CHAPTER ELEVEN: GLOBAL EFFECTS AND OTHER IMPACTS

Climate Change

Introduction

The earth's climate has changed throughout geological history because of a number of natural factors that affect the radiation balance of the planet, such as changes in earth's orbit, the output of the sun, and volcanic activity (IPCC 2007a). These natural changes in the earth's climate have resulted in past ice ages and periods of warming that take place over several thousand years. An example of changes to earth's climate over recent geological timeframes caused by natural factors has been observed in slowly rising global temperatures and sea levels since the end of the Pleistocene epoch (about 10,000 years before present). However, the rate of warming observed over the past 50 years is unprecedented in at least the previous 1,300 years (IPCC 2007a). The Intergovernmental Panel on Climate Change (IPCC) concludes that recent human-induced increases in atmospheric concentrations of greenhouse gases are expected to cause much more rapid changes in the earth's climate than have previously been experienced (IPCC 2007a). The buildup of greenhouse gases (primarily carbon dioxide) is a result of burning fossil fuels and forests and from certain agricultural activities. Other greenhouse gases released by human activities include nitrous oxide, methane, and chlorofluorocarbons. The global atmospheric concentration of carbon dioxide has increased from about 280 ppm during preindustrial times to 379 ppm in 2005, which far exceeds the natural range over the last 650,000 years (180-300 ppm) as determined from ice cores (IPCC 2007a).

In the Fourth Assessment Report of the IPCC, the Contribution of Working Group I issued the following conclusions (IPCC 2007a):

> Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.

In order to consider various possible futures for climate change effects, the IPCC developed a series of models, or scenarios, based upon different levels of greenhouse gas emissions. The higher-emissions scenario represented fossil fuel-intensive economic growth and global human population that peaks around 2050 and then declines. This model assumes atmospheric carbon dioxide concentrations to reach about 940 ppm by 2100, or about three times preindustrial levels (Frumhoff et al. 2007). The lower-emissions scenario also represents a global human population that peaks around 2050 but assumes a much faster shift to less fossil fuel-intensive industries and more resource-efficient technologies. This model assumes carbon dioxide concentrations to peak around 2050 and then to decline to about 550 ppm by 2100, which is about double preindustrial levels (Frumhoff et al. 2007).

Based on current global climate models for greenhouse gas emission scenarios, some of the 2007 IPCC report conclusions were:

1. By 2100 average global surface air temperatures will increase by 1.8°C (lower-emissions scenario) to 4.0°C (higher-emissions scenario) above 2000 levels. The most drastic warming will occur in northern latitudes in the winter.
2. Sea level rose 12-22 cm in the 20th century and may rise another 18-38 cm (lower-emissions scenario) and as high as 26-59 cm (higher-emissions scenario) by 2099. However, these projections were based upon contributions from increased ice flow from Greenland and Antarctica at rates observed for the 1993-2003 period. If this contribution were to grow linearly with global average temperature change, the upper ranges for sea level rise would increase by an additional 10-20 cm.
3. Global precipitation is likely to increase, with more precipitation and more intense storms in the mid to high latitudes in the northern hemisphere.
4. Increasing atmospheric carbon dioxide concentrations may acidify the oceans, reducing pH levels by 0.14 and 0.35 units by 2100, adding to the present decrease of 0.1 units since preindustrial times.

The average annual atmospheric temperature across the northeastern United States has risen by approximately 0.8ºC since 1900, although this warming trend has increased to approximately 0.3ºC per decade since 1970 (Frumhoff et al. 2007). Most climate models indicate the region will experience continued increased warming over the next century (Frumhoff et al. 2007; IPCC 2007a). Climate change models predict increased warming under the lower-emissions scenario to be 2.2-4.2°C and 3.8-7.2°C under the higher-emissions scenario by 2100 in New England and eastern Canada (Frumhoff et al. 2007). Over the next several decades, the greatest temperature changes are expected to be in the wintertime and early spring with warm periods expected to increase in frequency and duration (Nedeau 2004). For example, the average winter temperature in over the next few decades are expected to increase 1.4-2.2°C under both emission scenarios, while average summer temperature increases are expected to be 0.8-1.9°C (Frumhoff et al. 2007). However, by the end of the century, the average winter temperature is expected to increase 4.4-6.7°C under the higher-emissions scenario, while summer temperature is expected to increase 3.3-7.8°C (Frumhoff et al. 2007). Long-term increases in average temperatures, the frequency and intensity of extreme temperature and climatic events, and the timing of seasonal temperature changes can have adverse effects on ecosystem function and health. Combined with extreme precipation and drought and rising sea levels, these effects have the potential to result in considerable adverse changes to the northeast region's ecosystems.

Primary impacts of global climate change that may threaten riverine, estuarine, and marine fishery resources include:

1. Increasing rates of sea-level rise and intensity and frequency of coastal storms and hurricanes will increase threats to shorelines, wetlands, and coastal ecosystems;
2. Marine and estuarine productivity will change in response to reductions in ocean pH and alterations in the timing and amount of freshwater, nutrients, and sediment delivery;
3. High water temperatures and changes in freshwater delivery will alter estuarine stratification, residence time, and eutrophication and;
4. Increased ocean temperatures are expected to cause poleward shifts in the ranges of many marine organisms, including commercial species, and these shifts may have secondary effects on their predators and prey.

These affects may be intensified by other ecosystem stresses (pollution, harvesting, habitat destruction, invasive species), leading to more significant environmental consequences. It should be noted that while the general consensus among climate scientists today indicates a current and future warming of the earth's climate caused by emissions of greenhouse gases from anthropogenic sources, the anticipated effects at regional and local levels are less understood. Consequently, there are degrees of uncertainty regarding the specific effects to marine organisms and communities and their habitats from climate change. For example, although most climate models predict an increase in extreme rainfall events in the northeast region of the United States, the regional projections for average annual precipitation and runoff vary considerably (Scavia et al. 2002).

This section attempts to address some of the possible effects of global climate change to fishery resources in the northeast region of the United States. The effects discussed in this report reflect the general topics identified by participants of the Technical Workshop on Impacts to Coastal Fishery Habitat from Nonfishing Activities. However, other possible effects and consequences of climate change have been suggested, some of which may be inconsistent with those described in this report. A complete and thorough discussion of this rapidly-developing area of science is beyond the scope of this report. For a more thorough assessment of impacts caused by climate change, we recommend the reader refer to the publications cited in this chapter, as well as new research that will emerge subsequent to this report.

