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TWO HUNDRED YEARS OF ECOSYSTEM CHANGE IN THE OUTER BAY OF FUNDY
PART I – CHANGES IN SPECIES AND THE FOOD WEB

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Abstract

The Quoddy Region and Grand Manan Archipelago form a hotspot of marine species diversity and productivity in the Northwest Atlantic. We present the history of major human impacts and their consequences on the ecosystem over the last centuries. Using all available data, we reconstructed historical changes that occurred in species of all trophic levels, from phytoplankton and invertebrates up to fish, birds and mammals.

Selective fishing and hunting, and increasing effort, efficiency, and spatial extent of exploitation over time resulted in marked declines of target species abundance and size. This resulted in major shifts in dominance patterns and food-web structure, and shifts from high to low trophic level harvesting. Habitat degradation and destruction and chemical contamination reduced the amount of critical spawning, breeding, nursing, and feeding habitat. Multiple pollutants affected health, survival and reproduction of many species, and increasing human activities in coastal waters enhanced the level of stress and disturbance. Nutrient loads altered phytoplankton and phytobenthos communities, thereby favouring less edible or toxic species and mass occurrences of annual seaweeds. We demonstrate that this unique ecosystem over time expressed well-known signs of degradation typical for human-impacted coastal waters worldwide. Multiple human impacts affected species and their interactions on all trophic levels. This reduced productivity of traditional fisheries and predictability of the ecosystem. Compared to other degraded ecosystems, however, there is still potential to sustain a diverse and productive marine flora and fauna which could be restored if wise management actions are chosen.

Introduction

The Quoddy Region and the Grand Manan Archipelago form a hotspot of marine species diversity and productivity in the Northwest Atlantic. Ocean currents and circulation patterns, high tides, upwelling, and short, energy-efficient food chains support high concentrations of primary and secondary producers (Hardie 1979; Thomas 1983; Lotze and Milewski 2002). These lower trophic level species attract a wide range of birds, predatory fish and mammals which depend on the area for at least part of their life. In addition to the rich food supply, the diverse underwater and terrestrial landscapes provide an extraordinary variety of habitats fulfilling the species-specific needs for breeding, spawning, nursing, foraging, hiding and resting (Hardie 1979; Thomas 1983; Lotze and Milewski 2002). This habitat diversity, combined with the rich food supply, maintain the hotspot diversity and productivity.

Human Activities in Coastal Waters

The archeological record shows that Indigenous peoples have recognized and valued these diverse and abundant marine resources for several thousand years. Around Passamaquoddy Bay, prehistoric people focussed especially on marine resources and used a more diverse shellfish fauna than their neighbours in the Maritimes and Maine. Their distinct lifestyle was recognized as the 'Quoddy Tradition' in the Maritime Woodland period (2200-350 B.P.) (Black and Turnbull 1986). In their words, 'Passamaquoddy' denotes a "bay full of pollock" and "fishers of pollock" (Gatschet 1897). As hunters and gatherers, they targeted species from all trophic levels at low rates due to simple fishing and hunting methods and low population size. Therefore, we may describe them as 'low-impact omnivores'. Faunal remains from archaeological sites suggest that large cod, pollock and herring were used as food resources for more than 4,000 years without a visible decrease in body size, usually the first sign of overfishing (Black and Turnbull 1986; Spiess et al. 1990; Steneck 1997).

With European settlement in the late 18th century and subsequent industrialization in the late 19th century, human activities have altered this ecosystem at a rapidly increasing rate. Fishing and hunting pressure as 'top-down' impacts increased, especially on large species that were easy to catch. Whales were hunted from shore operations, seals were hunted for a bounty, and Harbour Porpoises were hunted by native people to trade oil with the Europeans (Ingersoll and Gorham 1978; Gaskin 1983; Percy 1996b). Birds were hunted heavily for food, but egg and down collection also occurred (Christie 1979). Large groundfish, especially cod and pollock were caught in the area, and herring was fished for bait (Perley 1852; Huntsman 1953). Thus, humans became 'top predators' in the food web, and by 1900 they had almost extirpated many birds and mammals.

