Chapter 1
The Ecological Importance of the Quoddy Region

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"Ecosystems result from the integration of populations of different species in a common environment. They rarely remain steady for long, and fluctuations lie in the very essence of the ecosystems and of every one of the […] *populations*." (Margalef 1960 in Smith 1994)

Although change in community configuration has been the norm throughout the history of the earth's ecosystems, anthropogenic influences have enormously increased the rates and scales of change (Vitousek 1994, Vitousek et al. 1997). In the marine realm, coastal ecosystems and estuaries have been most visibly affected by anthropogenic forces (Limburg 1999). Their high productivity, species abundance, and diversity have always attracted humans to settle and make a living near the shore, interacting in multiple ways with their environment and thereby altering it. Similar patterns of pollution, eutrophication, overfishing, and habitat destruction can be observed in a wide range of coastal regions (Schramm & Nienhuis 1996, Vitousek et al. 1997, HEED 1998, Pauly et al. 1998, Steneck 1998, Tegner & Dayton 1999). Some regions, however, are of special importance to both humans and nature.

The Quoddy Region in the outer Bay of Fundy represents such a special area, highly valued for its rich and diverse marine animal and plant life (Hardie 1979, Thomas 1983, Percy et al. 1996). A unique combination of environmental characteristics influenced by the geology, oceanography and climate of the area provides the conditions for one of the highest productivity areas on the east coast of Canada (Hardie 1979, Thomas 1983, Percy et al. 1996). An important focus of productivity within the area are the passages between the West Isles, in particular Head Harbour and L'Etete Passages, where almost all species known to occur in the region, from the phytoplankton to baleen whales, can be found (Hardie 1979). A mosaic of diverse inshore and offshore marine, littoral and terrestrial habitats provides a variety of different breeding, spawning, nursing, feeding, foraging, resting and staging habitats, which were described and mapped in an extensive resource inventory of the area (MacKay et al. 1978a, b, c, 1979a, b, c).

Today, the Quoddy Region supports many resident and migrant species, including several rare or endangered species that find important refuges here. For these reasons, the West Isles and Grand Manan were identified by Parks Canada as representative 'Natural Areas of Canadian Significance' (NACS) (Hardie 1979). In a report to the New Brunswick Department of Natural Resources, Hunter (1982) proposed the mouth of the Bay of Fundy as a "Special Ecological Region requiring protection from detrimental human activity." He suggested designation of the West Isles Archipelago, Head Harbour Passage and St. Croix Estuary as ecological reserves, and The Wolves and parts of Grand Manan as wildlands. However, only a few small areas, such as Machias Seal Island and Kent Island, have received any protection (see Harvey 1994). In recent years, private land stewardship organizations have acquired other small islands in the West Isles.

1.1 Ecosystem characteristics

1.1.1 Variety of biogeographic habitats

The Quoddy Region is located in southwestern New Brunswick, Canada, and straddles the border with the State of Maine, USA (Fig. 1.1). For purposes of this report, the Inner Quoddy zone is defined as Passamaquoddy Bay, its drainage basin, the West Isles archipelago (Deer Island and adjacent islands), and surrounding waters. The Outer Quoddy zone encompasses the water and islands inside a line drawn from Point Lepreau to the outer boundaries of the Grand Manan archipelago, and west to the Maine coast at West Quoddy Head, Lubec (Fig. 1.2).

In this region we find a mosaic of inshore and offshore marine, littoral and terrestrial habitats: sheltered bays, exposed shorelines, channels with strong currents and upwelling areas, and open waters towards the Gulf of Maine (Table 1.1, see also MacKay et al. 1978a, b, c, 1979a, b, c). Very high tides create extensive intertidal zones. Furthermore, the watersheds of the St. Croix River and Magaguadavic River running into Passamaquoddy Bay contain a large number of freshwater lakes, streams and brooks as well as brackish estuaries. The concentration of and interconnection among these diverse habitats on a relatively small geographic scale play an important role in supporting a high variety of resident and migrating species and their specific needs for spawning, breeding, nursing, wintering, feeding, foraging, staging and resting (Fig. 1.3, Thomas 1983, Percy et al. 1996).

The Quoddy Region is critical for a diverse fauna of migrating species, such as sea- and shorebirds (e.g. phalaropes, sandpipers, terns), whales (e.g. Northern right whale), and fish (e.g. Atlantic salmon), some of which are threatened or endangered. Because of these connections to populations which range for thousands of kilometres from the region, the importance of the Quoddy Region far exceeds its geographical boundaries, reaching into the high Arctic, Greenland, Chile and South Africa, among others.