Alteration of hydrological regimes

The hydrologic cycle controls the strength, timing, and volume of freshwater input, as well as the chemical and sediment load to estuaries and coastal waters (Scavia et al. 2002). Precipitation across the continental United States has increased by about 10% in the past 100 years or so, primarily reflected in the heavy and extreme daily precipitation events (Karl and Knight 1998; USGS 2005). This trend is also evident in the northeastern US region, which has experienced an increase in annual average precipitation by about 5-10% since 1900 (Frumhoff et al. 2007). In addition, increased early spring streamflows have occurred over the past century in New England, possibly a result of earlier melting of winter snowpack caused by increased air temperatures and/or greater rainfall (Hodgkins and Dudley 2005).

The IPCC Working Group II Report on Climate Change Impacts, Adaptation, and Vulnerability (IPCC 2007b) concluded that by mid-century average annual river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics. For the northeastern United States, climate change models indicate an increase in precipitation over the next 100 years (Frumhoff et al. 2007; IPCC 2007b). By the end of the century, the average annual precipitation is expected to increase by about 10%; however, the average winter precipitation is expected to increase 20-30%, and a much greater proportion of the precipitation would be expected to fall as rain rather than snow (Frumhoff et al. 2007; IPCC 2007b). Climate models also predict more frequent, heavy-precipitation events, which are expected to increase the probability of high-flow events in Maine, New Hampshire, and Vermont streams and rivers by about 80% during late winter and spring (Frumhoff et al. 2007). These changes in the intensity and frequency of high-flow events have the potential to increase the export of nutrients, contaminants, and sediments to our estuaries. Climate-related changes in the northeast region may alter the timing and amount of water availability. For example, increased temperatures during summer months can increase evapotranspiration rates. Combined with reduced summer rainfall, these changes can cause reductions in soil moisture and streamflows that may lead to seasonal drought (Frumhoff et al. 2007).

Accelerated sea-level rise resulting from climate change threatens coastal wetlands through inundation, erosion, and saltwater intrusion (Kennedy et al. 2002; Scavia et al. 2002). The quantity of freshwater discharges affects salt marshes because river flow and runoff deliver sediments that are critical for marshes to maintain or increase its elevation. An increase in freshwater discharge could increase supply of sediment and allow coastal wetlands to cope with sea-level rise (Scavia et al. 2002). However, some coastal areas may experience a decrease in precipitation and freshwater runoff, causing salt marsh wetlands to become sediment-starved and ultimately lost as sea levels rise and marshes are drowned (Kennedy et al. 2002). Greater periods of drought leading to a decrease in freshwater discharge might also cause salinity stress in salt marshes. Rising sea levels will also allow storm surges to move further inland and expose freshwater wetlands to high salinity waters.

Estuaries may be affected by changes in precipation and freshwater discharge from rivers and runoff from land. Precipitation patterns and changes in freshwater inflow can influence water residence time, salinity, nutrient delivery, dilution, vertical stratification, and phytoplankton growth and abundance (Scavia et al. 2002). Patterns of more frequent heavy-precipitation events during winter and spring months and increased temperature and reduced rainfall during summer months may exacerbate existing nutrient over-enrichment and eutrophication conditions that already stress estuarine systems (Scavia et al. 2002; Frumhoff et al. 2007).

A decline in the atmospheric pressure at the sea surface in the central Arctic during the late 1980s led to increased delivery of warmer, higher-salinity Atlantic water into the Arctic Ocean, mainly via the Barents Sea (Greene and Pershing 2007). In addition, there has been an increase in continental melting of permafrost, snow, and ice which, combined with increased precipitation, has resulted in greater river discharge into the Arctic Ocean over the past three decades. This is believed to have led to accelerated sea ice melting and reductions in Arctic sea ice. Although the relative importance of human versus natural climate forces in driving the observed changes in atmospheric and ocean circulation patterns continues to be debated, it has led to an enhanced outflow of low-salinity waters from the Arctic and general freshening of shelf waters from the Labrador Sea to the Mid-Atlantic Bight beginning in the early 1990s (Greene and Pershing 2007). Increased freshwater input in the upper layers of the ocean results in increased stratification, which suppresses upwelling of nutrients into the upper regions of the ocean and generally reduces the productivity of phytoplankton (Kennedy et al. 2002). Conversely, increased freshwater flux and stratification could also lead to enhanced biological productivity in some systems by enabling organisms to remain longer in the photic zone (Scavia et al. 2002). Greene and Pershing (2007) reported enhanced ocean stratification caused by increased freshwater outflow from the Arctic during the 1990s. They attributed increased phytoplankton and zooplankton production and abundance during the autumn, a period when primary production would otherwise be expected to decline, with enhanced freshening of the Northwest Atlantic shelf (Greene and Pershing 2007). Although some climate models predict a net decrease in global phytoplankton productivity under doubled atmospheric carbon dioxide conditions caused by increased thermal stratification and reduced nutrient upwelling, simple extrapolation to particular northeast marine waters is difficult (Kennedy et al. 2002). The climatic variability associated with natural, large-scale phenomena such as the El Nino-Southern Oscillation and the North Atlantic Oscillation/Northen Hemisphere Annular Mode effects water column mixing and stratification on regional and global scales and has implications on the productivity of the oceans. These natural phenomena may act in tandem with, or in opposition to, anthropogenic climate change (Kennedy et al. 2002).

A number of computer climate models indicate a slowing of the "overturning" process of ocean waters, known as the thermohaline circulation (THC). This phenomenon appears to be driven by a reduction in the amount of cold and salty, and hence, more dense water sinking into the depths of the ocean. In fact, surface waters of the North Atlantic Ocean have been warming in recent decades and parts of the North Atlantic Ocean are also becoming less salty (Nedeau 2004).

In the North Atlantic, a weakening of the THC is related to wintertime warming and increased freshwater flow into the Arctic Ocean and the North Atlantic Ocean (Nedeau 2004). An increased weakening of the THC could lead to a complete shut down or southward shift of the warm Gulf Stream, as was experienced during the last glacial period (Nedeau 2004). However, the response of the THC to global climate change remains uncertain, and predictions are dependent upon future greenhouse gas emissions and temperature increases (Kennedy et al. 2002). On a regional level, changes in ocean current circulation patterns may alter temperature regimes, vertical mixing, salinity, dissolved oxygen, nutrient cycles, and larval dispersal of marine organisms in the northeast coastal region, ultimately leading to a net reduction in oceanic productivity (Nedeau 2004).

