benefits. An important component of this approach is a holistic effort to assess environmental, economic, and societal impacts of all activities. Thus, a multidisciplinary integrated approach is preferred that links natural and social sciences and protects ecosystem services and societal benefits. The loss of ecosystem services and societal benefits due to anthropogenic pressures is a key element considered in sustainable and successful marine management programs [26] [27] [28].

Estuarine and coastal marine environments can change markedly when subjected to anthropogenic pressures. Three major sources of these pressures are recognized: 1) activities that remove materials and space from an ecosystem (e.g. fish, shellfish, and sediments); 2) activities that place materials into an ecosystem (e.g. wastewaters, toxic pollutants, and power plant thermal discharges); and 3) activities causing external and wider pressures on ecosystems (e.g. fossil-fuel burning, greenhouse gas emissions, and climate change) [3] [6] [26]. The environmental, economic, and societal impacts of all activities should be considered in an integrated analysis of these environments. The interaction of local pressures (e.g. coastal development, overfishing, nutrient enrichment) and global pressures (e.g. increasing temperatures, rising sea levels, and acidification) is deleterious to the structure and functioning of estuarine and coastal marine ecosystems. Effective ecosystem-based management must identify the influences of land-based drivers that can negatively impact and alter these ecosystems. Coastal watersheds are areas of potentially damaging anthropogenic activities that impact coastal waters, and hence proactive land-sea conservation planning and governance are vital to protecting these ecosystems together with efforts to mitigate local impacts along the land-sea continuum (Fredston-Hermann *et al.* 2016). For example, coastal runoff containing chemical contaminants, excess nutrients and sediments, bacterial and viral loadings, and other substances from land-based human activities can seriously impair estuarine and coastal marine waters and must be targets of management and remediation programs.

An ecosystem impacted by anthropogenic pressures may be degraded, or it may exhibit resistance to change. The ecosystem may also exhibit resilience by returning to a former state after removal of the pressure [26] [27]. Elliott and Kennish [28] defined ecological resilience as the ability of an ecosystem to return to its original state after being disturbed. However, after the pressure is removed, an ecosystem may not follow a trajectory reverting back to the original environmental condition but to an alternate stable state, although shifting baselines may still yield an improved condition. Degraded or disrupted ecosystems typically exhibit lower resilience. Broad changes in environmental condition over time due to anthropogenic pressures lead to shifting baselines away from the ecosystem reference condition, imposing dynamic trajectories that limit restoration and recovery capability [29].

### **3.2.1. Ecosystem-Based Marine Spatial Planning**

Ecosystem-based marine spatial planning (EB-MSP) is an effective strategy for



supporting healthy coastal and ocean ecosystems and sustained human uses of estuarine and marine waters [30] [31]. It is a strategy implemented to manage for cumulative activities in an area rather than for sectoral applications [25]. Foley *et al.* ([31], p. 956) defined EB-MSB as “an integrated planning framework that informs the spatial distribution of activities in and on the ocean in order to support current and future uses of ocean ecosystems and maintain the delivery of valuable ecosystem services for future generations in a way that meets ecological, economic, and social objectives”. According to Foley *et al.* [31], EB-MSP addresses declining health of marine ecosystems in the following ways: 1) informing the spatial distribution of activities in estuarine and marine environments; 2) maintaining human uses and reducing use conflicts in these environments; and 3) restoring, protecting, and sustaining ecosystem health and services. EB-MSB is a process based on ecological principles incorporated into a decision-making framework that leads to healthy and functioning ecosystems and services that contribute to sustainable economic and societal benefits.

Marine spatial planning has rapidly gained favor as an important aspect of integrated coastal management and sustainability of estuarine and coastal marine ecosystems and their resources in waters of the European Union [5] [21]. It is a framework to manage human activities in space and time and to achieve planning objectives that support uses of healthy marine ecosystems and maintenance of ecosystem services [20]. Factors of importance include land-sea connectivity, habitat structure, habitat heterogeneity, species diversity, and maintaining key species diversity that has disproportionately strong influence on community structure and functioning in these ecosystems [31].

The Maritime Spatial Planning Directive of 2014 established a framework for marine spatial planning of European Union waters. Several other policies, such as the Water Framework Directive, Marine Strategy Framework Directive, Habitat Directive, and Renewable Energy Directive have also steered marine spatial planning of these waters [21]. Katsanevakis *et al.* [20] showed that marine spatial planning supports ecosystem-based management by considering an array of interactions that occur within an ecosystem. Many estuarine and marine governing bodies now promote EB-MSP as the best way to ensure sustainability of estuarine and marine ecosystems and their services for humans [20] [21].

### **3.2.2. Integrated Coastal Zone Management**

Integrated Coastal Zone Management (ICZM) is a resource management system that uses an integrative, holistic approach and an interactive planning process to resolve complex coastal management issues [32]. Originated in 1992, ICZM has been implemented to address the coastal problems that can pose a threat to the economic sustainability and environmental quality of coastal environments. It incorporates input of governing bodies, administrators, scientists, and stakeholders to assess environmental and societal goals in a coastal area and to develop effective resolution to problems. The planning process seeks a balance of environmental, social, cultural, recreational, and economic elements affected by



coastal problems [8]. ICZM incorporates a multi-objective perspective that addresses potential conflicts of interest and complex environmental issues to advance resolution of coastal problems.

#### 4. Remediating Damaged Coastal Environments

Continued coastal population growth and development, increasing environmental stressors, and resulting impacts on coastal watersheds and estuaries are manifested by the changing structure and functioning of ecological communities, fragmented habitats, and reduced sustainability of ecosystems. Species abundance, distribution, and diversity in estuaries are affected by both natural and human-induced drivers of change such as increased intensity of hurricanes, nor'easters, and storm surges as well as nutrient enrichment, wastewater contaminant inputs, freshwater diversions, hardened shorelines, wetlands reclamation, fisheries overharvest, and other factors [4] [5] [9] [16] [33].