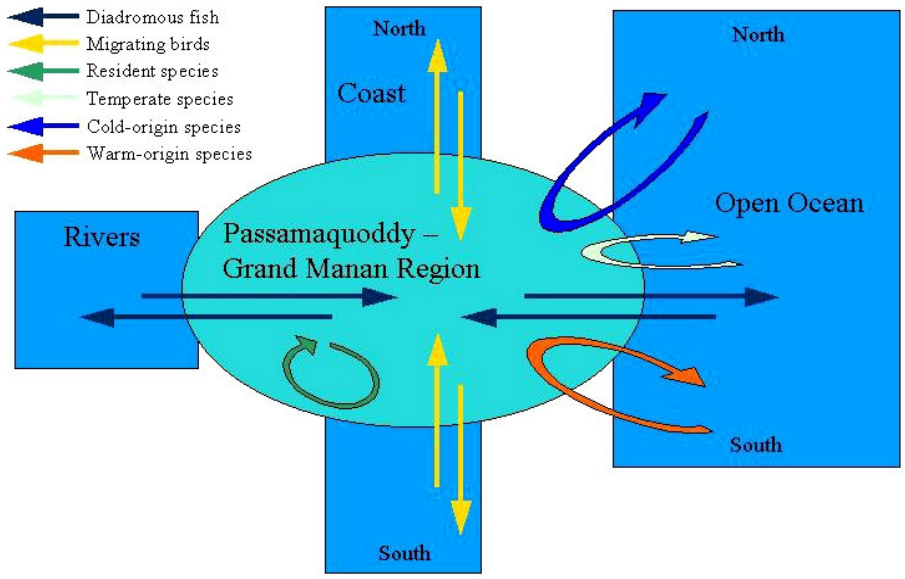

Fig. 1.3. *Importance of the Quoddy Region for resident and non-resident species that interconnect the area with rivers, coastlines and the open ocean in the Northern and Southern Hemisphere.*

Table 1.1. *Different habitat types represented in the Quoddy Region, species depending on these habitats to fulfill their species-specific needs, and threats caused by human activities resulting in potential habitat loss or degradation.*

Habitat ecotype	Species	Needs	Threats
Freshwater (river, stream, brook, lake)			
1. benthic	diadromous fish	spawning, nursery, feeding	damming, pollution
2. pelagic	diadromous fish, birds	feeding	damming, pollution
Terrestrial nearshore (coast, island)			
3. benthic – terrestrial			
-- grassland	seabirds	breeding	agriculture, settlements, land use
-- coastal forest	seabirds, raptors	breeding	logging, settlements, land use
4. benthic – shore			
-- sandy / gravel beach	seabirds, shorebirds	breeding, feeding	staging area for marine industries, tourism, recreational vehicles, marine debris
-- salt marsh	shorebirds, waterfowls raptors, mammals, fish	breeding, feeding, shelter	dyking, infilling, adjacent land use, draining
Brackish / marine (estuary, bay, archipelago, open water)			
5. benthic – intertidal			
-- mudflats	shorebirds, invertebrates	feeding	organic enrichment, pollution
-- soft bottom – clam beds	invertebrates	feeding	harvesting, pollution
-- hard bottom – mussel beds	ducks, waterfowls	feeding	harvesting, pollution
-- hard bottom – rockweed beds	fish, invertebrates ducks, seabirds	spawning, nursery, feeding	harvesting, eutrophication
6. benthic – subtidal			
-- soft bottom – eelgrass beds	brants, geese, fish, invertebrates	nursery, feeding, spawning	disease, shoreline development eutrophication
-- hard bottom – kelp beds	fish, invertebrates	feeding, nursery	dredging, dragging, sea urchin grazing
-- corals, sponges, anemones	groundfish, invertebrates	nursery, feeding	bottom trawling, dragging
-- sand / gravel / rocky bottom	groundfish, invertebrates	feeding, spawning	bottom dragging, aquaculture
-- mussel reefs	invertebrates	living	bottom dragging, aquaculture
-- scallop beds	invertebrates	living	bottom dragging, aquaculture
7. pelagic			
-- surface	seabirds, fish, plankton, mammals	feeding	debris, ship traffic, oil spills, pollution, noise, acoustic harassments, light
-- upwelling	seabirds, fish, mammals plankton	feeding, nursery	acoustic harassments, ship traffic, fishing nets, pollution
-- deep water	fish, mammals, plankton	feeding, nursery	acoustic harassments, ship traffic, fishing nets, pollution

1.1.2. Oceanographic features

Water circulation pattern.