Alteration of temperature regimes

Sea surface temperatures of the northeastern US coast have increased more than 0.6°C in the past 100 years, and are projected to increase by another 3.8-4.4°C under the high-emissions scenario and by 2.2-2.8°C under the lower-emissions scenario over the next 100 years (Frumhoff et al. 2007). The IPCC Working Group II Report (IPCC 2007b) concluded there is "high confidence" that observed changes in marine and freshwater biological systems are associated with rising water temperatures, including: (1) shifts in ranges and changes in algal, plankton, and fish abundance in high-latitude oceans; (2) increased algal and zooplankton abundance in high-latitude and high-altitude lakes; and (3) range changes and earlier migrations of fish in rivers.

Temperature affects nearly every aspect of marine environments, from cellular processes to ecosystem function. The distribution, abundance, metabolism, survival, growth, reproduction, productivity, and diversity of marine organisms will all be affected by temperature changes (Kennedy et al. 2002; Nedeau 2004). Most marine organisms are able tolerate a specific temperature range and will become physiologically stressed or die after exposure to temperatures above or below the normal range. At sublethal levels, temperature extremes can effect the growth and metabolism of organisms, as well as behavior and distribution patterns. Reproduction timing and the rates of egg and larval development are dependent upon water temperatures. The reproductive success of some cold water fish species may be reduced if water temperatures rise above the optimum for larval growth (Mountain 2002). For example, cold-adapted species, such as winter flounder (*Pseudopleuronectes americanus*), Atlantic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*), and ocean quahog (*Artica islandica*) may not be able to compete with warm-adapted species if coastal water temperatures increase, particularly for those populations that may be living near the southern distribution limit (Kennedy et al. 2002).

The predicted increase in water temperatures resulting from climate change, combined with other factors such as increased precipitation and runoff, may alter seasonal stratification in the northeast coastal waters. Stratification could affect primary and secondary productivity by altering the composition of phytoplankton and zooplankton, thus affecting the growth and survival of fish larvae (Mountain 2002). In the northeast Atlantic, studies have found shifts in the timing and abundance of plankton populations with increasing ocean temperatures (Edwards and Richardson 2004; Richardson and Schoeman 2004). Edwards and Richardson (2004) found long term trends in the timing of seasonal peaks in plankton populations with increasing sea surface temperatures. However, the magnitude of the shifts in seasonal peaks were not equal among all trophic groups, suggesting alterations in the synchrony of timing between primary, secondary, and tertiary production. Richardson and Schoeman (2004) reported effects of increasing sea surface temperatures on phytoplankton abundances in the North Sea. Phytoplankton production tended to increase as cooler ocean areas warmed, probably because higher water temperatures boost phytoplankton metabolic rates. However, in warmer ocean areas phytoplankton became less abundant as sea surface temperatures increased further, possibly because warm water blocks nutrient-rich deep water from rising to the upper strata where phytoplankton exist (Richardson and Schoeman 2004). These effects have been implicated as a factor in the decline in North Sea cod stocks (Edwards and Richardson 2004; Richardson and Schoeman 2004). Impacts to the base of the food chain would not only affect fisheries but will impact entire ecosystems.

Mountain (2002) predicted a northward shift in the distributional patterns of many species of fish because of increasing water temperatures in the Mid-Atlantic region as a result of climate change. Nearly thirty years of standardized catch data on the northeast continental shelf revealed significant surface and bottom water temperature anomalies that resulted in changes to the distribution of 26 out of 30 fish species examined (Mountain and Murawski 1992). Increased water temperatures were correlated with fish moving northward or shallower to cooler water (Mountain and Murawski 1992). Perry et al. (2005) investigated the distributional patterns of demersal fish species in the North Sea and found two-thirds of all species examined shifted in latitude or depth or both in response to increasing water temperatures. This study reported that most of the species with shifting distributions had moved north or to greater depths in areas of cooler waters. Temperature induced shifts in the distribution of fish have implications for stock recruitment success and abundance. Based on the projected sea surface temperature increases under the higher-emission scenarios, Frumhoff et al. (2007) predicted bottom temperatures by the year 2100 on Georges Bank would approach the 30ºC threshold of thermally-suitable habitat and practical limit of Atlantic cod distribution. The 26ºC threshold for the growth and survival of young cod would be exceeded by the end of the century under both emission scenarios on Georges Bank (Frumhoff et al. 2007).

The frequency of diseases and pathogens may increase with warming ocean temperatures caused by climate change. For example, Dermo, a disease that affects commercially valuable oysters, exhibits higher infection rates with increased temperature and salinity. Warm, dry periods (e.g., summer drought) may make oysters more susceptible to this disease. Extremely warm waters in New England and the mid-Atlantic regions are suspected as playing a role causing disease and mortality events in American lobsters (*Homarus americanus*), including lobster-shell disease, parasitic paramoebiasis, and calcinosis (Frumhoff et al. 2007). The eelgrass wasting disease pathogen (*Labyrinthula zosterae*) has reduced eelgrass beds throughout the east coast in the past and may become more problematic because of its preference for higher salinity waters and warmer water (both of which are expected in some estuaries because of sea-level rise) (Nedeau 2004).

Changes in dissolved oxygen concentrations

Dissolved oxygen concentrations are influenced by the temperature of the water. Because warmer water holds less oxygen than does colder water, increased water temperatures will reduce the dissolved oxygen in bodies of water that are not well mixed. This may exacerbate nutrient-enrichment and eutrophication conditions that already exist in many estuaries and marine waters in the northeastern United States. Increased precipitation and freshwater runoff into estuaries would effect water residence time, temperature and salinity, and increase vertical stratification of the water column, which inhibits the diffusion of oxygen into deeper water leading to reduced (hypoxic) or depleted (anoxic) dissolved oxygen concentrations in estuaries with excess nutrients (Kennedy et al. 2002; Scavia et al. 2002; Nedeau 2004). Increased vertical stratification of the water column occurs with increasing freshwater inflow and decreasing salinities, resulting from greater precipitation and storm water input. In addition, increased water temperatures in the upper strata of the water column also increase water column stratification.

