Chapter 4

Ecosystem Services Provided by Benthic Macroinvertebrate Assemblages in Marine Coastal Zones

Gwynne Stoner Rife

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.73150

Abstract

Ecosystem services provided by marine inter- and sub-tidal benthic macroinvertebrate assemblages are often overlooked given their benthic location that is not evident to most observers. The macro-flora and macro-fauna that are the basis for these assemblages are impacted by changes in physical, chemical, and hydrological short and long-term alterations to their habitats. Globally, benthic macroinvertebrate assemblages can be categorized to examine ecosystems services provided by these highly productive coastal areas and the significance of the biodiversity of these assemblages should not be taken for granted. Ecosystem services provided can be categorized just as other global ecosystem services. The ecosystem services provided by marine coastal zones thus include Provisional, Supporting, Regulating, and Cultural Services. Significant environmental impacts to all of these types of ecosystem services have ensued from both natural and human events during the last decade. In addition to ongoing coastal human activity related threats to these areas, the disturbances to these assemblages immediately after a natural disaster event are currently a focus of research. Quantifying the impacts across the subunit of macroinvertebrate benthos is a focus of much current research. The current knowledge base and predicted recovery timeframes, in addition to the need for further investigation of long-term environmental societal factors are important globally.

Keywords: macroinvertebrate assemblages, coastal zone ecosystem services, benthic macroinvertebrates, environmental perturbation

1. Introduction

Natural changes over time or environmental perturbations as the result of geological changes such impact the ecosystem services provided by macroinvertebrate assemblages in the marine coastal zones. Events such as seismic activities (like tsunamis or earthquakes) or large scale meteorological events (hurricane/cyclone, mudslides, or volcanic events) can trigger toxic land run off, changes in the hydrology, alteration to the topography, and increased sedimentation that have an immediate and devastating negative impact on the coastal macro-benthos that inhabit near shore marine waters. Human development and related environmental changes can locally affect the larger biotic system to produce the same negative impacts.

Global coastal zones are the most productive and highly used regions and support fisheries and myriad other human activities and impacts after major perturbation events are only beginning to be a focus of attention by the scientific community from multi-disciplinary research [1, 2].

The loss of ecosystem services provided by the macro-flora and macro-fauna in the marine coastal zones are significant concerns. Natural and human impacts that are the basis for environmental changes often negatively impact the biota of near shore marine waters that provide them. The near shore biotas provide both the structural diversity and trophic base for these ecosystem services, and the macroinvertebrates communities that are a key part of these assemblages in many cases are the foundation for these services.

The macro-biota that provide the trophic base for macroinvertebrate assemblages may be intertidal or sub-tidal, tropic or temperate, and have either a direct source of primary producers or subsist on suspended or settled organic materials [3]. In depth Coastal and Marine Ecological Classification Standards (CMECS) [4] can be used to categorize biotopes based upon water column, geoform, substrate and biotic components in near-shore waters of the Atlantic Coasts [5, 6] but are also being applied globally outside of North American Atlantic waters [7].

Macroinvertebrate assemblages that make up the near shore biota occur across coastal habitat types, and assemblages in major biotopes can be categorized into five major categories based on a CMECS systems identified for US marine coastal zones. These major categories are: (1) vascular plant dominated (VP), (2) macroalgae/protista dominated (MA), (3) unconsolidated substrate dominated (US), (4) hard substrate dominated (HB), and (5) reef species dominated (RS) indicated in **Table 1**.

The overall components (CMECS) are organized into four perspectives that make it possible to record and define the attributes of marine coastal environmental units and biota within each ecosystem setting. The four identified components are: the Water Column Component (WC), the Geoform Component (GC), the Substrate Component (SC), and the Biotic Component (BC). Each component is a stand-alone construct that can be used on its own or in combination with other components or settings. For the purposes of ecosystem services provided by the macroinvertebrate biota here, only the BC and SC units are a focus. Given the proximity to shorelines and providing direct impacts on ecosystem services in general, the benthic and biotic assemblages are the most wide scale identifiable ecosystem units. **Table 2** identifies the major biotic groups that are dominated by macroinvertebrates and their contribution to global

http://dx.doi.org/10.5772/intechopen.73150

Habitat type	Intertidal/subtidal	Temperate/temporal	Nutrient base
Sea grass bed (VP)	Subtidal	Temperate to tropical	Primary productivity
Salt marsh (VP)	Intertidal	Temperate	Primary productivity
Tidal mangrove (VP)	Intertidal	Tropical	Primary productivity
Kelp forest (MA)	Subtidal	Temperate	Primary productivity
Calcareous algae bed (MA)	Intertidal	Tropical	Primary productivity
Mud flat (US)	Intertidal/subtidal	Temperate/tropical	Suspended organics and infauna
Sandy bottom (US)	Intertidal/subtidal	Temperate/tropical	Suspended organics and infauna
Cobble/boulder (HS)	Intertidal/subtidal	Temperate/tropical	Suspended organics and infauna and epifauna
Rocky shoreline (HS)	Intertidal	Temperate/tropical	Suspended organics and epifauna
Human created (HS)	Intertidal/subtidal	Temperate/tropical	Suspended organics and epifauna
Coral reef (RS)	Subtidal	Tropical	Primary productivity, suspended organics and infauna and epifauna

Table 1. Categories of habitats that support coastal marine benthic macroinvertebrate assemblages (and thus ecosystem services) and their location in the marine coastal zone, dominate climate zone, and nutrient base (after Rife [2]).

ecosystem services are indicated in **Table 3**. The units within the BC and SC are organized into traditional hierarchical frameworks, and thus lend themselves to being connected directly to research available for the coastal zone macroinvertebrate assemblages from a global perceptive. The two designations identified that best identify the category of these assemblages are the Biogeographic Setting (BS) and the Aquatic Setting (AS).

The BS identifies ecological units based on species aggregations and features influencing the distribution of organisms. Coastal and marine waters are organized into regional hierarchies composed of realms (largest), provinces and ecoregions (smallest). CMECS adopts the approach described in Marine Ecosystems of the World (MEOW) to characterize Biogeographic Settings occurring in the Estuarine System and in the Marine Near-shore and Marine Offshore Subsystems [31]. MEOW is worldwide in coverage and identifies five realms, eight provinces, and 24 ecoregions in U.S. waters.