The major water inflow into the Bay of Fundy from the Gulf of Maine and Scotian Shelf occurs on the Nova Scotia side of the Bay. Some water circulates back in the upper reaches of the Bay of Fundy, but most of it reaches the central bay close to St. John before flowing back towards the Gulf of Maine on the New Brunswick side (Fig. 1.4.). This flow pattern creates a big gyre of counterclockwise circulation around the Grand Manan Basin in the outer Bay of Fundy. Together with a similar, large circulation in the Gulf of Maine, these water currents import phytoplankton and zooplankton, as well as fish eggs and larvae from Gulf of Maine into the Bay of Fundy.

High tides.

Lunar tides reach an average tidal range of four metres at the mouth of the Bay of Fundy and 5.6 m in the Quoddy region with extremes to about 8.3 m (Smith et al. 1984).

Bottom geography.

The high tides in combination with the bottom geography create strong currents in the passages that can reach 1.5-2.5 m per second. Topographic resistance to these tidal flows results in small-scale local upwellings, vigorous vertical mixing, and horizontal convergences (Smith et al. 1984, Gaskin & Smith 1979). These areas represent hotspots of intense biological activity (see below), because upwelling deep water contains high concentrations of plant nutrients such as nitrate, phosphate and silicate. Another effect of the bottom topography in combination with the water circulation pattern is that the Quoddy Region serves as a natural "fish trap," concentrating passively transported organisms such as phytoplankton, zooplankton, fish eggs and larvae. Vigorous mixing and tidal currents increase suspension of sediment material and silt, which increases turbidity. Although high turbidity may diminish phytoplankton production, it also may serve as a refuge for herring and other pelagic species (Graham 1936).

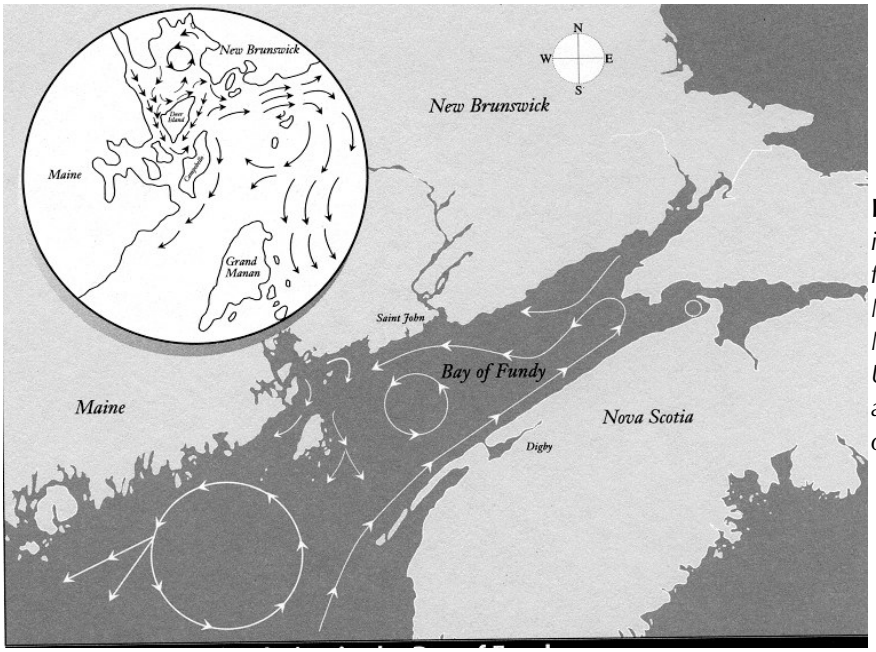

Fig. 1.4. *Surface circulation in the Bay of Fundy. Adapted from G. Godin (1968), Natural Resources Canada; Neal Pettigrew (1996), University of Maine; J. R. Chevries and R. W. Trites (1960), Journal of Fish Res. Board of Canada.*

1.1.3. Primary and secondary productivity

Import system.

The southwestern Bay of Fundy is an import system. Phytoplankton, zooplankton, and most fish eggs and larvae are produced outside the area, mainly in the Gulf of Maine and off Southwest Nova Scotia. Following the water circulation and current patterns, they become concentrated within the Quoddy Region (see above).

Short, energy-efficient food chain.

The pelagic food web in the Quoddy Region is characterized by a short and energy-efficient food chain (diatoms – krill – fish / birds / mammals), which is typical of highly productive systems such as upwelling zones and the Antarctic Ocean. With each transition from one trophic level to the next, about 90 percent of the energy is lost due to respiration and physiological energy needs (Pauly & Christensen 1995). Food chains with only three levels are thus more efficient and productive than those with four, five, or more.