Some species may be adversely affected by increasing surface water temperatures caused by climate change as they seek cooler and deeper waters. Deeper areas may be susceptible to hypoxic conditions near the bottom in stratified, poorly mixed estuarine and marine environments and would be unfavorable to many species. The habitats of aquatic species may be "squeezed" by warming surface waters and hypoxic bottom waters, resulting in greater physiologic stress and metabolic costs or death if the stress does not abate (Kennedy et al. 2002). However, an increase in coastal storm frequency and intensity, as predicted with some climate models, may contribute to some increase in vertical mixing of shallow habitats and reduce the effects of stratification.

Some phytoplankton populations may respond positively to increases in water temperatures and available carbon dioxide, which most climate models project are likely as a result of global warming (IPCC 2007a). Increased precipitation and runoff can increase the nutrient loads entering estuaries and marine waters that further exacerbate the proliferation of algae in nearshore waters. As algae die and begin to sink to the bottom, the decomposition of this increased organic material will consume more oxygen in the water, increasing the occurrence of hypoxic and anoxic conditions in coastal waters (Nedeau 2004).

Nutrient loading and eutrophication

Nitrate driven eutrophication is one of the greatest threats to the integrity of many estuaries in the northeast region (NRC 2000; Cloern 2001; Howarth et al. 2002). Increases in the amount of precipitation are very likely in northern latitudes (IPCC 2007a), and excess nutrients exported from watersheds and delivered to estuarine and marine waters may increase if freshwater flow from rivers and stormwater discharges are greater. Higher nutrient loads may increase the incidence of eutrophication and harmful algal blooms, which can cause hypoxia or anoxia in nearshore coastal waters. These effects on water quality can also negatively impact benthic communities and submerged aquatic vegetation (SAV). The environmental effects of excess nutrients or sediments are the most common and significant causes of SAV decline worldwide (Orth et al. 2006).

Release of contaminants

Increased precipitation and freshwater runoff may increase because of climate change and may lead to increased contaminant loading in coastal waters. Contaminants, such as hydrocarbons, metals, organic and inorganic chemicals, sewage, and wastewater materials, can be flushed from the watershed and exported to coastal waters, especially if the frequency and intensity of storms and floods are affected (Kennedy et al. 2002). These contaminants may be stored in coastal sediments or taken up directly by biota (e.g., bacteria, plankton, shellfish, or fish) and could ultimately affect fisheries and human health. Sea-level rise would inundate lowland sites near the coast, many of which contain hazardous substances that could leach contaminants into nearshore habitats (Bigford 1991).

Loss of wetlands and other fishery habitat

Global warming is expected to accelerate the rate of sea-level rise by expanding ocean water and melting alpine glaciers over the next century (Schneider 1998; IPCC 2007a). Average global sea levels rose 12-22 cm between 1900 and 2000 and are expected to rise another 18-38 cm (lower-emissions scenario) and as high as 26-59 cm (higher-emissions scenario) by 2100 (IPCC 2007a). In the US Atlantic coast, relative sea levels over the last century have risen approximately 18 cm in Maine and as much as 44 cm in Virginia (Zervas 2001). Sea-level rise may affect diurnal tide ranges, causing coastal erosion, increasing salinity in estuaries, and changing the water content of shoreline soils. Accelerated sea-level rise threatens coastal habitats with inundation, erosion, and saltwater intrusion (Scavia et al. 2002; Frumhoff et al. 2007). Sea-level rise may indundate salt marshes and coastal wetlands, at which point shorelines will either need to build upward (accrete) to keep pace with rising sea levels or migrate inland to keep pace with drowning/erosion on the seaward edge. In cases where the upland edge is blocked by steep topography (e.g., bluffs) or human development (e.g., shoreline protection structures) coastal wetlands including salt marsh will be lost (Scavia et al. 2002; Frumhoff et al. 2007; IPCC 2007b). Conservative estimates of losses to saline and freshwater wetlands from sea-level rise range from 47-82% of the nation's coastal wetlands, or approximately 2.3-5.7 million acres (Bigford 1991). Shoreline protection structures can also prevent the shoreward migration of SAV necessitated by sea-level rise (Orth et al. 2006).

Worldwide distribution, productivity, and function of SAV may be effected by climate change. Perhaps most critical to SAV are impacts from increases in seawater temperature resulting from the greenhouse gas effect; secondary impacts of changing water depths and tidal range caused by sea-level rise, altered current circulation patterns and current velocities; changes in salinity regimes; and potential impacts on plant photosynthesis and productivity resulting from increased ultraviolet-B radiation and carbon dioxide concentrations (Short and Neckles 1999).

The distribution and productivity of coastal wetlands may be effected by rising sea levels, altered precipitation patterns, changes in the timing and delivery of freshwater and sediment, and increases in atmospheric carbon dioxide and temperature (Scavia et al. 2002). Increased atmospheric carbon dioxide could increase plant production for some coastal wetland species, assuming other factors such as nutrients and precipitation are not limiting. However, rising sea levels may inhibit the growth of some brackish and freshwater marshes and swamps.

Shoreline erosion

Millions of cubic yards of sand are placed on northeast coastal beaches each year by state and federal governments to combat shoreline erosion. In addition, a variety of hard structures such as seawalls, revetments, groins, and jetties have been installed to protect eroding shorelines. Yet some areas of the northeast, such as Cape Cod, MA, Long Island, NY/CT, and coastal New Jersey, continue to experience a net loss of shoreline and have been identified by the US Geological Survey as being particularly at risk from sea-level rise (Frumhoff et al. 2007). It is uncertain how these engineering measures might affect the ability of natural processes to respond to future sea-level rise (Gutierrez et al. 2007). There exists a high degree of uncertainty in predicting long-term shoreline changes because of the uncertainty of the rate of future sea-level rise and the complex interactions of regional sediment budgets, coastal geomorphology, and anthropogenic influences, such as beach nourishment and seawall construction. However, Gutierrez et al. (2007) reported an increased likelihood for erosion and shoreline retreat for all types of mid-Atlantic coastal shorelines, including an increased likelihood for overwash and inlet breaching and the possibility of segmentation or disintegration of some barrier islands.

An increase in freshwater discharge, storm frequency and intensity, and sea-level rise can lead to increased erosion rates along coastal shorelines (Scavia et al. 2002). The loss of riparian and salt marsh vegetation because of climate change effects could serve as a feedback loop that reduces the ability of wetlands to withstand further increases in sea level and storm effects, which may exacerbate the effects of coastal erosion.

