Caring for the Coasts

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**Overview of Habitats**

Coastal habitats at the land–sea interface span from hard substratum, rocky intertidal environments to sediment-covered estuaries, salt marshes, eelgrass beds, mangals (mangrove habitats), and sandflats and mudflats (Figure 1). Sedimented intertidal and subtidal nearshore habitats occur globally; sandflats and mudflats occur from the equator to the poles, in contrast to temperate latitude salt marshes and tropical mangroves. Seagrasses occur globally except at the poles. The accessibility of these habitats has enabled studies that generated important ecological paradigms, but the extremely harsh conditions of some of these environments limits transferability of knowledge to other habitats. Many species cannot tolerate energy from waves, potential aerial exposure, and fluctuating temperatures and salinities, resulting in low species diversity, but the availability of abundant sunlight, nutrients from land, and substrata all help support high abundances of tolerant species. Indeed, these habitats provide critical support for abundant juveniles of many commercial species, among others. The structural complexity afforded by seagrass beds, salt marshes, and mangals also pre-empts coastal erosion.¹

Sandflats and mudflats are generally the least productive sedimented habitats. Nonetheless, their invertebrate fauna such as mud shrimp (amphipods) support migratory seabirds and other transient species. The plants that dominate eelgrass, salt marshes, and mangals produce organic matter and biogenic habitat that support high abundances of other species that utilize the plant detritus, associated grazers, and structural complexity to avoid predators. Microbial breakdown of organic material can exhaust oxygen, resulting in hypoxia (low oxygen) near the seafloor or just below the sediment surface, reducing species richness.

¹ D.M. Alongi, *Coastal Ecosystem Processes* (Boca Raton, FL: crc Press, 1998).
Tropical and temperate reefs, the primary occupants of hard substrata in coastal habitats, extend from intertidal to subtidal depths, limited primarily by light penetration to the seafloor. As with some sedimented habitats described above, both types of reefs create biogenic habitats where dominant species (corals and seaweeds, respectively) ‘engineer’ physical structure that provide refugia from predation, augment food supply, and enhance abundance and biodiversity, among other functions.
Most tropical coral reefs occur in warm, shallow waters between the Tropics of Cancer and Capricorn, covering a total area of ~ 250,000 to 600,000 km$^2$. The main architects, scleractinian (stony) corals, generate calcium carbonate skeletons and build structurally complex colonies. Corals harbor algal symbionts (termed zooxanthellae) that provide the coral with organic carbon, allowing them to thrive in regions depleted in nutrients and otherwise low in primary productivity.

Most ecologists consider coral reefs to be the most biodiverse marine habitat. This diversity results from the many species associated with the reef, rather than the corals themselves (~ 1,000 species worldwide). Tropical reef species range from macroalgae to diverse invertebrates (e.g., annelids, molluscs, echinoderms) to fish, with thousands of morphospecies in single regions. Macroalgae use the physical structure for attachment and the rich nutrients generated through excretion for growth. Similarly, increased particulate concentration, and thus, food availability, attracts many small invertebrate species. Fish use coral reefs for feeding, spawning, nesting, mating, and sheltering.

Highly productive temperate reefs similarly have increased biomass and biodiversity relative to the surrounding habitats. On these reefs, dense stands of canopy-forming macroalgae (mostly brown, but also reds and greens) generate habitat structures sufficiently complex to support entire ecosystems. Kelp beds and forests, and rockweed beds, are the most common plant-dominated ecosystems on rocky substrata in temperate and polar oceans. Kelp beds cover > 25 percent of the world’s coastlines and thrive in cold-water, nutrient-rich areas. Kelps live up to 25 years, depending on species, exhibit high rates of primary production, and provide important functions, thus attracting many species. Many herbivores, particularly gastropods (e.g., snails, abalone) and echinoids (sea urchins) aggregate in kelp beds because of the rich production, and many detritivores feed on degrading kelp material. Abundant secondary producers, in turn, attract predators (e.g., crabs, fish, mammals) to kelp beds. Many invertebrates (e.g., echinoids, asteroids) and fishes (e.g., rockfish) also use kelp bed shelter as nurseries. Kelp beds export large amounts of detritus to adjacent ecosystems, both onto beaches and into deeper, nutrient-limited subtidal environments. In regions with a narrow continental shelf, the reach can extend to bathyal submarine canyons at 200 to 2,000 meters.