In the case of fish, the first signs of overexploitation could be observed around 1900, when clear shifts in size distribution were observed. The size of cod and pollock strongly declined and the herring fishery shifted from large adults to medium "stringers" and further to small "sardines" (Perley 1852; Huntsman 1953). In the early 20th century, legal protection for some birds and mammals initiated slow recovery of some top predators. However, humans increased their pressure on fish, especially groundfish and herring through increasing effort, efficiency and spatial extent of fishing grounds (Steneck 1997, Percy 2000). Humans became 'highly efficient top predators'. Finally in the 1970s, a strong decline in abundance of groundfish and herring could be observed (Lotze and Milewski 2002). These strong recent declines or collapses of certain fisheries may be not only the result of actual high fishing pressure, but also of overfishing for decades and even centuries in the past. Jackson et al. (2001) suggested that extended time lags might occur between the onset of overfishing and the visible consequences. In our study area, the decline in formerly dominant groundfish species such as pollock and cod resulted in a shift in dominance patterns. Dogfish, hake and small groundfish such as sculpins increased in abundance over the last 20 years (Lotze and Milewski 2002).

The scarcity of traditionally abundant and valuable species induced the search for new resources and a shift to low-trophic level harvesting. Over the last 10–20 years, new fisheries for crabs, sea urchins and rockweed were developed, while traditional fisheries for periwinkles, scallops and lobster were intensified (Lotze and Milewski 2002). Further plans to develop fisheries for sea cucumbers, krill and mussels exist (Percy 1996a). This increasing exploitation of species at lower and lower levels of the food web has been identified as a global pathology, called "fishing down the food web" (Pauly et al. 1998). Many of these species are important prey or (in the case of rockweed) habitat-building species for upper trophic levels, including those species which were the traditional targets of the fishery. On the other hand, the fishery for large pelagic fish such as tuna, swordfish and sharks is of renewed interest.

Human Impacts in Coastal Waters

Around 2000, humans became 'top omnivores' targeting all trophic levels with increasing intensity. These strong top-down impacts resulted in clear shifts in food-web structure and species interactions. The loss or decline of high trophic level species resulted in shifts in species composition at the same and lower trophic levels because of the release from competition and predation pressure. In extreme cases, successive changes can be observed at several lower trophic levels known as "trophic cascades" (Steneck 1998).

In addition to top-down impacts, humans activities also altered species composition and productivity by 'bottom-up' impacts such as nutrient enrichment and shifts in nutrient ratios (N:P:Si). Nutrient sources include sewage, aquaculture (fish food, fish excrements), municipal runoff (garden and lawn fertilizer), organic discharges (food processing plants, pulp and paper mills), agricultural runoff (fertilizer, animal waste), burning of fossil fuel and atmospheric deposition (Bricker et al. 1999). This over-enrichment of the environment with the limiting plant nutrients nitrogen and phosphorus has severe consequences on the species composition and productivity among primary producers. Compared to the 1930s, we find a clear shift in the phytoplankton community from non-harmful diatom dominance to increasing amounts of less edible or toxic diatoms and dinoflagellates (Gran and Braarud 1935; Martin et al. 1999). In the phytobenthos, altered nutrient conditions result in a decline of long-lived rockweeds and eelgrasses, an increase in the amount of annual algal blooms, and partially a shift to the dominance of filter feeders. These changes are most visible close to nutrient point sources such as sewage outlets or fish farms (Worm 2000; Worm and Lotze 2000). In a recent eutrophication survey of estuaries in the United States, the St. Croix River/Cobscook Bay estuary was listed among the 44 out of 138 estuaries which showed the highest levels of expression of eutrophic conditions, which were expected to worsen towards 2020 (Bricker et al. 1999). Wastewater treatment plants were listed as the most important measure to mitigate nutrient inputs into rivers and the sea (Bricker et al. 1999).