Alteration of salinity regimes

Vertical mixing in coastal waters is influenced by several factors, including water temperatures and freshwater input, so warmer temperatures may affect the thermal stratification of estuaries (Nedeau 2004). Climate models project increased average temperatures and precipitation, particularly during the winter, in the northeastern US region (Frumhoff et al. 2007). Hotter and drier summers and warmer, wetter winters will alter the timing and volume of freshwater runoff and river flows. If freshwater flow from rivers is reduced or increased, salinities in rivers and estuaries will be altered which will have profound affects on the distribution and life history requirements of coastal fisheries. For example, increased freshwater input into estuaries would lower salinities in salt marsh habitat which could enhance conditions for invasive exotic plants that prefer low-salinity conditions, such as *Phragmites* or purple loosestrife (*Lythrum salicaria*). Increased freshwater runoff will increase vertical stratification of estuaries and coastal waters, which could have indirect effects on estuarine and coastal ecosystems (Kennedy et al. 2002). For example, upwelling of deep, nutrient-rich seawater could be reduced, leading to reductions in primary productivity in coastal waters. Rising sea levels could cause estuarine wetlands to be inundated with higher salinity seawater, altering the ecological balance of highly productive fishery habitat.

Alteration of weather patterns

Numerous long-term changes in climate have already been observed at continental, regional, and ocean basin scales, including changes in Arctic temperatures, ice, ocean salinity, wind patterns; and increased occurrences of extreme weather events including droughts, heavy precipitation, heat waves, and intensity of tropical cyclones (IPCC 2007a).

There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since the 1970s, correlated with increased tropical sea-surface temperatures (IPCC 2007a). Increases in the amount of precipitation are very likely in high latitudes, and extra-tropical storms are projected to move poleward (Frumhoff et al. 2007; IPCC 2007a). Although there continues to be debate over the link between global warming and increased hurricane frequency, observed ocean warming is a key condition for the formation and strengthening of hurricanes (Frumhoff et al. 2007). The integrity of shorelines and wetlands would be threatened by increased intensity and frequency of coastal storms and hurricanes resulting from climate change. The loss of coastal wetland vegetation and increased erosion of shorelines and riparian habitats caused by storms would have an adverse effect on the integrity of aquatic habitats. Reductions in dissolved oxygen concentrations and salinity are phenomena associated with coastal storms and hurricanes, and most aquatic systems require weeks or months to recover following severe storms (Van Dolah and Anderson 1991). Increased frequency and intensity of storms could lead to chronic disturbances and have adverse consequences on the health and ecology of coastal rivers and estuaries.

Changes in water alkalinity

Increasing atmospheric carbon dioxide concentrations can alter seawater carbonate chemistry by lowering seawater pH, carbonate ion concentration, and carbonate saturation state and by increasing dissolved carbon dioxide concentration (Riebesell 2004). According to the IPCC Working Group I Fouth Asssessment, increasing atmospheric carbon dioxide concentrations may acidify the oceans, reducing pH levels by 0.14 and 0.35 units by 2100 (IPCC 2007a). The uptake of anthropogenic carbon since 1750 has led to an average decrease in pH of 0.1 units; however, the effects of observed ocean acidification on marine ecosystems are unclear at this time (IPCC 2007b).

Increased acidity in oceans is expected to effect calcium carbonate availability in seawater, which would lower the calcification rates in marine organisms (e.g., mollusks and crustaceans, some plankton, hard corals) (IPCC 2007b). Alteration of water alkalinity could have severe impacts on primary and secondary production, which have implications at the ecosystem level (Orr et al. 2005). Increasing atmospheric carbon dioxide concentrations and altered seawater carbonate chemistry could have a range of effects, including physiological changes to marine plankton on the organismal level, changes in ecosystem structure and regulation, and large scale shifts in biogeochemical cycling (Riebesell 2004). For example, increased carbon dioxide concentrations are predicted to decrease the carbonate saturation state and cause a reduction in biogenic calcification of corals and some plankton, including coccolithophorids and foraminifera; however, increasing carbon dioxide concentrations could increase the rates of photosynthetic carbon fixation of some calcifying phytoplankton (Riebesell 2004).

Changes in community and ecosystem structure

The geographic distributions of species may expand, contract, or otherwise adjust to changing oceanic temperatures, creating new combinations of species that could interact in unpredictable ways. Fish communities are likely to change. For example, warming oceans may cause the southern range of northern species, such as Atlantic cod, American plaice (*Hippoglossoides platessoides*), haddock (*Melanogrammus aeglefinus*), and Atlantic halibut (*Hippoglossus hippoglossus*), to shift north as will the northern range limit of southern species, such as butterfish (*Peprilus triacanthus*) and menhaden (*Brevoortia tyrannus*) (Nedeau 2004; Frumhoff et al. 2007). Mountain and Murawski (1992) reported changes in the distribution of selected fish stocks in the northeast continental shelf that were attributed to changes in surface and bottom water temperatures. Distributional changes attributed to increased water temperatures were observed in 26 out of the 30 species examined and resulted in fish moving northward or shallower towards cooler water (Mountain and Murawski 1992). Temperature induced shifts in the distribution of fish have implications for stock recruitment success and abundance. Short-lived fish species may show the most rapid demographic responses to temperature changes, resulting in stronger distributional responses to warming (Perry et al. 2005). Range shifts could create new competitive interactions between species that had not evolved in sympatry, causing further losses of competitively inferior or poorly adapted species.

Because of changes in the atmospheric and oceanic circulation patterns in the Arctic Ocean, the Northwest Atlantic shelf waters became fresher during the 1990s relative to the 1980s (Greene and Pershing 2007). This freshening was believed to have enhanced stratification of shelf waters and led to greater phytoplankton and zooplankton production and abundance during the autumn, a period when primary production would otherwise be expected to decline (Greene and Pershing 2007). Although it is uncertain as to whether the increased abundances of plankton during the 1990s were solely attributed to enhanced stratification caused by greater inflow of freshwater (bottom-up control), overfishing of large predators, such as Atlantic cod (top-down control) or some combined effect, it is clear that changes in climate and oceanic circulation patterns can have profound effects on ecosystem functions and productivity (Greene and Pershing 2007). Mountain (2002) proposed several possible effects to fish stocks in the mid-Atlantic region in response to increased water temperatures, increased seasonal stratification of the water column, and changes in regional ocean circulation patterns. Direct effects included northward shift in stock distributions and reduced reproductive success for some cold water species because of increased water temperatures; indirect effects included changes in phytoplankton productivity and species composition that can impact the lower trophic levels affecting recruitment success of fish stocks (Mountain 2002).