High low-trophic level productivity.

Upwelling promotes phytoplankton productivity (high nutrient concentrations and water flow), zooplankton abundance (high food supply, low temperatures – especially for euphausiids), and zooplankton availability to higher trophic level (transport to surface waters, surface swarming). High phytoplankton abundance and water flow also promote benthic filter feeders. High nutrient supply and water flow favour benthic micro- and macroalgal growth, and thus food availability to benthic herbivores.

Concentrated feeding grounds.

These concentrated feeding grounds have historically attracted various resident and migrating species to the area (e.g. annual inward migration of predatory groundfish, mammals, seabirds), a feature for which the Quoddy Region has become renowned.

1.2. Food web description

Species interact as prey and predators, competitors or facilitators throughout their entire lives. They influence each other's abundance, distribution and behaviour. Some species serve as habitat, substratum or refuge for others (Table 1.1). These multiple species relationships form a complex interactive web. A food web illustrates only some of these interactions -- the major food-consumer or predator-prey relationships -- which can be complex on their own.

Inward and outward migration patterns of different species at different times change species composition in the area over the course of a year. Thus, linkages between species fluctuate spatially and temporally. We did not attempt to separate these as different seasonal and spatial food or interaction webs, but Fig. 1.5 illustrates major trophic levels and functional groups, as described below, and their food links.

Fig. 1.6. illustrates the distribution of biomass over the different trophic levels in a "trophic triangle". With each transition from one trophic level to the next, about 90 percent of the energy is lost due to respiration, temperature regulation, excretion and other physiological needs. Thus, the higher the trophic level, the lower is the amount of biomass that this level contributes to the entire food web.

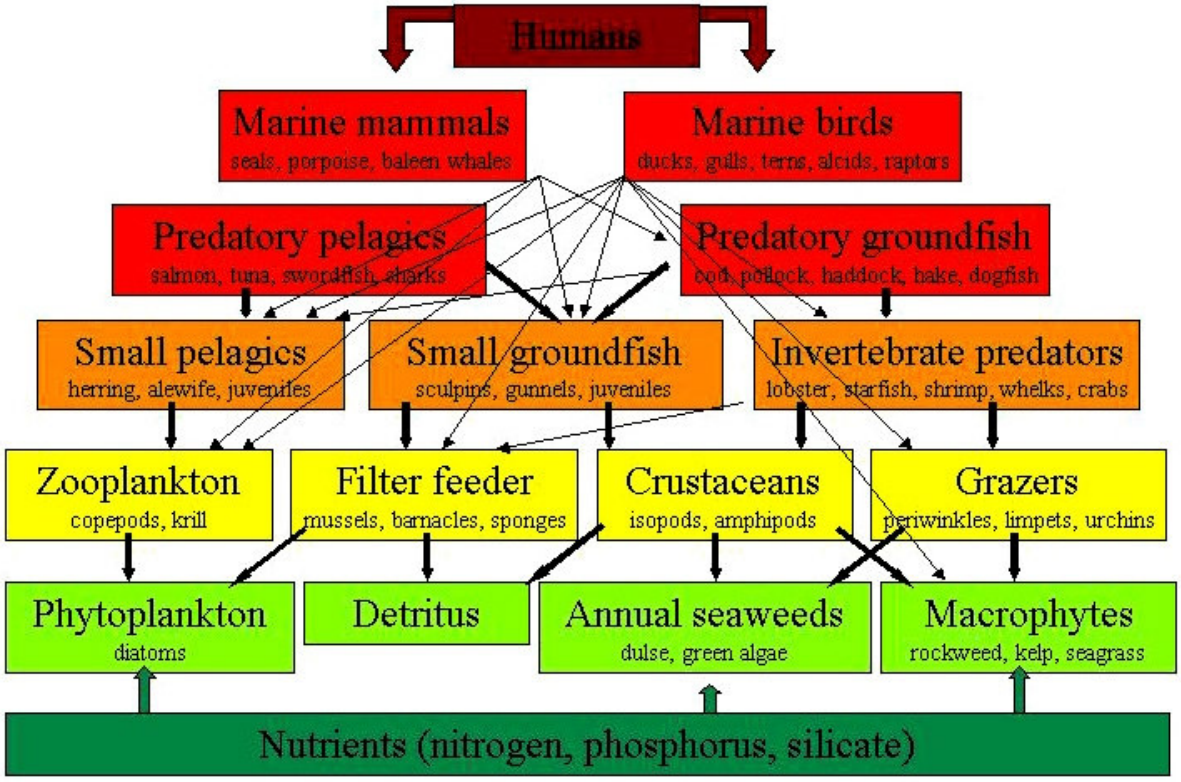

Fig. 1.5. *Simplified food web with major trophic levels (separated by colors), functional groups (separated by boxes), and their food links (arrows). The higher trophic level groups (red boxes) can feed on the several lower trophic levels or on species from a similar level (e.g. sharks can feed on seals), thus their position in the food web is variable. In any case, humans are the top predator, together with raptors, sharks, some marine mammals and birds.*