Drivers of change do not act in isolation in estuaries and coastal marine waters but are interactive, including climate change factors that can exacerbate the effects of direct, non-climatic anthropogenic factors. Multiple interactive drivers associated with anthropogenic climate change and non-climatic human pressures account for significant nonlinear effects of cumulative environmental impacts on biotic communities and ecosystem function. Driver effects can be additive, synergistic, or antagonistic, and they are often disruptive, leading to ecosystem dysfunction and depletion of resources [9]. Some estuaries exhibit insidious habitat degradation and biotic community alteration in response to some anthropogenic stressors (e.g. eutrophication), whereas others cause sudden acute changes (e.g. oil spills).

Elliott and Quintano [34] recount that estuaries are particularly difficult environments to assess human impacts because they are naturally stressed, highly variable ecosystems in nature, and hence it is often more challenging to detect anthropogenically-affected areas there than in more stable, less naturally stressed environments. Unless the action of an anthropogenic stressor is severe (e.g. sewage outfall or dredging), less acute anthropogenic impacts may go undetected in estuaries. The concept of Estuarine Quality Paradox, as related by Elliott and Quintano [34], emphasizes the difficulty of distinguishing natural from human-induced stresses in estuaries. Accurate assessment of natural and anthropogenic stresses in estuaries requires extensive data collection and analysis on the structure and functioning of biotic communities, as well as the condition of habitats [3] [4] [9] [33].

Impaired estuarine and coastal marine ecosystems often require considerable amounts of time to recover from anthropogenic and natural stressors after they are lifted. Borja *et al.* [35] noted that coastal ecosystems affected by anthropogenic stressors typically require up to 10 - 25 years recovering from the stressor impacts. Restoration can facilitate the recovery process, although impacted ecosystems often do not return to their original state but rather to an improved pre-existing condition [36] [37].

#### 4.1. Ecological Engineering

Mitsch [38] defined ecological engineering (also termed ecoengineering) as the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both. Ecological engineering is a vector for restoration of ecosystems altered by human activities with a goal of establishing sustainable resources having both human and ecological value and often employing ecohydrology to restore ecosystem functioning [39]. As such, ecological engineering is closely aligned with ecosystem restoration. It is a working arm of coastal marine management.

Ecological engineering is an applied approach to improve the ecology of an ecosystem through engineering of physical-chemical processes, such as water quality and quantity, or engineering of biotic components, such as replanting or restocking biota [39]. Ecological engineering often employs ecohydrology to create or re-create habitats that ecologically enhance development of natural populations, communities, and fisheries resources. They also are used for storm, flooding, and erosion protection of built communities in vulnerable coastal areas, for agriculture and lowland development, and for mitigation or elimination of pollutant loadings to coastal waterbodies. As noted by Elliott *et al.* ([39], p. 13), ecological engineering involves... “manipulating the estuarine or coastal system either to restore it from past degradation or to improve the delivery of nature conservation and natural structure and functioning to increase estuarine goods, services, and social benefits”.

#### 4.2. Restoration of Impacted Environments

There are long-term restoration programs in place that focus on recovery of damaged estuarine and coastal marine environments. They typically involve measures to restore ecosystem structure and functioning, although this process is generally protracted. Declining coastal ecosystems commonly exhibit an array of characteristics that warrant restoration, for example: 1) escalating habitat fragmentation; 2) reduced habitat and species diversity; 3) altered population size, dynamics, and range of species; and 4) decreased goods and services [28]. Major processes degrading estuarine and coastal marine environments typically include the introduction into or removal of physical and chemical materials, physical structures, and organisms in an area [40]. Restoration is not only limited to biotic and habitat components, but also may include the restoration of hydrodynamic and morphological characteristics. Innovative coastal marine ecosystem tools are available to reverse the decline of impacted areas.

Ecosystem restoration is an emerging field and a primary intervention strategy used to reverse the loss of estuarine and coastal marine habitats due to natural and anthropogenic pressures and to increase their resilience to climate change and other drivers of change. Abelson *et al.* ([41], p. 2) defined restoration simply as “the process of assisting the recovery of damaged, degraded, or destroyed ecosystems”. Recovery means an ecosystem will return to a prior condition after

being degraded or disrupted [28]. The United Nations Convention on Biological Diversity [42] has added that ecological restoration is a means of sustaining ecosystem resilience and conserving biodiversity. Coastal ecosystem restoration and rehabilitation are a means of addressing the loss of natural habitats, the consequent impacts on biotic communities, and the decreasing ecosystem services that adversely affect human uses. Elliott and Kennish ([28], p. 354) defined rehabilitation as “the act of partially or, more rarely, fully replacing structural or functional characteristics of an ecosystem that have been reduced or lost”. Rehabilitation of a degraded habitat does not mean it returns to an original state. Instead, it typically refers to an improved condition of the degraded state of a habitat or ecosystem, rather than one that has returned to its original state after being degraded or disrupted.

The magnitude of habitat losses in estuaries and other coastal environments has been significant for more than a century, as exemplified by global areal losses of salt marshes, mangroves, seagrasses, kelp beds, oyster reefs, and coral reefs amounting to 35% - 85% [43]. Because of the substantial goods and services these ecosystems provide, innovative conservation solutions are needed to sustain them, together with management approaches that integrate restoration targets to improve ecological conditions. Despite the ongoing loss of coastal habitat in many regions due to climate change-mediated sea level rise, surveys indicate that coastal ecosystem resilience persists in the face of climate change effects [44].