The Aquatic Setting (AS) identified in the CMECS divides the coastal and marine environment into three Systems: Marine, Estuarine, and Lacustrine. These align with those described in the Classification of Wetlands and Deep-water Habitats in the United States. This classification is a key aid in the discussion of ecosystem services as they define the areas as a whole geographically and biologically. Secondary and tertiary layers of the Aquatic Setting describe Subsystems (e.g., Near-shore, Offshore, and Oceanic within the Marine System) and Tidal Zones within the Estuarine System and Marine Near-shore Subsystem. The subsystems additionally aid in the identification of key macro-flora and macro-faunal components allowing ecosystem services to be examined.

Habitat type and global location	**Geo-morphological features**	**Hydrological features** **Photic quality modifier (PQM) and energy intensity modifier (EIM)**	**Climatic environmental factors** **Temperature range modifier (TRM) and salinity regime modifier (SRM)**	**Geographical aspects and key factors**
Vascular plant dominated habitat (VP) subset: sea grass bed *Globally VP assemblages are located in Shallow salty and brackish waters in many parts of the world, from the tropics to the Arctic Circle*	Tidal aquatic vegetation beds dominated by any number of seagrass or eelgrass species	PQM—photic or seasonally photic EMI—moderate current energy	TRM—cold to hot SRM—mesohaline, lower polyhaline, upper polyhaline, euhaline	Lacustrine, Estuarine, and/or Marine Temperate to Tropical with occasional polar littoral zones
Vascular plant dominated habitat (VP) subset: tidal salt marsh	Emergent tidal marsh communities dominated by emergent, halophytic, herbaceous vegetation and aquatic brackish marshes	PQM—photic or seasonally photic EIM—moderate current energy	TRM—cold to hot SRM—oligohaline, Mesohaline, lower polyhaline, upper polyhaline, euhaline, hyperhaline	Lacustrine and Estuarine coastal zones Temperate to tropical coastal zones
Vascular plant dominated habitat (VP) subset: mangels	Tidally influenced shore zone dominated by true halophytic mangroves (and associates)	PQM—photic or seasonally photic EIM—moderate current energy	TRM—warm to very warm SRM—oligohaline, mesohaline, lower polyhaline, upper polyhaline, euhaline, hyperhaline	Estuarine, and/or marine Tropical or subtropical shoreline zone
Macroalgae dominated habitat (MA) *Globally MA assemblages are located at all depths within the photic zone, on diverse substrates, and across a range of energy and water chemistry regimes*	Aquatic beds dominated by macroalgae attached to the substrate, such as kelp, intertidal fucoids, and calcareous algae	PQM—photic and seasonally photic EMI—very low current energy to moderate current energy	TRM—very cold to hot SRM—oligohaline, mesohaline, lower polyhaline, upper polyhaline, euhaline	Lacustrine, Estuarine and/or marine Circumglobal subtidal
Unconsolidated sediment dominated habitat (US) *Globally US assemblages are located in the subtidal zones of the nearshore and offshore marine subsystems*	Fine unconsolidated substrates (sand, mud) and that are dominated in percent cover or in estimated biomass by infauna, sessile epifauna and other macroinvertebrates	PQM—aphotic EIM—very low current to moderate current energy	TRM—very cold to hot SRM—oligohaline, mesohaline, lower polyhaline, upper polyhaline, euhaline hyperhaline	Lacustrine, Estuarine, and/or marine Circumglobal subtidal

http://dx.doi.org/10.5772/intechopen.73150

Habitat type and global location	Geo-morphological features	Hydrological features Photic quality modifier (PQM) and energy intensity modifier (EIM)	Climatic environmental factors Temperature range modifier (TRM) and salinity regime modifier (SRM)	Geographical aspects and key factors
Hard substrate dominated (HB) *Global HB assemblages are located in all depths and regions where hard substrate occur on the ocean bottom including boulder and cobble, and any areas where hard, persistent material has been placed either purposely or accidentally by humans*	Nearshore rocky reefs that have rich algal, invertebrate, fish, bird, and marine mammal communities	PQM—aphotic Dysphotic Photic and seasonally photic EIM—very low current energy high current energy	TRM—very cold to very hot SRM—oligohaline, mesohaline, lower polyhaline, upper polyhaline, euhaline, hyperhaline	Lacustrine, Estuarine, and/or marine Circumglobal
Coral reef dominated habitat (CS) *Globally CS assemblages are located in shallow tropical and subtropical area in the photic zone of the Western Pacific, Indian, and Atlantic Oceans*	Shallow/mesophotic coral reef biota Areas with ample light that are dominated by hermatypic (reef-building) hard corals or nonhermatypic reef colonizers	PQM—photic EIM—very low current energy to low current energy (occasionally moderate if shallow reef)	TRM—warm to very warm SRM—euhaline	Marine Tropical and subtropical subtidal in optimal depth for light penetration

Table 2. Macroinvertebrate assemblage with CMECS descriptors for geo-morphological, hydrological, climatic, and geographical aspects of the global habitat (after Rife [2] and CMECS [4]).

Category of macrobenthic community	Examples of sub-units identified by CMECS	Ecosystem services provided	Direct/ indirect	Supporting literature
Vascular Plant dominated (VP)	Seagrass bed Tidal mangrove Brackish Tidal aquatic vegetation	**Provisioning services** Provides building materials Areas for fisheries and associated industries **Supporting services** Soil formation, primary productivity, and nutrient cycling Nursery areas for the young stages of fishes and invertebrates **Regulating services** Capturing and filtering sediments and organic wastes in transit from inland regions to the ocean	Direct and indirect	[8–16]