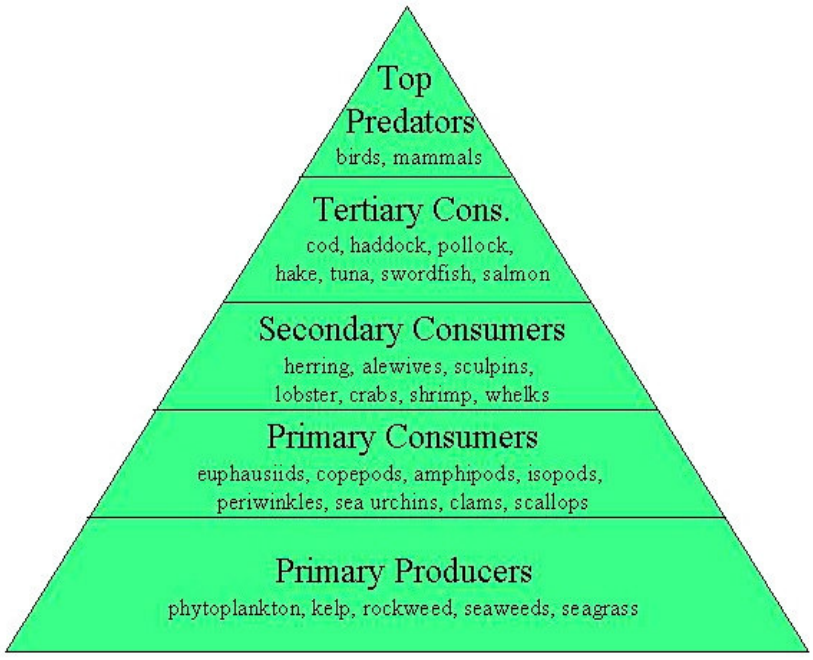

Fig. 1.6. *Illustration of the "trophic triangle" with major food web components in the outer Bay of Fundy. For further explanations refer to text.*

1.2.1. Trophic levels in the open water

Nutrients – limiting plant nutrients are nitrogen (nitrate, ammonium), phosphorus (phosphate), silicium (silicate, for diatoms).

Primary producers – phytoplankton such as diatoms and dinoflagellates.

Primary consumers – herbivorous zooplankton (copepods, euphausiids) and omnivorous zooplankton (e.g. detritivorous shrimp).

Secondary consumers – zooplanktivorous species such as carnivorous zooplankton (fish larvae, jellyfish), small pelagic fish (e.g. herring, mackerel, alewife), juvenile larger fish (pollock), squid, seabirds (phalaropes, terns, gulls), baleen whales, juvenile harbour porpoise.

Tertiary consumers – piscivorous species such as large pelagic fish (tuna, swordfish), benthopelagic fish (cod, dogfish, salmon), seabirds (terns, gulls), mammals (baleen whales, seals, harbour porpoise), squid, humans.

Top predators – these can be consumers of the second, third, fourth or higher level depending on the length of the food chain. In any case, top predators mark the end of a food chain. Common examples are sharks, raptors, whales, and humans

1.2.2. Trophic levels on the seafloor

Nutrients – limiting plant nutrients are nitrogen and phosphorus.

Primary producers – benthic microalgae (diatoms, cyanobacteria), annual macroalgae (*Enteromorpha, Ulva, Porphyra, Ectocarpus*), perennial macrophytes (rockweed, kelp, eelgrass, Irish moss, dulse, coralline algae).

Primary consumers – herbivorous grazer (snails, limpets, amphipods, isopods, sea urchins), detritivores (shrimp, sea cucumber, worms), filter feeders (mussels, clams, scallop, barnacles), waterfowl (brant, goose).

Secondary consumers – carnivorous birds (ducks, gulls), groundfish (cod, haddock, hake, halibut, skates), lobster, sea stars, crabs, shrimps, humans.

Tertiary consumers – large predatory groundfish (cod), birds (gulls), mammals (toothed whales, seals), humans.

Top predators – (see above) sharks, toothed whales, birds, humans.