Migratory and anadromous fish such as salmon and shad may be affected by climate change because they depend on the timing of seasonal temperature-related events as cues for migration. Ideal river and ocean temperatures may be out of synch as climate changes, making the saltwater-to-freshwater transition difficult for spawning adults or the freshwater-to-saltwater transition difficult for ocean-bound juveniles. Migration routes, timing of migration, and ocean growth and survival of fish may also be affected by altered sea-surface temperatures (Nedeau 2004).

Invasive species may flourish in a changing climate when shifting environmental conditions give certain species a foothold in a community and a competitive advantage over native species. Species inhabiting northern latitude islands may be particularly vulnerable as nonnative organisms adapted to warmer climates take advantage of changing climatic conditions (Scavia et al. 2002; IPCC 2007b).

Increases in the severity and frequency of coastal storms may result in cumulative losses of coastal marshes by eroding the seaward edge, causing flooding further inland, changing salinity regimes and marsh hydrology, and causing vegetation patterns to change. Healthy salt marshes can buffer upland areas (including human structures) from storm damage, and this ecosystem function will be impaired if marshes are destroyed or degraded. Increased sea-surface temperatures, sea-level rise, and intensity of storms and associated surge and swells, combined with more localized effects such as nutrients and increased loading of sediments, have had demonstrable impacts on SAV beds worldwide (Orth et al. 2006). The loss or degradation of freshwater, brackish, and salt marsh wetlands, SAV and shellfish beds, and other coastal habitats will affect critical habitat for many species of wildlife, which may ultimately affect biodiversity, coastal ecosystem productivity, fisheries, and water quality.

Changes in ocean/coastal uses

Commercial fisheries could be impacted by the cumulative effects of climate change, including rising sea levels and water temperatures and habitat degradation in estuaries, rivers, and coastal wetlands. Approximately 32% of species important to fisheries in New England are dependent upon estuaries during some portion of their life histories (Nedeau 2004). Climate change could also affect human health and the use of ocean resources if the frequency and intensity of harmful algal blooms, fish and shellfish diseases, coastal storms, and impacts to coastal wetlands increase. These effects, combined with sea-level rise, may result in a loss or inability to utilize coastal resources. Climate-induced changes to marine ecosystems will require consideration of longer time-scale effects in fisheries and coastal management strategies.

The IPCC Working Group II Report (IPCC 2007b) concluded there is “high confidence” that climate change will cause regional changes in the distribution and production of particular fish species, with adverse effects projected for aquaculture and fisheries. Conservative predictions of impacts to fisheries resources from sea-level rise and habitat loss from climate change would likely dwarf those impacts now attributed to direct human activities, like water quality degradation, coastal development, and dredging (Bigford 1991). It is possible that nonclimate stresses will increase the vulnerability to climate change impacts by reducing resilience and adaptive capacity (IPCC 2007b). However, it is likely that sustainable development, along with implementing strategies of climate change mitigation and adaptation, technological development (to enhance adaptation and mitigation), and research (on climate science, impacts, adaptation, and mitigation) can minimize some of the risks associated with climate change (IPCC 2007b).

The development of strategic mitigation and adaptation measures to address global climate change are beyond the scope of this report. However, conservation measures and best management practices that are consistent with sound coastal management and sustainable development may help mitigate some of the effects of global warming.

Conservation measures and best management practices for climate change impacts to aquatic habitat

1. Promote soft shore protection techniques, such as salt marsh restoration and creation and beach dune restoration, as alternatives to hard-armoring approaches.
2. Consider vertical structures such as concrete bulkheads for shoreline stabilization only as a last resort.
3. Establish setback lines for coastal development and rolling easements based on sea-level rise and subsidence projections that include local land movement.
4. Avoid development projects that involve wetland filling and increase impervious surfaces.
5. Improve land use practices, such as more efficient nutrient management and more extensive restoration and protection of riparian zones and wetlands.
6. Encourage the development and use of renewable, nongreenhouse gas emitting energy technologies, whenever practicable and feasible.
7. Encourage local, regional, and federal agencies to consider implications of climate change in their decision-support analysis and documents (e.g., National Environmental Policy Act) regarding permit decisions and funding programs.
8. Encourage the use of energy efficient technologies to be integrated into commercial and residential construction, including renewable energy and energy efficient heating and cooling systems and insulation.
9. Encourage the use of fuel-efficient vehicles and mass transportation systems.
10. Encourage communities and states to develop and implement strategies for sustainable development and greenhouse gas reduction initiatives, such as through the International Council for Local Environmental Initiatives (ICLEI).

Ocean Noise

Introduction

Sound is the result of energy created by a mechanical action dispersed from a source at a particular velocity and causes two types of actions: an oscillation of pressure in the surrounding environment and an oscillation of particles in the medium (Stocker 2002). Because water is 3500 times denser than air, sound travels five times faster in water (Stocker 2002). The openness of the ocean and relative density of the ocean medium allow for the transmission of sound energy over long distances. Factors that affect density include temperature, salinity, and pressure. These factors are relatively predictable in the open ocean but highly variable in coastal and estuarine waters. As a result of these factors along with water depth and variable nearshore bathymetry, sound attenuates more rapidly with distance in shallow compared to deep water (Rogers and Cox 1988).

Noise in the ocean environment can be categorized as natural and anthropogenic sources. Naturally generated sounds come from wind, waves, ice, seismic activity, tides and currents, and thunder, among other sources. Many sea animals use sound in a variety of ways; some use sound passively and others actively. Passive use of sound occurs when the animal does not create the sound that it senses but responds to environmental and ambient sounds. These uses include detection of predators, location and detection of prey, proximity perception of cospecies in schools or colonies, navigation, and perception of changing environmental conditions such as seismic movement, tides, and currents. Animals also create sounds to interact with their environment or other animals in it. Such active uses include sonic communication with cospecies for feeding and spawning (e.g., oyster toadfish [*Opsanus tau*]), territorial and social interactions, echolocation (e.g., marine mammals), stunning and apprehending prey, long distance navigation and mapping (e.g., sharks and marine mammals), and the use of sound as a defense against predators (e.g., croakers) (Stocker 2002).

