An Ecological Characterization of the Gulf of Maine: Estuarine, Intertidal and Nearshore Habitats

Coastal Landforms

The geology of the Gulf of Maine's coastal rim provides the underpinnings for its estuarine, intertidal and nearshore habitats, as well as for the region's abundant coastal watersheds. The details of vertical relief, slope, and mineral substrate form the basins within which fresh and salt waters flow - driven by gravity, tides and storms. These coastal basins, embayments, and watercourses have been worked and reworked over geologic time through the interplay of sea level with glacial advance and retreat. Meteorologic, hydrologic and oceanographic processes have scoured, eroded, and transported these substrates into their present coastal configurations - processes that continue in the present day. The rates and direction of change of fundamental sea level and climate processes have varied appreciably over the past 20,000 years, driven by the movement of the Laurentide Ice Sheet. The relatively gradual change in Gulf of Maine climate and sea level that characterized the past 5,000 years may now be giving way to more variable conditions, in response to human-wrought changes in local sediment supply and global atmosphere.

The Gulf's coastal landforms and bedforms create a mosaic of bedrock, clay hardpan, boulders, cobble, gravel, sands, silts and clays (listed here in descending order of grain size). The mosaic is apparent on the grand scale, with more hard substrates found along the Maine coast (ledge, boulders, cobble and gravel), and more soft substrates (sand and clay) eastward into the Fundy Basin, and westward into Massachusetts Bay. On the scale of individual estuaries, embayments or exposed headlands, the mosaic of materials is also apparent, with smaller grained sediments accumulating in slower moving backwaters created by larger rock and ledge.

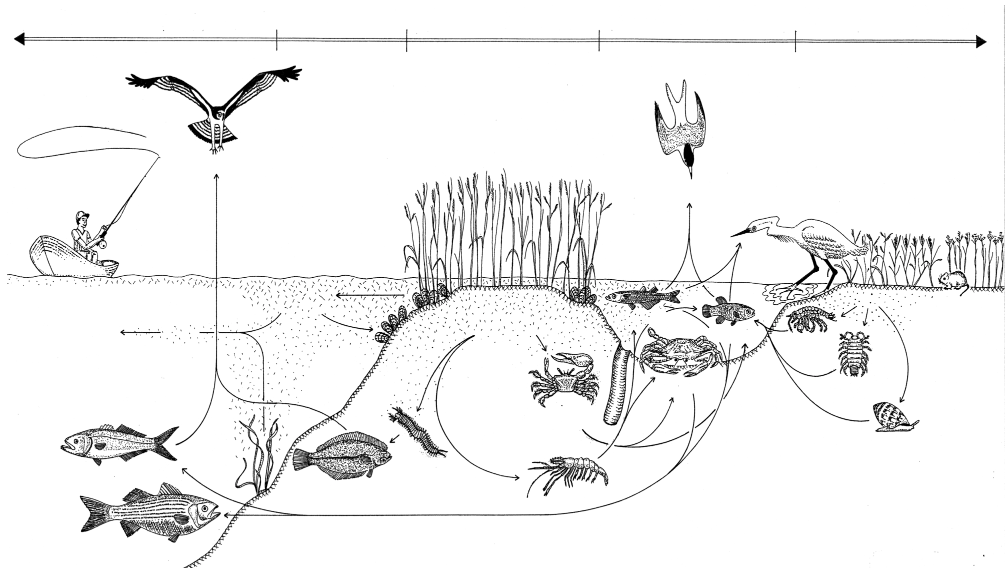
Familiar Habitats

There are many schemes that can be applied to the classification of habitats created by the interaction of geologic substrates with plants and animals. Here, for the most part, we will use familiar names, as opposed to technical terms, for our description of the coastal habitat features that characterize the Gulf of Maine shoreline. Habitats, in general, are defined by the animal communities that use them, and the food webs they support. Some coastal habitats are formed primarily from non-living, inorganic materials, while others are created primarily by organisms (biogenic). Organic matter created as byproducts from living and dead organisms is also an important feature of many habitats and food webs. Table 1 describes the most general habitat categories. Many of the habitat types presented below can be further "deconstructed" into a number of more precisely defined habitat components.