When Europeans settled in the area, their activities led to a successive alteration, degradation and destruction of the coastal environment, which reduced habitat availability, heterogeneity and complexity, as well as sediment and water quality. Damming of rivers, settlement on islands, coastal constructions, dyking and draining of wetlands, bottom trawling and dragging, aquaculture operations, and other activities reduced the overall amount of undisturbed high-quality habitat in rivers, on land, and in the sea (Percy 2000). Organic loads from pulp and paper mills, lumber harvest, fish processing plants and aquaculture operations decrease water quality and clarity and degrade benthic habitat (Wildish et al. 1993; Pohle 1999). Chemicals from municipal and industrial discharges impair health, fecundity and survival (Wells et al. 1997). Moreover, increasing boat traffic, increasing noise, light and smell 'pollution', and increasing human recreational activities such as whale, seal and bird watching increase the level of stress for animals (Percy 1996b). All these impacts can be called 'side-in' impacts, which have severe consequences on the extent and quality of habitat for reproduction and recruitment (breeding, spawning, nursery), feeding and foraging, refuge from predators, and simply living (e.g., settling, growing, staging, resting, wintering) (Rangeley 1994, 2000; Percy 2000). For example, during several periods in the past, the St. Croix and Magaguadavic Rivers were not accessible (dams without functioning fishways) or had lethal water conditions to anadromous fish such as Atlantic salmon and gaspereau (Marshall 1976). Human settlements on shorelines and islands destroyed breeding colonies of many birds (Christie 1979). Dragging and trawling, as well as recent rockweed harvesting, destroys important three-dimensional seafloor habitat (kelps, rockweed, eelgrass, mussel reefs, sponges, corals) for recruitment, nursery and feeding as well as refuge for many fish, bird and invertebrate species, many of which are of commercial interest (Rangeley 1994, 2000; Steneck 1997; DFO 1999; Percy 2000). Many aquaculture operations are located within important feeding, nursing and recruitment habitat for fish, birds, mammals, and lobsters.

In essence, the hotspot of marine diversity and productivity became also a hotspot of human activities. Over time, this unique ecosystem expressed some well-known signs of degradation, which are typical for human-impacted coastal waters worldwide (Vitousek et al. 1997; Pauly et al. 1998; Jackson et al. 2001). Unfortunately, many human activities concentrate within critical habitats that are used by many species at once such as West Isles archipelago, Grand Manan Archipelago, the Wolves and Maces Bay (Lotze and Milewski 2002).

Conclusion

Today, most species are simultaneously affected by multiple top-down, bottom-up and side-in effects that can create synergistic and feed-back effects. The cumulative effects of multiple human stressors on single species and entire food webs are hardly—if at all—predictable on the base of our current knowledge of species and food-web interactions (Worm and Lotze 2000; Lotze and Milewski 2002). This has important implications for any attempt of 'species' or 'ecosystem management'. It might be more appropriate to consider strategies for 'human-impact management'. Any integrated management approach should include not only the diverse human interests but also the critical needs of marine species such as adequate food and habitat and undisturbed space and time (Lotze and Milewski 2002).

Although human impacts widely affect coastal ecosystems, there are some encouraging conservation and restoration successes. In the Quoddy and Grand Manan regions, protection efforts enabled many birds and some mammals to recover (Christie 1979; Lotze and Milewski 2002). Periods of lower fishing pressure during World War II and after the extension of the 200-mile limit in the 1970s have enabled fish stocks to increase in abundance until fishing effort increased again (Lotze and Milewski 2002). Restoration of river habitat and effective fishways enabled gaspereau populations to increase (Lotze and Milewski 2002). The use of acoustic 'pingers' in gill nets reduces the by-catch of Harbour

Porpoise (Trippel et al. 1999). In other marine habitats, effective sewage treatment plants reduced nutrient loads in the Baltic (Savchuk and Wulff 1999). Designation of protection zones resulted in the recovery of benthic habitat and the increase in fish biomass in tropical and temperate marine reserves, with beneficial effects on adjacent fisheries (Roberts and Hawkins 2000; Roberts et al. 2001). Therefore, we strongly recommend reducing the use of destructive and unselective fishing gear, protecting critical habitats, reducing nutrient pollution and chemical contamination, and reducing stress and disturbance on species.

For the full report on this topic refer to: Lotze H.K. and I. Milewski. 2002. Two-hundred Years of Ecosystem and Food Web Changes in the Quoddy Region, Outer Bay of Fundy. Conservation Council of New Brunswick, Fredericton, New Brunswick, 188 pp.