Category of macrobenthic community	Examples of sub-units identified by CMECS	Ecosystem services provided	Direct/ indirect	Supporting literature
Macro-algae dominated (MA)	Kelp forest Calcareous algal bed Canopy-forming algal bed Coralline/crustose algal bed	**Provisioning services** Pharmaceutical compounds derived from marine algae and invertebrates **Regulating services** Capturing and filtering sediments and organic wastes in transit from inland regions to the ocean	Indirect	[17]
Unconsolidated Sediment dominated (US)	Tunneling megafauna Burrowing anemones Bivalve bed Other non-molluscan invertebrate bed	**Provisioning services** Pharmaceutical compounds derived from marine algae and invertebrates **Regulating services** Capturing and filtering sediments and organic wastes in transit from inland regions to the ocean Sediment stabilization Primary production of benthic algae, high levels of secondary production and great diversity in benthic animals, provide forage for crabs, finfish and shorebirds	Indirect	[18]
Hard substrate dominated (HS)	Mineral/wood boring fauna Diverse colonizers Attached tube-building fauna Mobile crustaceans and gastropods on hard or mixed substrates Sessile/attached molluscs and/ or non-molluscan invertebrate communites	**Provisioning services** Pharmaceutical compounds derived from marine algae and invertebrates **Regulating services** Capturing and filtering sediments and organic wastes in transit from inland regions to the ocean Hard substrate for attached animals, provides finfish, crustacean and shorebird forage Filters suspended material from the water for improved water quality. Sediment Stabilization erosion control via wave reduction. High levels of secondary production and great diversity in benthic animals, forage for crabs, finfish and shorebirds	Indirect	[19–21]
Reef species dominated (RS)	Branching/columnar/ foliose/plate/table coral reef Encrusting coral reef Massive coral reef Shallow molluscan dominated Mesophotic reef	**Provisioning services** Provides building materials Fisheries and associated industries Pharmaceutical compounds derived from marine algae and invertebrates **Supporting services** Soil formation, photosynthesis and nutrient cycling **Cultural services** Scuba diving and other nature-based tourism	Direct and indirect	[22–30]

Table 3. Marine coastal macro-biotic assemblages that comprise the benthic component for CMECS standards and ecosystems services provided [2, 4, 5].

http://dx.doi.org/10.5772/intechopen.73150

The sub-ecosystems of the biotic and substrate biotopes are described in terms of macrobiota for the identified biotopes, with the majority being named by the dominant macroinvertebrate faunal species. Identifying key components of these assemblages is facilitated by CMECS descriptors that allow for comparison across global biotic assemblages [4].

The biogeographic and aquatic setting for these coastal habitats, as defined this framework, is crucial for continued global comparisons of macroinvertebrate assemblages. Defining these lesser known assemblages in this way will allow discussion of how to manage these areas in terms of economic valuation, prediction of recovery times, and quantification of losses resulting from an environmentally perturbing event based on the coastal marine biotopes that are impacted by human or natural environmental perturbations.

2. Ecosystem services provided

Ecosystem services provided by coastal macroinvertebrates assemblages include both direct and indirect benefits (**Table 3**). Marine ecosystem services provided by these groups of macrofauna and flora that directly provide benefit encompass the services that provide food, medicine, recreation, support of fisheries, and storm protection. Other ecosystem services are less tangible, and so more difficult to documents, such as the habitat's role in absorbing carbon from the atmosphere—a positive effect on our global climate. In addition to the economic supports coastal areas provide, human attitudes, beliefs, behaviors, customs, and traditions are often associated with the surrounding nature and environmental quality. These cultural ecosystem services are often neglected but are a significant feature of the services that could be lost if the biodiversity of these assemblages becomes threatened.

Ecosystem services provided by marine coastal zones are classified by four categories (as they are for most identified ecosystem services). The four categories identified are Provisional, Supporting, Regulating, and Cultural Services. Provisioning services include food, water, and products such as building materials from mangrove and coral reef, and pharmaceutical compounds derived from marine algae and invertebrates. Supporting services include soil formation, primary productivity, and nutrient cycling; coastal habitats such as seagrass beds and mangroves are important nursery areas for the young stages of fishes and invertebrates that support coastal communities and commercial and recreational fisheries. Regulating services include regulation of climate; natural hazards such as floods, disease, wastes, and water quality, coastal wetlands play an important role in water quality regulation by capturing and filtering sediments and organic wastes in transit from inland regions to the ocean. On a global scale, fixation of atmospheric carbon by oceanic algae and its eventual deposition in deep water represents an important part of the global carbon cycle and thus influences climate trends. Cultural services include recreational, esthetic, and spiritual benefits derived from nature. Coastal tourism is the fastest-growing sector of the global tourism industry [9], and is a major part of the economies of many small island-developing nations. Moreover, the cultures and traditions of many coastal peoples are intimately tied to the marine ecosystems on which they depend.

Coastal marine ecosystem services are also provided directly, through human use or experience of the service or indirectly, via impacts of supporting and regulating services on other services and environments. Cultural ecosystems services of a variety provided by macroinvertebrate communities near the coasts include those tied to the culture and traditions of coastal peoples in many developing nations by supporting local small scale fisheries, recreational and esthetic services across the globe as a source of natural interest and exploration for people of all ages, scientific and sociological endeavors, and ecotourism opportunities like scuba diving and sport fishing.

Macroinvertebrate assemblages form the basis for the majority of the coastal marine services as illustrated by the biotopes that are defined by the species that characterize the biotic components.

Changes in the local coastal marine environments following perturbations are myriad and occur in both the short term and long term spatial and temporal realms [10–16]. Changes to these environments, either by a natural or human induced physical change can impact the resident macro-fauna assemblages and the ecosystem services they provide in a numerous of ways. The majority of the threats identified to these communities is heightened after an environmentally perturbing event that is of a large scale, and as documented are altered long-term for certain near shore biotopes (see **Table 3**).

Delineating the impacts of large scale events on coastal marine benthic invertebrate assemblages are identified in literature from natural hazards such as hurricane and earthquake events [17–19].

To examine the global effects that result in terms of the macro-benthic assemblages, one needs to characterize each major habitat type and synthesize current findings with related environmental disturbance known impacts. Based on the CMECS, major macroinvertebrate assemblages can be categorized as follows to examine the ecosystem services provided and possible impacts after a major change (see **Table 1**).

2.1. Vascular plant dominated habitat (VP)

Three subsets make up the VP biota (see **Table 4**). Sea grass beds, tidal marshes, and mangels globally provide significant ecosystem services but also experience the greatest threats from human activity. Seagrass beds, are a lesser known area for many, given their submergence and often hidden location for most observers. Rooted flowering aquatic grasses dominate this assemblage of biota. These sea grasses are significant refugia for the macroinvertebrate assemblages that depend on their bioprocessed and are dominated by turtle grass species in the tropical zones (*Thalassia* spp., *Halodule* spp., *Syringodium* spp., etc.), and *Posidonia* spp., *Ruppia* spp., and *Zostera* spp. in the more temperate waters [20]. These habitats stabilize and protect the shorelines, but additionally support a diverse array of macroinvertebrates. These various community members in tern support the higher order consumers and thus, support fisheries in both adult and juvenile stages. A significant feature of these (VP) areas is that they provide a complex structural habitat that serves as a nursery area for many commercially important species that might not depend on these areas beyond the nursery stages. An often overlooked global ecosystem service provided by these VP assemblages are the carbon stored in sediments from these coastal ecosystems and is known as "blue carbon" because it is stored in the marine environs.