Table 1. Common Gulf of Maine and Northeastern coastal habitats, grouped according to their characteristic substrate/medium/structural elements.

Estuarine Water Column						
Inlet	*Channel*	*Intertidal Creek*	*Subtidal Creek*			
Nearshore Water Column						
Surface	*Pelagic*	*Demersal*				
Rocky Intertidal/Subtidal						
Exposed Ledge	*Macroalgal Beds*	*Tide Pools*	*Submerged Ledge*	*Boulder*	*Cobble*	*Gravel*
Soft Sediment						
Sand Dune	*Beach*	*Sandflat*	*Mudflat*	*Sand Waves*		
Emergent Salt Marsh						
Peat Reef	*Peat Bank*	*Low Marsh*	*High Marsh*	*Marsh Panne*		
Submerged Aquatic Vegetation						
Eelgrass	*Widgeon Grass*					
Shellfish Reef						
Blue Mussel	*Horse Mussel*	*Oyster*				

Habitats, inhabitants, and food web linkages in a typical New England estuarine ecosystem. This figure was originally designed to illustrate a southern New England salt marsh. In the Gulf of Maine, the blue crab is replaced by the non-native green crab.



Artist:Thomas R. Ouellette

FOCUS ON FOOD WEBS

Food webs (also known as trophic webs) are the production networks formed by species interactions within a particular habitat or ecosystem. They link the packaging of energy, carbon and nutrients into organic matter, with subsequent consumption and recycling. In the Gulf of Maine, most new energy is derived from sunlight and packaged by plants into plant biomass. In coastal habitats these plants range from single celled microalgae (phytoplankton), to meters-long macroalgae (seaweeds), to flowering aquatic plants such as eelgrass. Plankton suspended in the water column are the first organisms to intercept solar radiation. Attached plankton, such as the ubiquitous group known as the “benthic diatoms”, as well as most macroalgae and submerged aquatic plants (SAV), can only persist at depths where sufficient light is available. By convention, plants forma food web’s first trophic level – the *primary producers*. All organisms that grow through direct consumption of living plants form the next level – the *primary consumers*. All animals that grow through direct consumption of primary consumers are referred to as *secondary consumers*, followed by *tertiary consumers* (animals that eat secondary or other tertiary consumers). Biomass created by plants is referred to as *primary production*, while that incorporated into animal tissue through trophic interactions is called *secondary production*. Secondary producers are often grouped by their functional role in the food web: herbivores, grazers, planktivores, omnivores, carnivores, scavengers and detritivores. Carnivores at the highest level of the food web are sometimes called “top” carnivores. The human species can be an important top carnivore in coastal food webs, as it is offshore.

Species within the food web persist by countering mortality with successful reproduction. The functional role of an individual consumer within the food web can change throughout its lifetime, determined by changes in morphology and size. As energy packaged into biomass moves progressively higher up the web, a certain amount is lost as heat through the metabolism of individual organisms. Thus, the total biomass at any one level is somewhat less (often by about 10%) than at the preceeding level. Concomitant with the reduction of total biomass at increasing trophic levels is the concentration of contaminants that are ingested and retained in living tissues, known as bioaccumulation. As mortality occurs within the living portion of the food web, dead plants and animals and their remains (detritus) are consumed by scavengers, detritivores, fungi and bacteria. During the process of decay, organic matter is broken down to its constituent elements and made available again to primary producers. Contaminants are released in the recycling process, and may or may not become available for incorporation into the food web once again.

It is useful to consider the value of coastal habitats from the perspective of the food webs that depend on them, given that food webs are responsible for the distribution and abundance of animal species within the Gulf of Maine. Some of these species are of interest due to rarity or non-native origin, others are harvestable, still others are valued for recreation by anglers or birders. We generally refer to food webs by their associated habitats, since habitats possess easily identifiable structural elements. Hence, we refer to salt marsh food webs (see Fig. 1 for an example), eelgrass food webs, rocky intertidal food webs, rocky subtidal food webs, soft-sediment food webs, pelagic (i.e. water column) food webs and others.