References

Black, D. W. and C. J. Turnbull. 1986. Recent archaeological research in the insular Quoddy region, New Brunswick, Canada. Current Anthropology 27: 400–402.

Bricker, S. B., C. G. Clement, D. E. Pirhalla, S. P. Orlando and D. R. G. Farrow. 1999. *National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries*. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, MD.

Canada. Department of Fisheries and Oceans (DFO). 1999. *The Impact of the Rockweed Harvest on the Habitat of Southwest New Brunswick*. DFO Maritimes Regional Habitat Status Report 99/2E. Maritime Regional Advisory Process, Department of Fisheries and Oceans, Dartmouth, NS.

Christie, D. S. 1979. Changes in maritime bird populations, 1878–1978. Journal of the New Brunswick Museum 1979: 132–146.

Gaskin, D. E. 1983. The marine mammal community. Pages 245–268. In: *Marine and Coastal Systems of the Quoddy Region, New Brunswick*. M. L. H. Thomas (Ed.). Canadian Special Publication of Fisheries and Aquatic Sciences 64. Department of Fisheries and Oceans, Ottawa.

Gatschet, A. S. 1897. All around the Bay of Passamaquoddy – with the interpretation of its Indian names of localities. National Geographic Magazine 8: 16–24.

Gran, H. H. and T. Braarud. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). Journal of the Biological Board of Canada 1: 279–467.

Hardie, D. 1979. West Isles natural area of Canadian significance. Pages 101–107. In: *Evaluation of Recent Data Relative to Potential Oil Spills in the Passamaquoddy Area*. D. J. Scarratt (Ed.). Fisheries and Marine Services Technical Report 901. Fisheries and Marine Services, St. Andrews, NB.

Huntsman, A. G. 1953. Movements and decline of large Quoddy herring. Journal of the Fisheries Research Board of Canada 10: 1–50.

Ingersoll, L. K. and S. W. Gorham. 1978. A history of the mammals of Grand Manan. Grand Manan Historian 20: 31–54.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. A. Tegner and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629–638.

Lotze H. K. and I. Milewski. 2002. *Two Hundred Years of Ecosystem and Food Web Changes in the Quoddy Region, Outer Bay of Fundy*. Conservation Council of New Brunswick, Fredericton, NB. 188 pp.

Marshall, T. L. 1976. *Historical Perspectives of Resource Development Branch Activities in Restoring Anadromous Fishes to the St. Croix River, New Brunswick – Maine*. Internal Report Series MAR/I 76-2. Freshwater and Anadromous Division, Resource Branch, Fisheries and Marine Service, Halifax, NS. 30 pp.

Martin, J. L., M. M. LeGresley, P. M. Strain and P. Clement. 1999. Phytoplankton Monitoring in the Southwestern Bay of Fundy during 1993–96. Canadian Technical Report on Fisheries and Aquatic Sciences 2265. 132 pp.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese and F. Torres Jr. 1998. Fishing down marine food webs. Science 279: 860–863.

Percy, J. A. 1996a. Expanding Fundy's harvest – Targeting untapped treasures. Fundy Issues, Bay of Fundy Ecosystem Partnership fact sheet 10. URL: <http://www.auracom.com/~bofep/underuti.htm>. Date accessed: 3 September 2002.

Percy, J. A. 1996b. Right Whales – Wrong places? North Atlantic Right Whales in the Bay of Fundy. Fundy Issues, Bay of Fundy Ecosystem Partnership fact sheet 6. URL: <http://netshop.net/~bofep/right.htm>. Date accessed: 3 September 2002.

Percy, J. A. 2000. Fishing in Fundy - Harming seafloor habitats? Fundy Issues, Bay of Fundy Ecosystem Partnership fact sheet 14. URL: <http://www.auracom.com/~bofep/Publications/Fundy%20issues/disturbance.htm>. Date accessed: 3 September 2002.

Perley, M. H. 1852. *Reports on the Sea and River Fisheries of New Brunswick*. Queen's Printer Fredericton, NB. 294 pp.