http://dx.doi.org/10.5772/intechopen.73150

Vascular plant dominated habitat (VP)	Important species of the assemblage	Assemblage biotic structure	Key biodiversity aspects of assemblage
CMECS biotic group: sea grass bed	The approximately 72 species of sea grasses are commonly divided into four main groups: Zosteraceae, Hydrocharitaceae, Posidoniaceae and Cymodoceaceae. The major sea grasses include Cymocedea sp., Halodule sp., Thalassia sp., Halophilla sp., Vallisnera sp., Ruppia sp., Phyllospadix sp., and Zostera sp.	Seagrass beds are complex structural habitats that provide refuge and foraging opportunities for abundant and diverse faunal communities. Slow moving mollusks, larger crustaceans, sponges and echinoderms are all commonly found associated with these areas	There are six seagrass bioregions according to Short et al. [2, 32] which is the current standard used by the international seagrass research community. These six bioregions are Temperate North Atlantic (I), Tropical Atlantic (II), Mediterranean (III), Temperate North Pacific (IV), Tropical Indo-Pacific (V), and Temperate Southern Ocean (VI), and are based on assemblages of taxonomic groups of seagrasses in temperate and tropical areas and the physical separation of the world's oceans
CMECS biotic subclass: emergent tidal marsh and biotic group: brackish marsh	Salt bushes and **grasses** are the dominant plants, with Sparina sp., Juncus sp. and Salicornia sp. common in the plant Communities. The plants are dominated by emergent, halophytic, herbaceous vegetation (with occasional woody forbs or shrubs) along low-wave-energy, intertidal areas of estuaries and rivers. Also brackish marshes dominated by species with a wide range of salinity tolerance	Fish and shrimp come into salt marshes looking for food or for a place to lay their eggs. Larger decapods and oysters are also key species that depend on the tidal marshes	Marine and freshwater species occur in the intertidal zone of coastal estuaries. These areas and are usually intermixed with intertidal mudflats that are rich with invertebrates and seaweeds. These transitional zones are key nursery areas for many commercial species
CMECS biotic group: tidal mangrove forest and tidal mangrove shrubland biotic group. Mangrove forests	Mangroves are not a taxonomic group but identified by their salt tolerance. Several tree and shrub species are the structural basis for these tropical vegetation that supports many diverse invertebrate species as juveniles	The list of common species supported by mangels is line and includes: barnacles, oysters, mussels, sponges, worms, snails and small fish live around the roots. Mangroves water contain crabs, jellyfish and are a nursery to many juvenile fish	Tidally influenced, dense, tropical or subtropical forest with a shore zone dominated by true mangroves (and associates) that generally are 6 m or taller. Dwarf shrub and short mangroves are placed in the tidal mangrove shrubland biotic group. Mangrove forests occur along the sheltered coasts of tropical latitudes of the Earth, and are commonly found on the intertidal mud flats along the shores of estuaries, usually in the region between the salt marshes and seagrass beds and may extend inland along river courses where tidal amplitude is high. Also, mangrove cays may occur within the lagoon complex of barrier reefs

This VP category of biota include these groups—biotic group: seagrass bed—tidal aquatic vegetation beds dominated by any number of seagrass or eelgrass species; biotic subclass: emergent tidal marsh—communities dominated by emergent, halophytic, herbaceous vegetation; and biotic group: tidal mangrove forest—tidally influenced, dense, tropical or subtropical forest with a shore zone dominated by true mangroves (and associates) that generally are 6 m or taller [4].

Table 4. Vascular plant dominated habitat (VP) CMECS definition and important species and dominancy relations in these ecosystems.

Perturbations to sea grass beads, and impacts of large-scale weather events (such as tsunamis for example) have indicated that seagrass beds are resilient to perturbations. The findings regarding the macroinvertebrate diversity of major taxonomic groups is less positive as it is most likely that the biota that are part of these VP areas are tied to density of vegetation [33, 34].

Another category of VP are the salt marshes of the temperate and tropic areas. These prominent vegetated coastal habitats and their proximal coastal areas are well known to of high value as a nursery grounds. Their value as land run off filters is significant. Lesser recognized for the importance of these areas is the high diversity of macroinvertebrate species. As a nursery grounds these areas are significant to both commercial and sport fishing activities. Perturbing events that shift the sediments and inundate the area with fresher water draining of streams or highly saline off shore water, can load toxic land run off, scour vegetative areas, and/or deposit debris that compromises the health of these habitats and thus the macroinvertebrate assemblages [22]. The transitional nature of these areas between land and ocean make them particularly subject to physical changes such as those often seen by development.

Mangels, also known as mangrove habitats, are a group of coastal tropical halophytes that provide structural complexity and protect the shoreline by stabilizing sediments. Because the halophytes that form the basis of these assemblages are from various taxonomic groups, different environmental factors (beyond salinity) can impact their viability. Development of these areas often occurs given the tropical climate and attractiveness for tourism, the development of these shorelines destroys these areas. Tsunami impacts have been examined for some habitats, and it appears mangroves may never fully recover from events that result in the extirpation of these halophytes [23, 35]. Loss of the mangroves mean loss of the ecosystem services they provide in addition to losing the associated macroinvertebrate fauna. As with the salt marshes of the temperate zones, mangels are a significant nursery for many fish, both sport and commercially important fisheries can be impacted by their loss.

2.2. Macroalgae dominated habitat (MA)

Table 5 offers an overview of the macroalgae dominated habitat. Kelp forests are temperate near-shore habitats that support diverse macro-invertebrate assemblages. There are other MA assemblages but the kelp forest are the most dominant example from a global perspective and also provide significant ecosystems services. Both the primary productivity and the structural complexity of their fronds are key factors in support of the whole ecosystem. Kelp, in particular the brown kelps, are well adapted to be resilient against strong currents, they are tolerant to storm surges. Interestingly, they appear to be prone to concentration radioactive material, after the tsunami of the Indian Ocean in 2010 radioactive were found in the kelp off the California coast in the weeks after the tsunami event in Japan. The materials did not remain in the kelp for a long period of time. This suggests they are able to be expelled into the biotope, but as a result presumably to be taken up by other organisms [24, 25].