The effectiveness of coastal marine ecosystem restoration increases when incorporating socio-economic elements [41] [45]. While ecological restoration of estuaries is a governance process, socio-economic interests are often preferred over ecological interests, which can influence outcomes. Successful development and implementation of ecological restoration projects in estuaries depend on the application of workable governance conditions. Buitenhuis and Dieperink [17] state that successful restoration projects are those contributing to healthy and resilient ecosystems. They conclude that there is greater success of ecological restoration projects when three conditions are met: 1) when stakeholders provide sufficient project support; 2) when individuals in key positions provide support for the project; and 3) when undertaking research on the target area prior to the development and implementation process of the project.

Saunders *et al.* [43] reported that restoration interventions in coastal marine environments can be successful over large spatial scales (1000s to 100,000s of hectares), while also being cost-effective and providing social and economic benefits. While restoration has proven highly effective in rehabilitating many damaged estuarine and coastal marine environments, it can be expensive to implement and complete, as evidenced by the cost of previous restoration projects in these environments. Bayraktarov *et al.* [46] indicated that the median costs for restoration projects are in the hundreds of thousands of dollars per hectare, although many successful scaled-back restoration projects are in the tens of thousands of dollars per hectare.

Restoration is an integral part of conservation management that uses science-based techniques and methodologies to enhance the structure, functioning, and health of degraded estuarine and coastal marine ecosystems [45]. More recently, the social dimensions of ecological restoration have been incorporated as well [43]. There are many examples of restoration success in coastal ecosystems, such as the rebuilding of salt marshes, mangroves, and seagrass habitats, repopulating shellfish beds, removing contaminated bottom sediments and hardened shoreline structures, installing oyster reef substrate, enhancing coral reefs, re-establishing freshwater inflow, eliminating problematic invasive species, and improving water quality of land runoff [37], although there is much more work remaining to advance restoration practices in estuarine and coastal marine environments [41].

The use of living shorelines, artificial oyster reefs, and thin-layer sediment application on wetland surfaces is mitigating the effects of habitat loss due to sea level rise, inundation, and erosion, thereby increasing wetland resilience, sustainability, and vital ecosystem services [47] [48]. Furthermore, they can enhance sediment deposition and accretion to expand the area of the wetlands, providing additional coastal protection services from storm surges and other extreme events [47]. For example, Sun and Carson [49] reported that the protective effects of 1 km<sup>2</sup> of coastal wetlands saved an average of \$1.8 million per year from tropical storm damage based on analysis of the damage caused by 88 tropical storms and hurricanes in coastal counties of the USA between 1996 and 2016. Counties with greater wetlands coverage had much less property damage, indicating the significant value of the wetlands protection.

Coastal wetlands are important environments in climate change mitigation as well, particularly as blue carbon habitat that sequesters carbon dioxide and other greenhouse gas emissions [50]. In addition, restoration of blue carbon habitats increases coastal carbon storage areas [48]. While often effective, soft engineering restoration strategies such as those noted above are not as widely used today as hard engineering shoreline structures such as bulkheads, revetments, and seawalls, which typically alter water flow, truncate habitats, sever ecosystem connectivity, reduce species diversity, and interfere with landward migration of low-lying habitats in the face of rising sea level. In most cases, the implementation of living shoreline stabilization includes hybrid components (*i.e.* both soft and hard structural materials) along shorelines that can increase connectivity of ecosystems [51].

Restoration is a challenging process with mixed outcomes [41]. This is so because of significant vagaries in environmental conditions of estuarine and coastal marine environments, difficulties in differentiating anthropogenic and natural-mediated impacts, and the financial cost of conducting habitat and ecosystem recovery [37]. One view is that altered natural ecosystems do not recover from human-induced pressures unless secondary succession returns them to a pre-existing condition or state [35]. There are three pathways of recovery: 1)

passive restoration through ecological succession; 2) re-direction through active ecological restoration; and 3) unattainable recovery (*i.e.* ecosystem collapse) [35]. Monitoring frameworks have been developed and applied to determine if restoration goals for recovery of an impacted habitat or ecosystem are being successful.

The recovery of ecosystem structure and function in damaged estuarine and coastal marine environments is typically protracted, because of multiple factors involved, notably the type and severity of human-mediated pressures, the kind of habitats impacted, the vagaries of environmental conditions, and the geographic location of the impacted area. For example, Jones and Schmitz [52] determined that the recovery time for restored brackish and marine ecosystems is 10 - 20 years, similar to the 10 - 25 years time span of recovery reported by Borja *et al.* [35] for biota and bottom substrates of estuarine ecosystems after removal of human pressures. Lotze *et al.* [53] emphasized, however, that some estuaries do not show significant ecological improvement even after many years of extensive restoration and conservation efforts. The most successful restoration of degraded estuarine habitats has occurred in semi-enclosed coastal bays and lagoons and fringing habitats (e.g. salt marshes, mangroves, and seagrasses) than in open waters of high energy estuarine, coastal, and marine ecosystems [4] [27] [37]. The restoration and rehabilitation of fringing habitats are critical for developing management solutions to rising sea level and other climate change drivers.

Ecological restoration can increase the capacity of ecosystems and biotic communities to adapt to shifting environmental conditions. Although restoration programs have not been viewed as very cost effective, De Groot *et al.* [54] found that when appropriately analyzed, most ecological restoration projects were not only profitable but also high-yielding investments. Many of these projects were vital both for recovery of biodiversity and ecosystem goods and services useful to people [55]. Across a broad range of biomes and ecosystem types analyzed, coastal wetlands and inland wetlands offered the most value for restoration investment in absolute terms.