Continental shelves include some of Earth’s most productive habitats, fueled by nutrients from land and rivers, and upwelling from deeper waters. These habitats support most of the world’s major fisheries. Reduced wave energy relative to the intertidal and shallow subtidal environments, coupled with sediments supplied by riverine input and coastal runoff, cover much of the
continental shelf in sediment. Depending on wave energy, sediment supply, and history, mud or sand may dominate a location, each with different faunas. Suspension feeding organisms, such as surf clams, dominate higher energy sand environments, whereas deposit feeding organisms, such as sea cucumbers, dominate lower energy, mud-covered environments. Collectively, these environments recycle organic matter and regenerate nutrients critical to ocean production.

**Knowledge Gaps**

The complexity of coastal systems (e.g., population connectivity, dispersal potential, species interactions, biodiversity, and ecosystem functioning) leaves many knowledge gaps that limit our capacity for their sustainable use. Our current knowledge is biased towards larger organisms (e.g., fish) and commercial species relative to small invertebrates and microbes, and towards temperate environments in developed nations over those in tropical and polar environments and developing nations.

**Overview of Pressures**

Because of their proximity to human populations, coastal environments experience many human-induced pressures acting together, including pollution, loss of habitat, ocean warming, ocean acidification, sea level rise, invasive species, aquaculture, and increased fishing pressure.²

Increased coastal development has caused habitat loss in recent decades on the order of 1–10 percent per year. Physical disturbance, such as from dredging and bottom trawling, alters substrate and thus modifies habitat suitability or physically removes ecosystem engineers, such as seagrass and kelp beds. Increased sedimentation, whether from deforestation or increased riverine input, reduces light penetration, inhibiting plant and algal growth. Inorganic (e.g., metals) and organic pollutants (e.g., untreated waste, fertilizers, plastics) can affect marine organisms and their communities, lethally or sub-lethally, or cause eutrophication (excess nutrient supply) and anoxia.

Global change can impact coastal habitats profoundly. Faster warming of coastal waters than of the open ocean places key species at risk, causing

² C.M. Duarte et al., “Paradigms in the Recovery of Estuarine and Coastal Ecosystems,” *Estuaries and Coasts* 38, no. 5 (2015): 1202–1212.
‘tropicalization’ of temperate ecosystems in some regions. Coral death from bleaching, caused by symbiotic algae when a thermal threshold is exceeded over protracted periods, has reached alarming levels in most tropical oceans. Cold-adapted kelps are also vulnerable to warming waters, resulting in ongoing regime shifts to surf-dominated ecosystems, particularly in rapidly changing regions, such as the Northwest Atlantic. Temperate species that inhabit coastal areas are shifting towards polar regions, with profound ecosystem-level changes. Ocean acidification will further impact coastal ecosystems, reducing survival of species with calcareous shells or skeletons, such as economically valuable bivalves (e.g., oysters, clams, mussels) and reef-building corals. Lastly, sea level rise is expected to impact low lying coastal areas globally. Models predict average rises of 30 to 120 cm by the year 2100, although predicted rises increase annually with ongoing delays in implementing strategies to mitigate climate change. Sea level rise will affect regions of the world differently, with purported disappearance of some low-lying islands already (e.g., five reef islands in the Solomon Islands, Southwest Pacific).

Increased marine traffic globally has already accelerated the spread of invasive species. Proximity to ports, tourism operations, and aquaculture sites has impacted coastal habitats in particular. Non-native species typically lack predators and competition, grow fast, and are generalists in the invaded regions. In turn, they can outcompete native species, limit the abundance of their prey, and alter trophic interactions. Several systems illustrate significant ecosystem changes, such as the alteration of intertidal trophic interactions on the east coast of North America by introduced Chinese mitten crabs, and the effects of lionfish introductions on fish recruitment in Caribbean reefs.