2.3. Unconsolidated sediment dominated habitat (US)

Perhaps one of the most overlooked macro-faunal assemblages are mud flats and other fine sediment habitats (**Table 6**). Although not at all evident to most, these areas support infaunal

http://dx.doi.org/10.5772/intechopen.73150

Macroalgae dominated habitat (MA)	Important species of the assemblage	Assemblage biotic structure	Key biodiversity aspects of assemblage
CMECS biotic subclass: benthic macroalgae	Aquatic beds dominated by macroalgae attached to the substrate, such as kelp (*Fucus* sp., *Macrocystis* sp.), intertidal fucoids, and other calcareous algae	Kelp forests provide both primary productivity and a structural base for many species. The holdfasts as well as the surface mats of kelp fronds support thousands of invertebrate individuals, including polychaetes, amphipods, decapods, and ophiuroids. Larger vertebrates frequent these areas	Many macroalgal types and communities have low temporal persistence and can bloom and die-back within short periods. This aspect of macroalgae impact the nature of the ecosystem services at an given time

Macroalgal communities can exist at all depths within the photic zone, on diverse substrates, and across a range of energy and water chemistry regimes [4].

Table 5. MA biotic subclass: benthic macroalgae—aquatic beds dominated by macroalgae attached to the substrate, such as kelp, intertidal fucoids, and calcareous algae.

Unconsolidated sediment dominated habitat (US)	Important species of the assemblage	Assemblage biotic structure	Key biodiversity aspects of assemblage
CMECS soft sediment fauna	Often dominated in percent cover or in estimated biomass by infauna, sessile epifauna, mobile epifauna, mobile fauna that create semi-permanent burrows as homes, or by structures or evidence associated with these fauna	Species tunnel freely within the sediment or embed themselves wholly or partially in the sediment (e.g., tilefish burrows, lobster burrows). Other organisms such as crustaceans, echinoderms and mollusks may be locally abundant	Subtidal soft bottom habitats are diverse based on distinct organism assemblages that are influenced by differences in substrate type (sand vs. mud), organic content and bottom depth. Most of these fauna possess specialized organs for burrowing, digging, embedding, tube-building, anchoring, or locomotory activities in soft substrates

Table 6. Biotic class: soft sediment fauna—areas that are characterized by fine unconsolidated substrates (sand, mud) and that are dominated in percent cover or in estimated biomass by infauna, sessile epifauna, mobile epifauna, mobile fauna that create semi-permanent burrows as homes, or by structures or evidence associated with these fauna [4].

macrobenthos that provides key services. These small and relatively overlooked groups of invertebrates turn the sediments and process organics. These fine soils and the high degree of organics and detritus associated can be harmed by strong surges and deposited elsewhere smothering other areas with hypoxic sludge [26]. These US areas are frequently dredged to replenish shorelines and considered to be unattractive. Overlooking the services they provide would be an error.

Sand habitats are teeming with diversity despite the common assumption that they do not, the macro-invertebrates present in these tidal zones show resilience to storm events and recover quickly after a Tsunami event [27]. The recovery of the macro-invertebrates in these assemblages can be quick if recruitment areas adjacent are not impacted. The planktonic nature of the larvae of most invertebrates living in these areas allows for quick recruitment and recovery after a large environmental change like the shifting of sediments from a beach restoration or large-scale weather event.

2.4. Hard substrate dominated biotopes (HB)

This category includes artificial reefs (human places). Macroinvertebrates that colonize hard substrates are generally in competition for space to attach to in the larval stages (**Table 7**). After a large weather event with strong currents or storm surges, boulders and cobble are scattered, and rocky shores could be scoured by these water movements or also by thermal pollution. New human created habitat can also occur in the form of unintentional deposition of sediments of large size and intentional artificial reef type habitat (many recreational charter captains create and maintain their own reefs by submerging solid structures as a base such as old chicken coops or shopping carts to create a reef that they can locate to support their businesses). Little is known about the specific effects on these types of macroinvertebrate assemblages that populate the HB areas. The high larval settling needs and competition for hard places for larvae to settle, these coastal assemblages may be the first to recover after a storm event [28, 29].

2.5. Coral reef dominated habitat (CS)

The highest biodiversity in the list of coastal macro-invertebrate assemblages is not surprising to be the coral reefs and related invertebrate reef macroinvertebrate assemblages (**Table 8**). As identified by CMECS "The Shallow/Mesophotic Coral Reef Biota are largely based on the growth form of the dominant corals that (a) reflect differences in environmental conditions and (b) provide varied habitat circumstances (such as increased cover) for associated fish and invertebrate species. The same coral species can present different growth forms under different environmental circumstances. For example, *Acropora* sp. can have both branching and table growth forms, depending on the environment. To reflect the differences in the physical and biological environments, the same species may be used to define communities in more than one coral group the interaction between ecological processes responsible for the growth of

Hard substrate dominated (HB)	Important species of the assemblage	Assemblage biotic structure	Key biodiversity aspects of assemblage
CMECS biotic subclass: attached fauna/ anthropogenic origin hard substrates	Dominated by fauna which maintain contact with the substrate surface, including firmly attached, crawling, resting, interstitial, or clinging fauna. Fauna may be found on, between, or under rocks or other hard substrates or substrate mixes	Depending on water depth, light penetration, wave energy, and other physical and biological processes, algae and macroalgae can provide extensive or sporadic cover and food for other species in the nearshore subsystem. Many attached fauna are suspension feeders and feed from the water column. Other attached fauna are benthic feeders, including herbivores, predators, detritivores, deposit feeders, and omnivores	Rocky subtidal habitat includes all hard substrate areas of the ocean bottom. Anthropogenic reefs include any areas where hard, persistent material has been placed either purposely or accidentally by humans. Examples include rock jetties at the entrance to many bays, shipwrecks, anchoring systems for renewable energy projects, and unburied portions of underwater cables or pipelines

Table 7. Biotic subclass: attached fauna—areas characterized by rock substrates, gravel substrates, other hard substrates, or mixed substrates that are dominated by fauna which maintain contact with the substrate surface, including firmly attached, crawling, resting, interstitial, or clinging fauna [4].