### 4.3. Marine Protected Areas and Refugia

One way of conserving coastal environments is to establish protected areas through management programs that prohibit human activities stressful and potentially destructive to biotic communities and habitats. Another way is through coastal land purchases that can limit land-based pollutant inputs and other development impacts on estuarine and coastal marine environments [56].

Coastal management is also identifying and protecting refugia, that is, areas having more favorable environmental conditions that render them less vulnerable to climate change disturbances or other chronic stressors, thereby strengthening local or regional ecosystem resilience and survival of organisms [57]. In addition, expanding marine ecosystem restoration to integrate social-ecological concepts

will increase the scope of restoration science and facilitate recovery of degraded habitats and impacted biotic communities. Restoration of coastal ecosystems has evolved over the past 50 years to consider social elements and ecosystem service outcomes. For example, Martin [58] documented the emergence and significance of the social dimensions of ecological restoration. Coastal marine ecosystem restoration is part of an ongoing management strategy to address anthropogenic impacts, although there are perceived negative aspects such as their high cost, limited spatial extent, and narrow goals [41].

Marine Protected Areas (MPAs) are selected areas intended to protect all or part of a marine ecosystem [59]. They are an important tool to conserve, restore, and sustain estuarine and marine environments by protecting threatened ecosystems and their resources from intrusive anthropogenic activities. As such, MPAs are effective for restoring marine biodiversity, enhancing fisheries, and ecosystem services [60]. These selected areas, which can take various forms such as refugia to research sites, are set aside to ensure that habitats and resources (including threatened, rare, and endangered species) are protected in vulnerable areas by restricting human activity. MPAs are also an effective means of mitigating climate change effects. Hence, in 2021, the USA, Chile, Costa Rica, and France announced a global partnership to advance the role of MPAs as a nature-based solution to remediate climate change effects in coastal and marine environments [61].

Not all MPAs are equal. Sala and Giakoumi [59] and Sala *et al.* [60] have assessed the effectiveness of different types of MPAs. As of March 2021, only ~7% of the ocean had been designated or proposed as MPAs, and only 2.7% had been implemented as fully or highly protected, no-take MPAs [60]. Highly protected MPAs are areas in which extractive and destructive human activities are banned [60]. They offer protection from fishing, mining, and habitat destruction. No-take MPAs are effective in restoring biomass and structure of fish assemblages. According to Sala and Giakoumi [59], the biomass of whole fish assemblages was on average 670% greater within marine reserves than in adjacent unprotected areas, although fish biomass in partially protected MPAs was less, that is, 183% greater than in unprotected areas. As such, MPAs can contribute substantially to three major goals: 1) biodiversity protection; 2) food provision; and 3) carbon storage, the latter playing a positive role in climate change mitigation. In addition, MPAs can protect other ecosystem services as well.

Halpern [62], however, presented reasons why MPAs fail to meet their full environmental protection targets. As noted by Katsanevakis *et al.* [20], it is not unusual for MPAs to fail to achieve target goals due to poor design, insufficient enforcement, and unrealistic expectations. Many MPAs are only partially protected, with recreational and hook-and-line fishing allowed. Other MPAs provide limited spatial coverage to protect species. Conservation benefits of MPAs vary, and thus identifying the most significant MPA attributes could be vital in achieving maximum conservation success. A broader limitation of MPAs is that

there is no global legal framework for their establishment beyond national jurisdiction [63] [64].

## 5. Regulatory Frameworks

Legislative frameworks exist to protect and conserve estuarine and coastal marine environments, their habitats, biotic communities, and other ecosystem components. Examples of relevant federal laws in the USA are the National Environmental Policy Act (1970), Clean Air Act (1970) and its amendments (1977 and 1990), Clean Water Act (1972) and its amendments (1977 and 1987), Coastal Zone Management Act (1973), and Endangered Species Act (1973). In the European Union (EU), directives of significance include the Habitats and Species Directive (1992), Water Framework Directive (2000), Strategic Environmental Assessment Directive (2001), Marine Strategy Framework Directive (2008), Birds Directive (2009), Maritime Spatial Planning Directive (2014), and Single-Use-Plastic Directive (2019). These legislative acts and directives provide protection of coastal, estuarine, and marine ecosystems adversely affected by anthropogenic pressures and impacts and in so doing promote sustainable growth of maritime economies and sustainable use of marine resources [3] [4] [5] [65]. NATURA 2000 is a network of EU protected areas designated under the Birds and Habitats Directives. As such, they also support other coastal and marine ecosystem management programs. Similar legislation has been enacted in other countries as well. For example, the Environmental Protection and Biodiversity Conservation Act (1999) in Australia and the National Water Act (1998), Integrated Coastal Management Act (1998), and the Marine Living Resources Act (2008) in South Africa afford protection and conservation of estuarine and coastal marine ecosystems as well as their sustainability.

Some national legislation, such as the National Environmental Policy Act and the Clean Water Act and its amendments in the USA, provides sweeping protection of water quality, habitats, and organisms from pollution and other environmental impacts. These laws enable federal government agencies (e.g. US Environmental Protection Agency) to regulate human activities that are damaging to coastal ecosystems, threatening to organisms, and an impediment to habitat and ecosystem sustainability. Through this federal government process, the legislative acts and policies support ecosystems services and interests of the public for healthy and sustained estuarine, coastal, and ocean waters.

The Estuary Restoration Act (ERA) became law in the USA in 2000 and was amended in 2007. This legislation established a national estuary restoration strategy consisting of a coordinated and integrated federal approach, also involving non-federal partners, to restore damaged estuarine habitats [37]. The environmental legislation and policies targeting coastal problems in the USA have been widely successful, as has the integrated implementation of the EU directives through time [65].