HUMAN-HABITAT INTERACTIONS

Human activities along the upland margin of the Gulf of Maine alter coastal habitats both directly and indirectly. The great majority of these actions have the potential to reduce coastal habitat functions and values. While ecological habitats have some ability to recover from certain types, frequencies and intensities of human action, their capacity to recover can be exceeded, especially as the effects of multiple, ongoing impacts accumulate over time. The type of impact varies dramatically; from those associated with densely populated urban centers - to those associated with historic farming and wetland management practices. Urban and suburban sprawl are transforming watershed shorelands from woodland to intensively managed turfs and pavement. Efforts to protect property threatened by rising sea level magnify the effects of coastal erosion. In estuaries and nearshore waters some fishing and navigation practices physically disturb habitats on a regular basis, as do wakes from both commercial and recreational vessels. Maintenance and expansion of transportation networks fragment and disrupt aquatic habitats and their hydrology. Direct physical alterations through dredging, diking and filling of coastal habitats were much more common and extensive in the past than they are today, but the effects of these historic impacts persist in the present day. Many current day impacts tend to be indirect, and therefore more difficult to relate to specific actions: nutrient enriched or contaminated runoff; atmospheric deposition of nutrients and pollutants; meteorologic and sea level responses to climate change; altered salinity, temperature and oxygen regimes; inputs of treated and untreated sewage; boating fuel and wastes; erosion and sedimentation of shorelines and waterways; salt marsh subsidence; introduction and spread of invasive species.

ACTIONS THAT DEGRADE OUR COAST

As with habitat classification schemes, there are many ways in which to classify human alterations to coastal habitats that reduce ecological function. Here we provide a non-technical overview of impact types, along with simple explanations. The habitat types affected, the temporal pattern of impact, and potential ecological consequences of the different impacts are summarized in Table 2. In this table we find it helpful to group human actions into those that happened in the past, and those that are current or ongoing. If not set apart, continuing impacts from past actions can be inadvertently overlooked.

DIRECT PHYSICAL ALTERATION

Activities that change the physical or hydrologic structure of coastal habitats and watersheds include the following:➔ Dredging - removal of sediments, generally as an aid to navigation➔ Diking - construction of berms to hold back tidewater and allow drainage of tidal habitats, generally for use in agriculture or aquaculture ➔ Filling - creation of dry land in aquatic habitats ➔ Dragging - trawling over submerged habitats for harvestable marine species with large, weighted nets ➔ Piers - construction of structures above aquatic habitats supported by pilings ➔ Armouring - construction of rigid, fixed barriers to protect property in areas subject to shoreline erosion ➔ Impoundment - use of a dike or dam to pond fresh water in a marsh or stream➔ Restriction - reduction of flow in estuaries and coastal watersheds due to roads, causeways and undersized bridges and culverts ➔ Channelization – straightening of watercourses to increase flows or reduce travel time ➔ Diversion – rerouting flow in a watercourse to use the water elsewhere.

POINT SOURCE POLLUTION

Point sources of pollution are discharged in significant volumes from specific points, primarily discharge pipes from commercial, manufacturing and industrial operations. Effluent from sewage treatment plants, and storm water from combined sewer outfalls, discharge material collected from large, densely populated areas. Common point source discharges in the Gulf of Maine include the following: ➔ nutrients and chlorine - from secondarily treated sewage effluent ➔ toxic organic, metal, and hydrocarbon compounds –from combined sewer outfalls ➔ dioxins and furans – from paper mills and other industries ➔ hydrocarbons – from fuel spills. In addition to current inputs, the historic prevalence of tanning, metal fabrication, ship building and paper making has left a legacy of organic and metal contaminants in many quiescent, "depositional" habitats throughout the Gulf's bays and estuaries. Eight superfund sites have also been identified along the Gulf of Maine coast.