Pohle, G. 1999. Benthos Assessment at Fallow Sites. Final Report to the New Brunswick Department of Fisheries and Aquaculture. Atlantic Reference Centre, Huntsman Marine Science Centre, St. Andrews, NB. 39 pp.

Rangeley, R. W. 1994. The effects of seaweed harvesting on fishes: A critique. Environmental Biology of Fish 39: 319–323.

Rangeley, R. W. 2000. Aquatic macrophytes as foraging and refuging habitats for fish. Pages 18-23. In: *Gulf of Maine Rockweed: Management in the Face of Scientific Uncertainty*. R.W. Rangeley and J. Davies (Eds.). Huntsman Marine Science Centre Occasional Report 00/1. Huntsman Marine Science Centre, St. Andrews, NB.

Roberts, C. M. and J. P. Hawkins. 2000. *Fully-protected Marine Reserves: A Guide*. WWF Endangered Seas Campaign, 1250 24th Street, NW, Washington, DC 20037, USA and Environment Department, University of York, York, Y010 5DD, UK.

Roberts, C. M., J. A. Bohnsack, F. Gell, J. P. Hawkins and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science 294: 920–1923.

Savchuk, O. and F. Wulff. 1999. Modelling regional and large-scale response of Baltic Sea ecosystems to nutrient load reductions. Hydrobiologia 393: 35–43.

Spiess, A. E., E. Trautman and T. Kupferschmid. 1990. Prehistoric Occupation at Reversing Falls. Unpublished file report, Maine Historic Preservation Commission, Augusta, Maine, 28 pp.

Steneck, R. S. 1997. *Fisheries-induced Biological Changes to the Structure and Function of the Gulf of Maine Ecosystem. Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop, Hanover, NH*. Regional Association for the Research on the Gulf of Maine (RARGOM Report 91-1).

Steneck, R.S. 1998. Human influences on coastal ecosystems: does overfishing create trophic cascades? Trends in Ecology and Evolution 13(11): 429–430.

Thomas, M. L. H. 1983. *Marine and Coastal Systems of the Quoddy Region, New Brunswick*. Canadian Special Publication of Fisheries and Aquatic Sciences 64. 306 pp.

Trippel, E. A., M. B. Strong, J. M. Terhune and J. D. Conway. 1999. Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Canadian Journal of Fisheries and Aquatic Sciences 56: 113–123.

Vitousek, P. M., H. A. Mooney, J. Lubchenco and J. M. Melillo. 1997. Human domination of Earth´s ecosystems. Science 277: 494–499.

Wells, P. G., P. D. Keizer, J. L. Martin, P. A. Yeats, K. M. Ellis and D. W. Johnston. 1997. The chemical environment of the Bay of Fundy. Pages 37–61. In: *Bay of Fundy Issues: A Scientific Overview. Proceedings of a workshop, January 29–February 1, 1996, Wolfville, NS*. J. A. Percy, P. G. Wells and A. J. Evans (Eds.). Environment Canada Atlantic Region Occasional Report No. 8. Environment Canada, Atlantic Region, Environmental Conservation Branch, Sackville, NB.

Wildish, D. J., P. D. Keizer, A. J. Wilson and J. L. Martin. 1993. Seasonal changes of dissolved oxygen and plant nutrients in seawater near salmonid net pens in the macrotidal Bay of Fundy. Canadian Journal of Fisheries and Aquatic Sciences 50: 303–311.

Worm, B. 2000. *Consumer Versus Resource Control in Rocky Shore Food Webs: Baltic Sea and NW Atlantic Ocean*. Berichte aus dem Institut für Meereskunde 316. Institut für Meereskunde, Universität Kiel, Kiel. 147 pp.

Worm, B. and H. K. Lotze. 2000. Nutrient pollution, low-trophic level harvesting and cumulative human impact on coastal ecosystems. Pages 40–41. In: *Gulf of Maine Rockweed: Management in the Face of Scientific Uncertainty*. R.W. Rangeley and J. Davies (Eds.). Huntsman Marine Science Centre Occasional Report 00/1. Huntsman Marine Science Centre, St. Andrews, NB.