International and regional agreements, together with legislative instruments at



national and state levels and effective policies, administration and management strategies, exist to protect and conserve estuarine, coastal, and marine environments through an integrated ecosystem approach to managing maritime activities [2] [20]. They address anthropogenic pressures and impacts on estuarine and marine environments, which is relevant to ecosystem-based management practices effective for the preservation of ecosystem services and achieving environmental sustainability [65] [66] [67]. Elliott *et al.* [5] and Katsanevakis *et al.* [20] discuss international legislation, agreements, laws, and policies relevant to ecosystem-based management of estuarine and marine environments. Examples are the International Convention for the Prevention of Pollution from Ships (MARPOL) (1973), International Convention on Biological Diversity (1993), United Nations Convention on the Law of the Sea (1994), FAO Code of Conduct for Responsible Fisheries (1995), and United Nations Agenda 21 (2002). Regional agreements, such as the Regional Seas Conventions, relate to estuarine, coastal, and ocean waters for the NE Atlantic, the Baltic, the Mediterranean, and the Black Sea. Nation states implement these agreements, which cover a broad array of stressors, ecosystem components, and assessments, such as chemical contaminants, nutrient over-enrichment, deoxygenation, altered hydrological systems, biodiversity, endangered species, and environmental impact assessment.

## 6. Conclusions

A major challenge of integrated/interlinked ecosystem-based management of estuarine and coastal marine environments is to assemble the elements of a holistic approach necessary for successful and sustainable ecosystem components [5] [26]. A need exists for effective science-informing policy and policy-informing science and recognition of the limitations of each [16]. There is also a need for natural and social scientists and policymakers to work more collaboratively on the complex coastal environmental problems that currently exist and are worsening in many regions due to escalating climate change effects [19]. If these approaches are successful, the outlook for improved conditions of estuarine and coastal marine environments is a positive one.

This article examines the management strategies and legislative frameworks that address anthropogenic drivers of change and impacts in estuarine and coastal marine environments. The conclusions are as follows:

- 1) Numerous anthropogenic drivers of change affect estuarine and coastal marine environments, and various management strategies and legislative frameworks are in place to address them.
- 2) The main goal of estuarine management is to protect biotic communities and habitats from adverse effects of human activities and from changes that pose a threat to ecosystem structure, functioning, and sustainability.
- 3) Ecosystem-based management of estuarine and coastal marine environments is a holistic strategy that considers the entire ecosystem, including human activities.

4) Effective integrated ecosystem management should consider the application of a holistic problem-structuring framework such as a Drivers-Activities- Pressures-State Change-Impacts-Responses approach.

5) Ecosystem-based marine spatial planning (EB-MSP) is an improved strategy for supporting healthy coastal and marine ecosystems and sustained human use of marine waters. It informs the spatial distribution of activities to support the use of healthy marine ecosystems and to maintain valuable ecosystem services for humans while concurrently meeting ecological, economic, and social objectives.

6) Drivers of change in estuaries do not act in isolation but are interactive, including climate change factors that can exacerbate the effects of direct, non-climatic anthropogenic factors such as pollutants.

7) Ecosystem restoration is an emerging field and a primary intervention strategy used to reverse the loss of estuarine and coastal marine habitats and biotic communities due to natural and anthropogenic pressures and to increase their resilience to climate change and other drivers of change.

8) Ecohydrology and ecoengineering are important tools used in estuarine management to restore altered or damaged habitats and biotic communities and improve ecosystem conditions.

9) Coastal management also promotes protective refugia having more favorable environmental conditions that render them less vulnerable to climate change disturbances or other chronic stressors, strengthening local or regional ecosystem resilience.

10) Marine Protected Areas (MPAs) are intended to protect all or part of a marine ecosystem. They are an important tool to conserve and sustain estuarine and marine environments by protecting threatened ecosystems and their resources from anthropogenic activities.

11) Legislative and regulatory frameworks exist to protect and conserve estuarine and coastal marine environments, their habitats, biotic communities, and other ecosystem components.

12) International and regional agreements, as well as legislative instruments at national and state levels together with policies, administration and management strategies, are in place to protect and conserve estuarine, coastal, and marine environments through an integrated ecosystem approach to managing maritime activities.

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## **Conflicts of Interest**

The author declares no conflicts of interest regarding the publication of this paper.