Coral reef dominated habitat (CS)	Important species of the assemblage	Assemblage biotic structure	Key biodiversity aspects of assemblage
CMECS biotic subclass: shallow/mesophotic coral reef biota	Stony (scleractinian) corals and crustose coralline red algae	Macroinvertebrates from all taxonomic groups comprise the assemblages	Nearly 25% of all known marine species are associated with coral reefs the rich biodiversity covers most taxonomic groups and has many complex interactions with adjacent fauna as well
In order to be classified as reef biota, colonizing organisms must be judged to be sufficiently abundant to construct identifiable biogenic substrates. When not present in densities sufficient to construct reef substrate [4].			

Table 8. Biotic class: reef biota areas dominated by reef-building fauna, including living corals, mollusks, polychaetes or glass sponges.

coral and other carbonate producers and physical processes such as waves and currents that modulate ecological processes and redistribute carbonate material within reef systems." [4]. These areas are well known as the most diverse and likely also provide the most significant oceanic ecosystems services as a result. These areas additionally provide the most varied in terms of type of services as they provide more esthetic and ecotourism support to a greater degree than any other macroinvertebrate assemblages. Yet these significant areas are also some of the most delicate and threatened habitats. Coral bleaching can occur as the result of numerous stressors and large-scale weather events can devastate large regions from both abiotic and biotic stressors [27, 30, 36, 37]. Of all the marine coastal biotopes, literature suggests it is the coral dependent fauna that can be devastated from large-scale changes such as those that occur after a tsunami event, but more investigation is needed to determine if recovery is possible.

Although much more study is needed to determine specific impacts in local areas, globally speaking, macroinvertebrate assemblages do recover after severe natural environmental perturbing events in general, but do so differentially. Anthropogenic perturbations that destroy the physical support of the biotic assemblages are less likely to recover, generally due to development of the shoreline and drainage of these areas. More work is needed to verify the longer term impacts that natural events have from habitat perturbation to ecosystem service losses, anthropogenic impacts have yet to be documented to a great degree from a global perspective. Human impacts are more often permanent, so prevention of further threats are the main reason more knowledge and awareness of the ecosystem services is crucial [32, 38–49].

In general, vascular plant dominated biotopes (VP) seem resilient (except for mangroves) after an environmentally perturbing events with recovery well underway in one annual cycle. Macroalgae/protista dominated biotopes (MA) may be impacted even at great distance from source of perturbations or related contamination little is known about the effects on the fauna they support. Both unconsolidated substrate dominated (US) and hard substrate dominated biotopes (HB) are noted to have recovery times close to that identified for sea grass areas. Reef species dominated areas (CS) are subject to many environmental stressors, the physical and chemical changes that result from an environmental perturbing event impact the corals species negatively but the fauna that rely on the physical structural components may shift in diversity but do persist. Defining recovery in terms of the macro invertebrate assemblage would seem to suggest that recovery occurs relatively quickly, with mangroves being the exception as it is suggested that they may never fully recover once the integrity of the habitat is destroyed.

There are many environmentally perturbing threats both natural and human that can limit the ecosystem services provided by marine coastal zone assemblages (**Table 9**). There are new research areas that focus on different regions and habitats, and more large scale methods are beginning to allow a picture of ecosystem services and the complex ways these macroinvertebrate assemblages provide them [21, 42, 44, 46–51].

Identified threats to coastal marine macro-invertebrate communities	**Mechanisms of impact**	**Potentially heightened by an environmentally perturbing event**
Toxic substances	Organochlorine compounds, heavy metals, organic tin compounds, organophosphates, polycyclic aromatic hydrocarbons, synthetic detergents, and surfactants	Yes—reach the oceans either directly (because the pollutants originate in coastal area), or indirectly through river systems or the atmosphere. In some cases they are released as a result of ocean dumping
Organic pollution	Excessive input of organic water and/or nutrients, or to a deterioration in the natural cleansing power	Yes—more pronounced in bays and other enclosed or semi-enclosed waters
Introduction of debris	Either direct dumping or indirect introduction of waste materials	Yes—more significant adjacent to urban areas
Nutrient depletion	Over development and urbanization which results in depletion of key nutrients and the indirect impact to decreased productivity and/or fertility	Yes—often as the result of loading and blooms and die offs as the result of agriculture or development
Radioactive contamination	Above-ground nuclear tests conducted in years past constitute the principal source of such pollutants. Nuclear-powered ships, discharges by land-based nuclear facilities, and ocean dumping (including illegal dumping) are major sources of marine radioactive contamination	Yes—particularly in the case of facilities begin breached by earthquake activity
Depletion of resources vital to preservation	Land reclamation operations, embankment reinforcement projects, and other physical alterations to shallow-water environments have directly as well as indirectly contributed to the loss of seaweed beds, tidal marshes, coral reefs, mangrove forests	Yes—marine nutrient imbalances as well as degeneration of the natural resilience or cleansing ability of marine ecosystems
Public awareness	Lack of understanding of the aquatic habitats and biotic interaction and their role is goods and services such as assuring human populations opportunities for closer contact with the natural world	Yes—but perhaps in a positive manner if the event increases awareness and understanding
Biotic disruptions	Many non-native wildlife species have penetrated marine ecosystems simply because they were attached to ship hulls or concealed in ship ballast water	Yes—a potential for introduction of previously un established species that have the potential to effect the biotic balance
Thermal pollution	Heat energy discharged by power plants or factory cooling water, or by urban wastewater effluent (warm wastewater)	Yes—but localized

Identified threats to coastal marine macro-invertebrate communities	Mechanisms of impact	Potentially heightened by an environmentally perturbing event
Oil pollution	Human activities, including the flushing of ocean vessel bilges, leakage from undersea oil wells, and runoff or discharges from land-based facilities	Yes—significant for breached coastal nuclear and industrial facilities
Declining fishery resources	Marine environmental change and the fishery industry effects on environmental disruption	Yes—death assemblages and large numbers of eggs or fry of certain fish species

Table 9. Threats and potential for heightened effects to macro invertebrate near shore communities after an environmentally (human impacts or natural) perturbing event.

3. Conclusions

Limiting the human environmental changes to the coastlines from the decision-making perspective are one significant way that the ecosystem services of the marine coastal zone macroinvertebrate and associated macro-flora can be sustained. The macroinvertebrate biodiversity of these areas is resilient overall but the basis for the ecological assemblages, either the physical aspects or the biotic bases, must be able to provide the structure needs for refuge or attachment to support them. Additional challenges in considering the ecosystem services provided by macroinvertebrate assemblages in marine coastal zones resides in the policy makers, the planning decisions, coastal development, and most importantly of building consensus around ecosystem services in a locality. Research is needed that explores the application of a consensus approach across different land and seascape units. Assessment of the coastal zone biota still requires much research and practical work; finding ways to incorporate ecosystem services and its myriad values into the work of planners and policy makers in the marine and coastal environment is as important as it is challenging (**Table 9**) [8].