Coastal mineral and oil extraction add further pressures. Removal of sand for beach replenishment or for minerals alters local seafloor biota, and dumping of waste material from mining can smother seafloor communities. Oil exploration adds noise and unknown impacts of seismic surveys, whereas drill cuttings can smother local seabed communities, in contrast to the more widespread and catastrophic effects of oil spills, particularly on seabirds, marine mammals, and intertidal environments.

Humans extract large quantities of living resources from coastal environments in various fisheries, from fish to invertebrates to macroalgae. Nations depending on these fisheries for jobs, revenue, and food, i.e., protein, have depleted many stocks. This intense fishing effort has also altered food webs and damaged bottom habitat. The removal of many top predators has necessitated switches to other, lower value fish species and extension of fishing effort into deeper water. Bottom contact fishing gear can damage biogenic habitats,
homogenizing complex seafloor habitat and eliminating the species associated with those habitats.

The collapse of many fisheries has contributed to rapid expansion of marine aquaculture of many finfish and invertebrate species, as well as macrophytes such as kelp and commercial seaweeds. Most aquaculture occurs in nearshore habitats, sometimes increasing organic enrichment, spreading disease, and decreasing the genetic diversity of wild populations. Finfish aquaculture usually depends on fishmeal produced from wild fisheries, e.g., anchovies, a practice that further pressures natural populations.

Needs and Solutions

The dense, complex human activities in the coastal region require multiple approaches to achieve sustainable use, maintenance of ecosystem integrity, and, where possible, rehabilitation of degraded ecosystems. However, although some pressures can be addressed locally or regionally, others require coordinated global efforts.

Integrated ecosystem based management (IEBM) and marine spatial planning are integral components of a solution. The spatial proximity of and multiple connections between coastal ecosystems require holistic management of human use of coastal areas. IEBM recognizes complex interactions within and among ecosystems, rather than focusing on the ecology and pressures experienced by single species. Although slow to operationalize, the approach is gaining momentum with increasing recognition of the complexity of coastal environmental issues. Marine spatial planning (MSP) is one tool to support IEBM. MSP brings together multiple marine users and stakeholders and allows comprehensive evaluation of individual and cumulative pressures in a particular area, facilitating IEBM implementation.

Marine protected areas (MPAs) can protect relatively unaffected coastal ecosystems or facilitate recovery once stressors of impacted systems are removed. Most coastal states that signed the Convention on Biological Diversity are now establishing MPAs to meet their commitment to protect at least 10 percent of their coastal and marine environments by the year 2020. Effective MPAs, zoned to include some no-take areas, are difficult to achieve in coastal regions because of the needs of multiple stakeholders. However, effective

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3 J. Claudet, *Marine Protected Areas: A Multidisciplinary Approach* (Cambridge: Cambridge University Press, 2011).
networks of MPAs do exist, based on sound ecological principles and direct engagement of major stakeholders (e.g., along coastal California).

Ecological restoration can rehabilitate degraded coastal ecosystems, such as seagrass beds and oyster reefs. Some restoration efforts include mass seagrass planting to restore meadows, out-planting cultured oysters to create oyster reefs, and creation of artificial coral reefs to enhance recruitment to natural reefs. Though time-consuming and expensive, ecological restoration has met success in regions of the United States such as Virginia and Florida (seagrasses) and Chesapeake Bay (oysters). Effective restoration requires first removing the stressor that degraded the ecosystem. Additionally, success hinges upon ecosystem monitoring during restoration. Trade-offs between marine protection and restoration will determine the best approach for a particular location.

Many also view ecosystem based management as critical for enhanced fisheries management efforts, which also uses tools such as gear restrictions (and size selection), spatial and temporal closures, and bycatch limits. But many fisheries biologists emphasize a precautionary approach that identifies population reference points for each species, below which significant declines in numbers will occur. In parallel, aquaculture is working to develop plant-based feeds and better containment practices.

Conclusion

Intense human interaction with the coastal ocean has depleted coastal habitats more severely than other marine regions. Our dependence on fisheries, aquaculture, and other coastal resources demands more sustainable efforts, particularly given expected increases in human populations and their need for protein and other marine resources. Improvements in scientific tools (sensors, genetics, models, digital imaging, etc.) offer substantial opportunities for addressing how we manage ocean use. However, political will and societal support will ultimately determine whether we can reverse coastal degradation and sustain these critically important habitats.