## References

- [1] Dürr, H.H., Laruelle, G.G., Van Kempen, C.M., Slomp, C.P., Meybeck, M., Middelkoop, H., *et al.* (2011) Worldwide Typology of Nearshore Coastal Systems: Defining the Estuarine Filter of River Inputs to the Oceans. *Estuaries and Coasts*, **34**, 441-458. <https://doi.org/10.1007/s12237-011-9381-y>
- [2] Lonsdale, J.-A., Leach, C., Parsons, D., Burkwith, A., Manson, A. and Elliott, M. (2022) Managing Estuaries under a Changing Climate: A Case Study of Humber Estuary, UK. *Environmental Science and Policy*, **134**, 75-84. <https://doi.org/10.1016/j.envsci.2022.04.001>
- [3] Kennish, M.J. (2016) *Encyclopedia of Estuaries*. Springer, Dordrecht. <https://doi.org/10.1007/978-94-017-8801-4>
- [4] Kennish, M.J. (2019) *Practical Handbook of Marine Science*. 4th Edition, CRC Press, Taylor and Francis, New York and London. <https://doi.org/10.1201/b22246>
- [5] Elliott, M., Houde, E.D., Lamberth, S.J., Lonsdale, J.-A. and Tweedley, J.R. (2022) Management of Fishes and Fisheries in Estuaries. In: Whitfield, A.K., Able, K.W., Blaber, S.J.M. and Elliott, M., Eds., *Fish and Fisheries in Estuaries: A Global Perspective*, Vol. 2, John Wiley and Sons, New York, 706-797. <https://doi.org/10.1002/9781119705345.ch12>
- [6] Kennish, M.J. and Elliott, M. (2011) Human-Induced Problems (Uses and Abuses) in Estuaries and Coasts. In: Wolanski, E. and McLusky, D.S., Eds., *Treatise on Estuarine and Coastal Science*, Vol. 8, Elsevier, Oxford, 1-315.
- [7] Defeo, O. and Elliott, M. (2021) Editorial—The “Tripple Whammy” of Coasts under Threat—Why We Should Be Worried! *Marine Pollutant Bulletin*, **163**, Article ID: 111832. <https://doi.org/10.1016/j.marpolbul.2020.111832>
- [8] Day, J.W., Crump, B.C., Kemp, W.M. and Yáñez-Arancibia, Y. (2012) *Estuarine Ecology*. John Wiley and Sons, Hoboken. <https://doi.org/10.1002/9781118412787>
- [9] Kennish, M.J. (2021) Drivers of Change in Estuarine and Coastal Marine Environments: An Overview. *Open Journal of Ecology*, **11**, 224-239. <https://doi.org/10.4236/oje.2021.113017>
- [10] Lepage, M., Capderrey, C., Elliott, M. and Meire, P. (2022) Estuarine Degradation and Rehabilitation. In: Whitfield, A.K., Able, K.W., Blaber, S.J.M. and Elliott, M., Eds., *Fish and Fisheries in Estuaries: A Global Perspective*, Vol. 2, John Wiley and Sons, New York, 458-552. <https://doi.org/10.1002/9781119705345.ch8>
- [11] Landrigan, P.J., Stegeman, J.J., Fleming, L.E., Allemand, D., Anderson, D.M., Backer, L.C., *et al.* (2020) Human Health and Ocean Pollution. *Annals of Global Health*, **86**, 151, 1-64. <https://doi.org/10.5334/aogh.2831>
- [12] He, Q. and Silliman, B.R. (2019) Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene. *Current Biology*, **29**, R1021-R1035. <https://doi.org/10.1016/j.cub.2019.08.042>
- [13] Doney, S.C., Ruckelshaus, M., Duffy, J.E., Barry, J.P., Chang, F., English, C.A., *et al.* (2012) Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, **4**, 11-37. <https://doi.org/10.1146/annurev-marine-041911-111611>
- [14] Poloczanska, E.S., Burrows, M.T., Brown, C.J., Molinos, J.G., Halpern, B.S., Hoegh-Guldberg, O., *et al.* (2016) Responses of Marine Organisms to Climate Change across Oceans. *Frontiers in Marine Science*, **3**, Article 62. <https://doi.org/10.3389/fmars.2016.00062>
- [15] Hallett, C.S., Hobday, A., Tweedley, J., Thompson, P., McMahon, K., Valesini, F., *et al.* (2018) Observed and Predicted Impacts of Climate Change on the Estuaries of

- South-Western Australia, a Mediterranean Climate Region. *Regional Environmental Change*, **18**, 1357-1373. <https://doi.org/10.1007/s10113-017-1264-8>
- [16] Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., De Jonge, V.N. and Turner, R.K. (2017) “And DPSIR Begat DAPSI(W)R(M)!”—A Unifying Framework for Marine Environmental Management. *Marine Pollution Bulletin*, **118**, 27-40. <https://doi.org/10.1016/j.marpolbul.2017.03.049>
- [17] Buitenhuis, Y. and Dieperink, C. (2019) Governance Conditions for Successful Ecological Restoration of Estuaries: Lessons from the Dutch Haringvliet Case. *Journal of Environmental Planning and Management*, **62**, 1990-2009. <https://doi.org/10.1080/09640568.2018.1529556>
- [18] Elliott, M. (2011) Marine Science and Management Means Tackling Exogenic Unmanaged Pressures and Endogenic Managed Pressures—A Numbered Guide. *Marine Pollution Bulletin*, **62**, 651-655. <https://doi.org/10.1016/j.marpolbul.2010.11.033>
- [19] Elliott, M. (2013) The 10-Tenets for Integrated, Successful and Sustainable Marine Management. *Marine Pollution Bulletin*, **74**, 1-5. <https://doi.org/10.1016/j.marpolbul.2013.08.001>
- [20] Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T.R., Jones, P.J.S., Kerr, S., et al. (2011) Ecosystem-Based Marine Spatial Management: Review of Concepts, Policies, Tools, and Critical Issues. *Ocean and Coastal Management*, **54**, 807-820. <https://doi.org/10.1016/j.ocecoaman.2011.09.002>
- [21] Kelly, C., Gray, L., Shucksmith, R.J. and Tweddle, J.F. (2014) Investigating Options on How to Address Cumulative Impacts in Marine Spatial Planning. *Oceans and Coastal Management*, **102**, 139-148. <https://doi.org/10.1016/j.ocecoaman.2014.09.019>
- [22] Ehler, C. and Douvère, F. (2009) Marine Spatial Planning: A Step-by-Step Approach towards Ecosystem-Based Management. *Intergovernmental Oceanographic Commission and Man the Biosphere Programme*, Unesco, Paris, 99 p. <https://repository.oceanbestpractices.org/handle/11329/459>
- [23] Secretariat of the Convention on Biological Diversity (2004) The Ecosystem Approach. CBD Guidelines. Secretariat of the Convention on Biological Diversity, Montreal, 50 p. <https://www.cbd.int/doc/publications/ea-text-en.pdf>
- [24] Pittman, J. and Armitage, D. (2016) Governance across the Land-Sea Interface: A Systematic Review. *Environmental Science and Policy*, **64**, 9-17. <https://doi.org/10.1016/j.envsci.2016.05.022>
- [25] Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F. and D’Agrosa, C. (2008) A Global Map of Human Impact on Marine Ecosystems. *Science*, **319**, 948-952. <https://doi.org/10.1126/science.1149345>
- [26] Elliott, M. (2014) Integrated Marine Science and Management: Wading through the Morass. *Marine Pollution Bulletin*, **86**, 1-4. <https://doi.org/10.1016/j.marpolbul.2014.07.026>
- [27] Elliott, M., Burdon, D., Hemingway, K.I. and Apits, S.E. (2007) Estuarine, Coastal and Marine Ecosystem Restoration: Confusing Management and Science—A Revision of Concepts. *Estuarine, Coastal and Shelf Science*, **74**, 349-366. <https://doi.org/10.1016/j.ecss.2007.05.034>
- [28] Elliott, M. and Kennish, M.J. (2011) Human-Induced Problems (Uses and Abuses). In: Wolanski, E. and McLusky, D.S., Eds., *Treatise on Estuarine and Coastal Science*, Vol. 8, Oxford, Elsevier, 1-15.
- [29] Duarte, C.M., Conley, D.J., Carstensen, J. and Sánchez-Camacho, M. (2009) Return