Further scientific and societal endeavors are needed to identify ecosystem services in a locality and to then identify effects to ecosystem services provided by the macroinvertebrate assemblages specifically. Globally a picture of services and negative impacts on the services provided are identified in general. Specific impacts for categories of macroinvertebrate assemblages are lesser known, even as the body of research grows (**Table 3**). To maintain the ecosystem services provided by marine coastal zones macroinvertebrate assemblages (Provisioning, Supporting, Regulating, and those relating to Cultural Services) will `require an understanding and collaborative approach among researchers, planners, and those that ultimately rely on these services. Ultimately, more research is needed to identify which actions can be taken to lessen the loss and speed the recovery of these communities after large-scale events originating from both natural and human impacts to restore these important human related ecosystem services. The most significant gains could be made in determining further what recovery after an event is possible can be made in the different biotic assemblages, and what methods to safeguard against human impact can be possible.

Author details

Gwynne Stoner Rife

Address all correspondence to: rife@findlay.edu

The University of Findlay, Findlay, Ohio, USA

References

[1] Kontar Y, Swarzenski P, Paytan A, Singh R, Rife G, Henderson-Dean B, Murphy T, Kawamura H, Fujima K, Yamashiki Y, Shunichi K, Takahashi T, Behera S, Santiago-Fandiño V, Tan Y-C, Tang DL, Gusiakov V, Ozorovich Y, Gleeson T. OS07-17-A025 Groundwater/Surface Water Exchange in Tsunami Affected Areas in Japan—Ecological and Societal Significance. In AOGS-AGU Joint Assembly; 2012. p. 139

[2] Rife GS. Impacts of tsunami events on ecosystem services provided by benthic macro-invertebrate assemblages of marine coastal zones. In: Kontar Y, Santiago-Fandiño V, Takahashi T, editors. Tsunami Events and Lessons Learned. Advances in Natural and Technological Hazards Research. Vol. 35. Dordrecht: Springer; 2014

[3] Bolam SG, Fernandes TF, Huxham M. Diversity, biomass, and ecosystem processes in the marine benthos. Ecological Monographs. 2002;**72**:599-615

[4] CMECS 2012. Federal Geographic Data Committee FGDC-STD-018-2012 Coastal and Marine Ecological Classification Standard. June 2012

[5] Madden C, Goodin K, Allee B, Finkbeiner M, Bamford D. Coastal and Marine Ecological Classification Standard. NOAA and NatureServe; 2008. 77 p

[6] Madden CJ, Goodin KL. Ecological Classification of Florida Bay Using the Coastal Marine Ecological Classification Standard (CMECS). Arlington, Virginia: NatureServe; 2007

[7] Gandomi Y, Shadi A, Savari A. Classification of Gomishan Lagoon (Caspian Sea, Iran) by using the Coastal and Marine Ecological Classification Standard (CMECS). Middle-East Journal of Scientific Research. 2011;**8**(3):611-615

[8] Batker D et al. Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta. Tacoma, WA: Earth Economics; 2010

[9] Alongi D. Present state and future of the world's mangrove forests. Environmental Conservation. 2002;**29**:331-349

[10] Cebrian J. Variability and control of carbon consumption, export and accumulation in marine communities. Limnology and Oceanography. 2002;**47**(1):11-22

[11] Dahdouh-Guebas F, Jayatisse LP, Di Nitto D, Bosire JO, Lo Seen D, Koedam N. How effective were mangroves as a defence against the recent tsunami? Current Biology. 2005;**15**(12):R443-R447

[12] Quarto A, Suryadiputra N. The Asian tsunami: A protective role for coastal vegetation. Science. 2005;**310**:643

[13] de Graaf GJ, Xuan TT. Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. Mangroves and Salt Marshes. 1998;**2**:159-166

[14] Ewel KC, Twilley RR, Ong JE. Different kinds of mangrove forests provide goods and services. Global Ecology and Biogeography Letters. 1998;**7**:83-94

[15] Fast AW, Menasveta P. Mangrove forest recovery in Thailand. World Aquaculture. 2003; **34**(3):6-9

[16] Lacerda LD, Abrao JJ. Heavy metal accumulation by mangrove and saltmarsh intertidal sediments. Revista Brasiliera de Botanica. 1984;**7**:49-52

[17] Krumhansl KA, Bergman JN, Salomon AK. Assessing the ecosystem-level consequences of a small-scale artisanal kelp fishery within the context of climate-change. Ecological Applications. 2017;**27**(3):799

[18] Lenihan HL, Micheli F. Soft-sediment communities. In: Bertness MD, Gaines SD, Hay ME, editors. Marine Community Ecology. Sunderland: Sinauer Associates, Inc.; 2001. pp. 253-287

[19] Fox HE, Pet JS, Dahuri R, Caldwell RL. Recovery in rubble fields: Long-term impacts of blast fishing. Marine Pollution Bulletin. 2003;**46**:1024-1031

[20] Sasaki R, Shepherd SA. Ecology and post-settlement survival of the Ezo abalone. Haliotis discus hannai. *on* Miyagi coasts, Japan. Journal of Shellfish Research. 2001;**20**:619-626

[21] Ma L, Lu ZQ, Zhang YB, Zhao X, Yang SY. Distribution and sources apportionment of polycyclic aromatic hydrocarbons in the edible bivalves and sipunculida from coastal areas of Beibu Gulf, China. Applied Ecology and Environmental Research. 2017;**15**: 1211-1225. DOI: 10.15666/aeer/1503_12111225

[22] Rudi MSE, Siregar AM. Acehnese reefs in the wake of the Asian tsunami. Current Biology. 2005;**15**:1926-1930

[23] Bellwood DR, Hughes TP, Folke C, Nystrom M. Confronting the coral reef crisis. Nature. 2004;**429**:827-833

[24] Berg H, Ohman MC, Troeng S, Linden O. Environmental economics of coral reef destruction in Sri Lanka. Ambio. 1998;**27**:627-634

[25] Burke L, Maidens J. Reefs at Risk in the Caribbean. Washington DC: World Resources Institute; 2004. 80 pp

[26] Burke L, Selig E, Spalding M. Reefs at Risk in Southeast Asia. Washington DC: World Resources Institute; 2002