The degree to which an individual fish exposed to noise will be affected is dependent upon a number of variables, including: (1) species of fish; (2) fish size; (3) presence of a swimbladder; (4) physical condition of the fish; (5) peak sound pressure and frequency; (6) shape of the sound wave (rise time); (7) depth of the water; (8) depth of the fish in the water column; (9) amount of air in the water; (10) size and number of waves on the water surface; (11) bottom substrate composition and texture; (12) tidal currents; and (13) presence of predators (Hanson et al. 2003).

Anthropogenic sources of noise include commercial shipping, seismic exploration, sonar, acoustic deterrent devices, and industrial activities and construction. The ambient noises in an average shipping channel are a combination of propeller, engine, hull, and navigation noises. In coastal areas the sounds of cargo and tanker traffic are multiplied by complex reflected paths – scattering and reverberating because of littoral geography. These cargo vessels are also accompanied by all other manner of vessels and watercraft: commercial and private fishing boats, pleasure craft, personal watercraft (e.g., jet skis) as well as coastal industrial vessels, public transport ferries, and shipping safety and security services such as tugs boats, pilot boats, US Coast Guard and coastal agency support craft, and of course all varieties of US Navy ships – from submarines to aircraft carriers. In large part, anthropogenic activities creating ocean noise are concentrated in coastal and nearshore areas. The most pervasive anthropogenic ocean noise is caused by transoceanic shipping traffic (Stocker 2002). The average shipping channel noise levels are 70-90 dB, which is as much as 45 dB over the natural ocean ambient noise in surface regions (Stocker 2002). Ships generate noise primarily by propeller action, propulsion machinery, and hydraulic flow over the hull (Hildebrand 2004). Considering all of these noises together, noise generated from a large container vessel can exceed 190 dB at the source (Jasny et al. 1999). Refer to the Marine Transportation chapter for additional information on ocean noises generated from vessels.

The loudest noises may be the sounds of marine extraction industries such as oil drilling and mineral mining (Stocker 2002). The most prevalent sources of these sounds are from “air guns” used to create and read seismic disturbances. Air guns are used in seismic exploration to create a sound pressure wave that aids in reflection profiling of underlying substrates for oil and gas. These devices generate and direct huge impact noises into the ocean substrate. Offshore oil and gas exploration generally occurs along the continental margins; however, a recent study indicated that air gun activity in these areas propagates into the deep ocean and is a significant component of low frequency noise (Hildebrand 2004). Peak source levels of air guns typically are 250-255 dB. Following the exploration stage, drilling, coring, and dredging are performed during extraction which also generates loud noises. Acoustic telemetry is also associated with positioning, locating, equipment steering, and remotely operated vessel control to support extraction operations (Stocker 2002).

Sonar systems are used for a wide variety of civilian and military operations. Active sonar systems send acoustic energy into the water column and receive reflected and scattered energy. Sonar systems can be classified into low (<1 kHz), mid (1-20 kHz), and high frequency (>20 kHz). Most vessels have sonar systems for navigation, depth sounding, and “fish finding.” Some commercial fishing boats also deploy various acoustic aversion devices to keep dolphins, seals, and turtles from running afoul of the nets (Stocker 2002).

Because the ocean transfers sound over long distances so effectively, various technologies have been designed to make use of this feature (e.g., long distance communication, mapping, and surveillance). Since the early 1990s, it has been known that extremely loud sounds could be transmitted in the deep-ocean isotherm and could be coherently received throughout the seas. Early research in the use of deep-ocean noise was conducted to map and monitor deep-ocean water temperature regimes. Since the speed of sound in water is dependent on temperature, this characteristic was used to measure the temperature of the deep water throughout the sea. This technology has been used to study long-term trends in deep-ocean water temperature that could give a reliable confirmation of global warming. This program, Acoustic Thermometry of Ocean Climates (ATOC), uses receivers stationed throughout the Pacific Basin from the Aleutian Islands to Australia. ATOC is a long wavelength, low frequency sound in the 1-500 Hz band and is the first pervasive deep-water sound channel transmission, filling an acoustical niche previously only occupied by deep sounding whales and other deep water creatures (Stocker 2002). Concurrent with the development of ATOC, the US Navy and other North American Treaty Organization (NATO) navies have developed other low frequency communications and surveillance systems. Most notable of these is low frequency active sonar (LFAS) on a mobile platform, or towed array (Stocker 2002). Recently, the use of LFAS for military purposes has received considerable attention and controversy because of the concerns that this technology has resulted in injury and death to marine mammals, particularly threatened and endangered whales. Fernandez et al. (2005) found the occurrence of mass stranding events of beaked whales in the Canary Islands to have a temporal and spatial coincidence with military exercises using mid-frequency sonar. Beaked whales that died after stranding were found to have injuries to tissues consistent with acute decompression-like illness in humans and laboratory animals. Additional monitoring and research will need to be conducted to determine the degree of threat sonar has on marine organisms, particularly marine mammals. The effects of LFAS on bony fish and elasmobranches are unknown at this time.

Industrial and construction activities concentrated in nearshore areas contribute to ocean noise. Primary activities include pile driving, dredging, and resource extraction and production activities. Pile driving activities, which typically occur at frequencies below 1000 Hz, have led to mortality in fish (Hastings and Popper 2005). Intensity levels of pile driving have been measured up to 193 dB in certain studies (Hastings and Popper 2005). Refer to the chapter on Coastal Development for additional information on the affects of pile driving.

Underwater blasting with explosives is used for a number of development activities in coastal waters. Blasting is typically used for dredging new navigation channels in areas containing large boulders and ledges; decommissioning and removing bridge structures and dams; and construction of new in-water structures such as gas and oil pipelines, bridges, and dams. The potential for injury and mortality to fish from underwater explosives has been well-documented (Hubbs and Rechnitzer 1952; Teleki and Chamberlain 1978; Linton et al. 1985; and Keevin et al. 1999). Generally, aquatic organisms that possess air cavities (e.g., lungs, swim bladders) are more susceptible to underwater blasts than are those without. In addition, smaller fish are more likely to be impacted by the shock wave of underwater blasts than are larger fish, and the eggs and embryos tend to be particularly sensitive (Wright 1982). However, fish larvae tend to be less sensitive to blasts than are eggs or post-larval fish, probably because the larval stages do not yet possess air bladders (Wright 1982). Impacts to fishery habitat from underwater explosives may include sedimentation and turbidity in the water column and benthos and the release of contaminants (e.g., ammonia) in the water column with the use of certain types of explosives.