- to Neverland: Shifting Baselines Affect Eutrophication Restoration Targets. *Estuaries and Coasts*, **32**, 29-36. <https://doi.org/10.1007/s12237-008-9111-2>
- [30] Douvère, F. (2008) The Importance of Marine Spatial Planning in Advancing Ecosystem-Based Sea Use Management. *Marine Policy*, **32**, 762-771. <https://doi.org/10.1016/j.marpol.2008.03.021>
- [31] Foley, M.M., Halpern, B.S., Micheli, F., Armsby, M.H., Caldwell, M.R., Crain, C.M., *et al.* (2010) Grading Ecological Principles for Marine Spatial Planning. *Marine Policy*, **34**, 955-966. <https://doi.org/10.1016/j.marpol.2010.02.001>
- [32] Thia-Eng, C. (1993) Essential Elements of Integrated Coastal Zone Management. *Ocean and Coastal Management*, **21**, 81-108. [https://doi.org/10.1016/0964-5691\(93\)90021-P](https://doi.org/10.1016/0964-5691(93)90021-P)
- [33] Kennish, M.J. (2019) Anthropogenic Impacts on Estuaries. In: Finkl, C.W. and Makowski, C., Eds., *Encyclopedia of Coastal Science*, 2nd Edition, Springer, Dordrecht, 803-806.
- [34] Elliott, M. and Quintano, V. (2018) Estuarine Quality Paradox Concept. In: Fath, D.F., Ed., *Encyclopedia of Ecology*, Vol. 1, 2nd Edition, Elsevier, Amsterdam, 78-85. <https://doi.org/10.1016/B978-0-12-409548-9.11054-1>
- [35] Borja, Á., Dauer, D.M., Elliott, M. and Simenstad, C.A. (2010a) Medium- and Long-Term Recovery of Estuarine and Coastal Ecosystems: Patterns, Rates and Restoration Effectiveness. *Estuaries and Coasts*, **33**, 1249-1260. <https://doi.org/10.1007/s12237-010-9347-5>
- [36] Palmer, M.A. (2009) Reforming Watershed Restoration: Science in Need of Application and Applications in Need of Science. *Estuaries and Coasts*, **32**, 1-17. <https://doi.org/10.1007/s12237-008-9129-5>
- [37] Kennish, M.J. (2012) Restoration of Estuaries. *Nature Education*, **3**, 1-5.
- [38] Mitsch, W.J. (2012) What Is Ecological Engineering. *Ecological Engineering*, **45**, 5-12. <https://doi.org/10.1016/j.ecoleng.2012.04.013>
- [39] Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesine, F., Whitfield, A., *et al.* (2016) Ecoengineering with Ecohydrology: Successes and Failures in Estuarine Restoration. *Estuarine, Coastal and Shelf Science*, **176**, 12-35. <https://doi.org/10.1016/j.ecss.2016.04.003>
- [40] McLusky, D.S. and Elliott, M. (2004) *The Estuarine Ecosystem: Ecology, Threats, and Management*. 3rd Edition, Oxford University Press, Oxford.
- [41] Abelson, A., Reed, D.C., Edgar, G.J., Smith, C.S., Kendrick, G.A., Orth, R.J., *et al.* (2020) Challenges for Restoration of Coastal Marine Ecosystems in the Anthropocene. *Frontiers in Marine Science*, **7**, Article ID: 544105. <https://doi.org/10.3389/fmars.2020.544105>
- [42] United Nations Convention on Biological Diversity (2016) *Ecosystem Restoration: Short-Term Action Plan*. CBD/COP/DEC/XIII/5.
- [43] Saunders, M.I., Doropoulos, C., Bayraktarov, E., Babcock, R.C., Gorman, D., Eger, A.M., *et al.* (2016) Bright Spots in Coastal Marine Ecosystem Restoration. *Current Biology*, **30**, R1500-R1510. <https://doi.org/10.1016/j.cub.2020.10.056>
- [44] O'Leary, J.K., Micheli, F., Airoidi, L., Boch, C., Leo, G.D.E., Elahi, R., *et al.* (2017) The Resilience of Marine Ecosystems to Climatic Disturbances. *Bioscience*, **67**, 208-220. <https://doi.org/10.1093/biosci/biw161>
- [45] Abelson, A., Halpern, B.S., Reed, D.C., Orth, R.J., Kendrick, G.A. and Beck, M.W. (2015) Upgrading Marine Ecosystem Restoration Using Ecological-Social Concepts. *Bioscience*, **66**, 156-163. <https://doi.org/10.1093/biosci/biv171>