[27] Halfpenny E. Marine Ecotourism: International Guidelines and Best Practice Case Studies—A Resource for Tourism Operators and Coastal Planners and Managers. Burlington, Vermont, USA: The International Ecotourism Society; 2002. 96 pp

[28] Bryant D, Burke L, McManus J, Spalding M. Reefs at Risk. Washington DC: World Resources Institute; 1998

[29] Hawkins JP, Roberts CM, Van't Hof T, de Meyer K, Tratalof J, Aldam C. Effects of scuba diving on Caribbean coral and fish communities. Conservation Biology. 1999; **13**(4):888-897

[30] Fernando HJS, Mendis SG, McCulley JL, Perera K. Coral poaching worsens tsunami destruction in Sri Lanka. Eos, Transactions, American Geophysical Union. 2005;**86**:301

[31] Spalding MD, Fox HE, Allen GR, Davidson N, Ferdana ZA, Finlayson M, Halpern BS, et al. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. Bioscience. 2007;**57**(7):573-583

[32] Short F, Carruthers T, Dennison W, Waycott M. Global seagrass distribution and diversity: A bioregional model. Journal of Experimental Marine Biology and Ecology. 2007;**350**:3-20

[33] Cone M. Fukushima's radioactivity found in Californian's kelp; levels spike then disappeared. Environmental Health News. 2012. http://www.environmentalhealthnews.org/ehs/news/2012/radioactive-iodine-from-fukushima-in-california-kelp [Accessed: 29, 2012]

[34] Manley SL, Lowe CG. Canopy-forming kelps as California's Coastal Dosimeter: 131I from damaged Japanese reactor measured in *Macrocystis pyrifera*. Environmental Science & Technology. 2012;**46**:3731-3736. DOI: 10.1021/es203598r

[35] Bagulayan A, Bartlett-Roa JN, Carter AL, Inman BG, Keen EM, Orenstein EC, Patin NV, Sato KNS, Sibert EC, Simonis AE, Van Cise AM. Journey to the Center of the Gyre: The Fate of the Tohoku Tsunami Debris Field 2012. Oceanography. 2012;**25**(2):200-207. DOI: 10.5670/oceanog.2012.55

[36] Suo AN, Lin Y, Sun YG. Impact of sea reclamation on zoobenthic community in adjacent sea area: A case study in Caofeidian, north China. Applied Ecology and Environmental Research. 2017;**15**:871-880. DOI: 10.15666/aeer/1503_871880

[37] Obdura DO, Tamelander J, Linden O, editors. Ten year after bleaching—Facing the consequences of climate changein the indian Ocean. CORDIO Status REport 2008. CIORDIO (Coastal Ocean Research and Development in the Nidian Ocean)/Sida-SAREC Mombasa. 2008

[38] Portman ME. Ecosystem services for oceans and coasts. In: Environmental Planning for Oceans and Coasts, Geotechnologies and the Environment. Vol. 15. Cham: Springer; 2016

[39] Constable AJ. Ecology of benthic macroinvertebrates in soft-sediment environments: A review of progress toward quantitative models and predictions. Australian Journal of Ecology. 1999;**24**(4):452-476

[40] Hall D. Trends in ocean and coastal tourism: The end of the last frontier? Ocean and coastal Management. 2001;**44**(9-10):601-618

[41] Johnston EL, Roberts DA. Contaminants reduce the richness and evenness of marine communities: A review and meta-analysis. Environmental Pollution. 2009;**157**(6):1745-1752

[42] Peterson CH, Kennicutt MC II, Green RH, Montagna P, Harper DE Jr, Powell EN, Roscigno PF. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: A perspective on long-term exposures in the. Gulf of Mexico Canadian Journal of Fisheries and Aquatic Sciences. 1996;**53**(11):2637-2654

[43] Lomovasky BJ, Firstater FN, Salazar AG, Mendo J, Iribarne OO. Macro benthic community assemblage before and after the 2007 tsunami and earthquake at Paracas Bay, Peru. Journal of Sea Research. February 2011;**65**(2):205-212. ISSN: 1385-1101. DOI: 10.1016/j.seares. 2010.10.002 http://www.sciencedirect.com/science/article/pii/S138511011000122X

[44] Jaramillo E, Dugan JE, Hubbard DM, Melnick D, Manzano M, et al. Ecological implications of extreme events: Footprints of the 2010 earthquake along the Chilean coast. PLoS One. 2012;**7**(5):e35348. DOI: 10.1371/journal.pone.0035348

[45] Castilla JC, Manríquez PH, Camaño A. Effects of rocky shore coseismic uplift and the 2010 Chilean mega-earthquake on intertidal biomarker species. Marine Ecology Progress Series. 2010;**418**:17-23

[46] Nakaoka M, Tanaka Y, Mukai H, Suzuki T, Aryuthaka C. Tsunami impacts on biodiversity of seagrass communities in the Andaman Sea, Thailand: (1) Seagrass abundance and diversity. In: Rigby PR, Shirayama Y, editors. Selected Papers of the NaGISA World Congress 2006. Publications of the Seto Marine Biological Laboratory, Special Publication Series. Vol. VIII. 2007. pp. 49-56

[47] Neumayer E, Barthel F. Normalising economic loss from natural disasters: A global analysis. Global Environmental Change. 2011;**21**:13-24

[48] Kearney MS, Rogers AS, Townshend J, Lawrence W, Dorn K, Eldred K, Lindsay F, Rizzo E, Stutzer D. Developing a model for determining coastal marsh "health". Proceedings of the Third Thematic Conference on Remote Sensing for Marine and Coastal Environments. 1995;**1**:263-272

[49] Maynard NG. Satellites, settlements, and human health. In: Ridd M. editor. Remote Sensing of Human Settlements. American Society of Photogrammetry and Remote Sensing, 3rd edition—2003 Manual of Remote Sensing; 2003. 869 pp

[50] Schröter M, Barton DN, Remme RP, Hein L. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. Ecological Indicators. 2014;**36**:539-551. ISSN: 1470-160X. DOI: 10.1016/j.ecolind.2013.09.018

[51] Lotze HK, Guest H, O'Leary J, Tuda A, Wallace D. Public perceptions of marine threats and protection from around the world. Ocean & Coastal Management. 2018;**152**(1): 14-22. ISSN: 0964-5691. DOI: 10.1016/j.ocecoaman.2017.11.004