NON-POINT SOURCE POLLUTION

Inputs of pollutants from diffuse sources are referred to as non-point sources of pollution (NPS). They are generally delivered to aquatic systems with overland runoff during and after rain events in developed shoreland areas, or through deposition of particulate contaminants from the atmosphere. Common components of NPS that occur within Gulf of Maine coastal watersheds include the following: ➔ nutrients, toxic organics – from conversion of shoreland buffers to lawns, golf courses, agriculture and other intensively managed land covers ➔ heavy metals (e.g. mercury, lead, cadmium, copper) – from gasoline, paints, pesticides ➔ PAHs and other hydrocarbon breakdown products - from paved surfaces ➔ airborn heavy metals and hydrocarbon breakdown products - from vehicular exhaust, power combustion, incinerators and industrial emissions ➔ sediment (often with adsorbed pollutants) – from forestry, land clearing, landscaping, impervious surfaces and their maintenance, along with sediments from excessive stream erosion resulting from increased runoff.

SEA LEVEL AND CLIMATE CHANGE

Climate change is one of the drivers of increasing sea level in the Gulf of Maine. The frequency and intensity of storm events, and the seasonal pattern of temperature change may also be in the process of departing from long term trends. The combination of storm events and rising seas cause increased erosion, especially in areas where the natural ability of the landscape to respond to erosive forces has been altered. Jetties and sea walls exacerbate wave and storm driven erosion, and reconfigure beach and dunes by altering sand transport. Prolonged periods of maximum summer water temperatures and reduced periods of winter water temperature minima may facilitate range extensions of more southerly species as well as invasive species into Gulf waters. Changes in seasonal temperature patterns will consequently alter the patterns of stratification, mixing, and plankton blooms that support water column food webs, and may increase the incidence and persistence of harmful algal blooms (HABs).

ACTIONS THAT IMPROVE OUR COAST

COMMUNITY AWARENESS

There are many excellent guidelines and ordinances that define limits to the deleterious activities and inputs of harmful materials listed above. Because many of these limits are not practically enforced when it comes to individual citizens, voluntary compliance is essential. The level of voluntary action is directly related to individual awareness of the benefits of that come with changing habits to reduce impacts on coastal habitats. Community awareness and support of land conservation efforts is also critical for the success of coastal habitat protection be it through acquisition or conservation easement.

RESOURCE MANAGEMENT

Effective resource management of coastal habitats depends upon 1) adequate programmatic infrastructure, 2) adequate science-based data regarding habitats, species, and population change. In the Gulf of Maine there are numerous state and federal natural resource agencies and non-governmental organizations that play a role in managing habitats and species in estuarine, intertidal and nearshore zones, as well as their adjacent watersheds. These groups pursue their missions both independently, and through opportunistic ad hoc partnerships. The human and financial resources available to support coastal resource management, relative to the scale of the resources being managed, varies greatly across the five Gulf of Maine jurisdictions of Massachusetts, New Hampshire, Maine, New Brunswick and Nova Scotia.

MUNICIPAL PLANNING

Many of the decisions and policies regarding land-based activities that cumulatively alter and disturb coastal habitats are made at the municipal level, by non-professional, volunteer boards. Board members represent a wide array of personal and constituent interests. In most jurisdictions, there is little ability to develop coordinated land use plans across town lines. There is great potential to improve coastal habitat protection through education, support and coordination of municipal decisionmakers.

ACTIVE RESTORATION

As with resource management, effective coastal habitat restoration depends upon adequate infrastructure, funding, and science-based information. Coastal habitat restoration is very much an evolving realm of endeavor, using the model of “adaptive management” whereby ecological evaluation of restoration response indicates whether changes should be made in the application of restoration techniques. The amount of funding for estuarine habitat restortation has increased in the past several years, so many projects have been funded and a number of them are following the adaptive management model. To date, the primary targets of restoration projects in the Gulf of Maine have been salt marsh and eelgrass habitats and anadromous fish passageways. There is a strong site-specific component to the design of successful coastal habitat restoration projects. Designs that are appropriate for more southerly regions of the east coast do not necessarily apply in the Gulf of Maine. Within the Gulf of Maine itself there is a wide range of tidal and salinity regimes experienced by any given habitat type. These and many other site-specific biological variables must be considered for successful project design.

COAST AND OPEN GULF – HOW ARE THEY LINKED?