- [46] Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., *et al.* (2016) The Cost and Feasibility of Marine Coastal Restoration. *Ecological Applications*, **26**, 1055-1074. <https://doi.org/10.1890/15-1077>
- [47] Bilkovic, D.M., Mitchell, M.M., La Peyre, M.K. and Toft, J.D. (2017) Living Shorelines: The Science and Management of Nature-Based Coastal Protection. CRC Press, Taylor and Francis, New York and London. <https://doi.org/10.1201/9781315151465>
- [48] Windham-Myers, L., Crooks, S. and Troxler, T.G. (2018). A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice and Policy. CRC Press, Taylor and Francis, New York and London. <https://doi.org/10.1201/9780429435362>
- [49] Sun, F. and Carson, R.T. (2020) Coastal Wetlands Reduce Property Damage during Tropical Cyclones. *PNAS*, **117**, 5719-5725. <https://doi.org/10.1073/pnas.1915169117>
- [50] Lovelock, C.E. and Duarte, C.M. (2019) Dimensions of Blue Carbon and Emerging Perspectives. *Biology Letters*, **15**, Article ID: 20180781. <https://doi.org/10.1098/rsbl.2018.0781>
- [51] Smith, C.S., Rudd, M.E., Gittman, R.K., Melvin, E.C., Patterson, V.S., Renzi, J.J., *et al.* (2020) Coming to Terms with Living Shorelines: A Scoping Review of Novel Restoration Strategies for Shoreline Protection. *Frontiers in Marine Science*, **7**, Article 434. <https://doi.org/10.3389/fmars.2020.00434>
- [52] Jones, H.P. and Schmitz, O.J. (2009) Rapid Recovery of Damaged Ecosystems. *PLOS ONE*, **4**, e5653. <https://doi.org/10.1371/journal.pone.0005653>
- [53] Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., *et al.* (2006) Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas. *Science*, **312**, 1806-1809. <https://doi.org/10.1126/science.1128035>
- [54] De Groot, R.S., Blignaut, J., Van Der Poeg, S., Aronson, J., Elmqvist, T. and Farley, J. (2013) Benefits of Investing in Ecosystem Restoration. *Conservation Biology*, **27**, 1286-1293. <https://doi.org/10.1111/cobi.12158>
- [55] Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., *et al.* (2007) Identification, Definition, and Quantification of Goods and Services Provided by Marine Diversity: Implications for the Ecosystem Approach. *Marine Pollution Bulletin*, **54**, 253-265. <https://doi.org/10.1016/j.marpolbul.2006.12.003>
- [56] Robb, C.K. (2014) Assessing the Impact of Human Activities on British Columbia's Estuaries. *PLOS ONE*, **9**, e99578. <https://doi.org/10.1371/journal.pone.0099578>
- [57] Darling, E.S. and Côté, I.M. (2018) Seeking Resilience in Marine Ecosystems. *Science*, **359**, 986-987. <https://doi.org/10.1126/science.aas9852>
- [58] Martin, D.M. (2017) Ecological Restoration Should Be Redefined for the Twenty-First Century. *Restoration Ecology*, **25**, 668-673. <https://doi.org/10.1111/rec.12554>
- [59] Sala, E. and Giakoumi, S. (2018) No-Intake Marine Reserves Are the Most Effective Areas in the Ocean. *ICES Journal of Marine Science*, **75**, 1166-1168. <https://doi.org/10.1093/icesjms/fsx059>
- [60] Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Atwood, T.B., Auber, A., *et al.* (2021) Protecting the Global Ocean for Biodiversity, Food and Climate. *Nature*, **592**, 397-402. <https://doi.org/10.1038/s41586-021-03371-z>
- [61] National Oceanic and Atmospheric Administration (NOAA) (2021) New Global Partnership to Elevate Marine Protected Areas as a Tool in Climate Response. NOAA, U.S. Department of Commerce, Silver Spring. <https://www.noaa.gov/news-release/new-global-partnership-to-elevate-marine-protected-areas-as-tool-in-climate-response>

- [62] Halpern, B.S. (2014) Making Marine Protected Areas Work. *Nature*, **506**, 167-168. <https://doi.org/10.1038/nature13053>
- [63] Druel, E. (2011) Marine Protected Areas in Areas beyond National Jurisdiction: The State of Play. IDDRI, Working Paper No. 07/11.
- [64] Billé, R., Kelly, R., Biastoch, A., Harrould-Kolieb, E., Herr, D., Joos, F., *et al.* (2013) Taking Action against Ocean Acidification: A Review of Management and Policy Options. *Environmental Management*, **52**, 761-779. <https://doi.org/10.1007/s00267-013-0132-7>
- [65] Borja, Á., Elliott, M., Carstensen, J., Heiskanen, A.-S. and Van De Bund, W. (2010) Marine Management—Towards an Integrated Implementation of the European Marine Strategy Framework and the Water Framework Directives. *Marine Pollution Bulletin*, **60**, 2175-2186. <https://doi.org/10.1016/j.marpolbul.2010.09.026>
- [66] McLusky, D.S. and Elliott, M. (2007) Transitional Waters: A New Approach, Semantics or Just Muddying the Waters? *Estuarine, Coastal and Shelf Science*, **71**, 359-363. <https://doi.org/10.1016/j.ecss.2006.08.025>
- [67] Wolanski, E., Day, J.W., Elliott, M. and Ramachandran, R. (2019) *Coasts and Estuaries: The Future*. Elsevier, Amsterdam.