The Gulf of Maine is a geologically complex coastal and ocean basin, giving rise to a great variety of habitats. Coastal habitat diversity and complexity is greater here than it is in more southerly temperate coastal regions. It seems reasonable to hypothesize that the ecology of estuarine, intertidal and nearshore habitats are linked with the ecology of the Gulf's open waters. It is also reasonable to suggest that land-based human activities, such as those we have just described, are a significant driver of ecological change in the Gulf of Maine. However, much of the strong and growing body of research in the Gulf of Maine pertains to offshore waters, deep water bottom habitats, and shallow offshore bank habitats. The land-water margin that defines, contains and drains into the Gulf of Maine boasts no parallel body of science-based information. We recommend that a new emphasis be placed on the study of estuarine-nearshore-offshore linkages in Gulf of Maine ecosystem processes. A Gulf-wide program to monitor coastal habitats would provide the initial database with which to explore linkages between the region's coastal human inhabitants and the greater Gulf of Maine ecosystem.

Human-Habitat Interactions	Time Frame: Onset		Time Frame: Impact		Habitat Type							Potential Ecological Consequences
	Historic	Current	Historic	Current	Estuarine Water Column	Nearshore Water Column	Rocky Inter-tidal/subtidal	Soft Sediment	Emergent Salt Marsh	Submerged Aquatic Plants	Shellfish Reef	
Direct Physical Alteration												
Dredging	✓	✓	✓	✓								Habitat disturbance , suspended seds., chronic erosion from ↑ tidal prism
Diking	✓		✓	✓								Conversion of intertidal habitats to freshwater marsh or dry land; invasive plants
Filling	✓		✓	✓								Habitat loss/fragmentation/invasion, alteration of drainage, ↑ point and NPS
Dragging	✓	✓	✓	✓								Recurrent habitat disturbance and sediment suspension, food web manipulation
Macroalgal Harvest		✓		✓								Habitat removal, disturbance, food web manipulation
Armouring	✓	✓	✓	✓								Habitat erosion and loss, ↑ disturbance
Impoundment	✓		✓	✓								Habitat alteration via ponding, ↓ fish/ invertebrate passage, ↓ dissolved oxygen (DO)
Restriction	✓		✓	✓								Freshening, subsidence, invasion, ↓ tidal exchange and DO, ↓ or lost fish/ invert passage
Channelization	✓		✓	✓								Loss of instream habitat; loss of water column food web elements, including fish
Diversion	✓	✓	✓	✓								Increased salinities, species shifts, alteration of fresh-tidal estuarine zone
Point Source Pollution												
Nutrients/Chlorine		✓		✓								Species loss, altered food webs, shifts to nuisance algae and harmful algal blooms (HABs)
Organics/Metals	✓	✓	✓	✓								Physiological stress leading to altered/reduced food web productivity, ↑ bioaccumulation
Dioxins/Furans	✓	✓	✓	✓								Physiological stress leading to altered/reduced food web productivity, ↑ bioaccumulation
Hydrocarbon Spills		✓		✓								Habitat disturbance, destruction; persistant contamination → altered/reduced food webs
Non-Point Source Pollution												
Nutrients/Organics		✓		✓								Stress→altered food webs, ↑ bioaccumulation,↑ harmful algal blooms, ↓ DO
Heavy Metals		✓		✓								Physiological stress leading to altered/reduced food web productivity, ↑ bioaccumulation
PAHs		✓		✓								Effects largely unknown in this coastal region
Airborn Metals/HCs		✓		✓								Stress→altered/reduced food web productivity, ↑ bioaccumulation,↑ harmful algal blooms
Sediment	✓	✓	✓	✓								↓ fish habitat, ↑ contamination, invasives, reduced water clarity and primary productivity
Climate Change												
Rapid Sea Level Rise		✓		✓								Landward habitat transgression where possible; ↑ habitat loss via erosion/submersion
Warming Waters		✓		✓								Species shifts in primary and secondary producers; invasion of warm water species; ↓ DO

Table 2. Summary matrix of common human-habitat interactions experienced by northeastern coastal habitats, with shaded cells in the habitat columns indicating impact occurence. This matrix serves only to highlight some of the **potential** ecological consequences that can be expected from notable human-mediated impacts, and is by no means comprehensive. The **actual** ecological consequences from these impacts can only be assessed with adequate and appropriate monitoring and evaluation of habitats and human impacts. Such a regional system of coastal habitat evaluation does not currently exist.