Noise generated from anthropogenic sources covers the full frequency of bandwidth used by marine animals (0.001-200 kHz), and most audiograms of fishes indicate a higher sensitivity to sound within the 0.100-2 kHz range (Stocker 2002). Evidence indicates that fish as a group have very complex and diverse relationships with sound and how they perceive it. It should be noted that relatively little direct research has been conducted on the impacts of noise to marine fish. However, some studies and formal observations have been conducted that elucidate general categories of impacts to fish species. Noise impacts to fish can generally be divided into four categories: (1) physiological; (2) acoustic; (3) behavioral; and (4) cumulative.

Physiological impacts to fish

Increased pressure from high noise levels may have impacts on other nonauditory biological structures such as swim bladders, the brain, eyes, and vascular systems (Hastings and Popper 2005). Any organ that reflects a pressure differential between internal and external conditions may be susceptible to pressure-related impacts. Some of the resulting affects on fish include a rupturing of organs and mortality (Hastings and Popper 2005). Sounds within autonomic response ranges of various organisms may trigger physiological responses that are not environmentally adapted in healthful ways (Stocker 2002).

The lethality of underwater blasts on fish is dependent upon the detonation velocity of the explosion; however, a number of other variables may play an important role, including the size, shape, species, and orientation of the organism to the shock wave, and the amount, type of explosive, detonation depth, water depth, and bottom type (Linton et al. 1985). Fish with swimbladders are the most susceptible to underwater blasts, owing to the effects of rapid changes in hydrostatic pressures on this gas-filled organ. The kidney, liver, spleen, and sinus venosus are other organs that are typically injured after underwater blasts (Linton et al. 1985).

Acoustic impacts to fish

Acoustic impacts include damage to auditory tissue that can lead to hearing loss or threshold shifts in hearing (Jasny et al. 1999; Heathershaw et al. 2001; Hastings and Popper 2005). Temporary threshold shifts and permanent threshold shifts may result from exposure to low levels of sound for a relatively long period of time or exposure to high levels of sound for shorter periods. Threshold shifts can impact a fish's ability to carry out its life functions.

Behavioral impacts to fish

While tissue damage would be a significant factor in compromising the health of fish, other effects of anthropogenic noise are more pervasive and potentially more damaging. For example, masking biologically significant sounds by anthropogenic interference could compromise acoustical interactions from feeding to breeding, to community bonding, to schooling synchronization, and all of the more subtle communications between these behaviors. Anthropogenic sounds that falsely trigger these responses may have animals expend energy without benefits (Stocker 2002). With respect to behavioral impacts on fish, studies in this area have been limited. Clupeid fish, including Atlantic herring (*Clupea harengus*) are extremely sensitive to noise, and schools have been shown to disperse when approached by fishing gear, such as trawls and seines (NOAA Fisheries 2005). Several studies indicate that catch rates of fish have decreased in areas exposed to seismic air gun blasts (Engås et al. 1996; Hastings and Popper 2005). These results imply that fish relocate to areas beyond the impact zone. One study indicated that catch rates increased 30-50 km away from the noise source (Hastings and Popper 2005). Several studies have indicated that increased background noise and sudden increases in sound pressure can lead to elevated levels of stress in many fish species (Hastings and Popper 2005). Elevated stress levels can increase a fish's vulnerability to predation and other environmental impacts. New studies are addressing the masking effects by background noise on the ability of fish to understand their surroundings. Because fish apparently rely so heavily on auditory cues to develop an "auditory scene," an increase in ambient background noise can potentially reduce a fish's ability to receive those cues and respond appropriately (Jasny et al. 1999; Scholik and Yan 2002; Hastings and Popper 2005). Furthermore, the auditory threshold shifts of fish exposed to noise may not recover even after termination of the noise exposure (Scholik and Yan 2002).

Cumulative impacts to fish

Few research efforts have focused on the cumulative effects of anthropogenic ocean noise on fish. Subtle and long-term effects on behavior or physiology could result from persistent exposure to certain noise levels leading to an impact on the survival of fish populations (Jasny et al. 1999; Hastings and Popper 2005).

Conservation measures and best management practices for ocean noise

1. Develop mitigation strategies for noise impacts to consider the frequency, intensity, and duration of exposure and evaluate possible reductions of each of these three factors. Mitigation strategies for ocean noise are challenged by the fact that a sound source may move in addition to the movement of affected fish in and out of the insonified region.
2. Assess the “acoustic footprint” of a given sound source and develop standoff ranges for various impact levels. Standoff ranges can be calculated by using damage risk criteria for species exposure, source levels, sound propagation conditions, and acoustic attenuation models. Development of standoff ranges implies that sound sources be relocated or reduced since the sound receptors (fish) are more difficult to control. Because the potential number of species affected and their location is most likely unknown, development of a generic approach for mitigation by using the species with the most sensitive hearing would produce a precautionary approach to reducing impacts on all animals (Heathershaw et al. 2001).
3. Recommend an assessment and designation of “acoustic hotspots” that are particularly susceptible to acoustic impacts and reducing sound sources around them. These hotspots may include seasonal areas for particularly susceptible life history activities like spawning or breeding (Jasny et al. 1999).
4. Recognize that reducing noise intensity at the source primarily relies on technological solutions. These options include the use of “quiet” technology in marine engines and using bubble curtains for activities such as pile driving.
5. Encourage the use of sound dampening technologies for vessels and port/marine infrastructure to reduce ocean noise impacts to aquatic organisms.
6. Manage the duration of sound when the source level of a sound cannot be reduced in order to reduce impacts. Underwater sounds should be avoided during sensitive times of year (e.g., upstream and downstream river migrations, spawning, and egg and larvae development).
7. Avoid using underwater explosives in areas supporting productive fishery habitats. The use of less destructive methods should be encouraged, whenever possible. In some cases, the use of mechanical devices (e.g., ram hoe, clamshell dredge) may reduce impacts associated with rock and ledge removal.
8. Investigate options to mitigate the impacts associated with underwater explosives. Avoiding use during sensitive periods (e.g., upstream and downstream river migrations, spawning, and egg and larvae development) may be one of the most effective means of minimizing impacts to fishery resources. Other methods may include the use of bubble curtains; stemming (back-filling charge holes with gravel); delayed charges (explosive charges broken down into a series of smaller charges); and the use of repelling charges (small explosive charges used to frighten and drive fish away from the blasting zone) (Keevin 1998).

Atmospheric Deposition

Introduction

Pollutants travel through the atmosphere for distances of up to thousands of miles, often times to be deposited into rivers, estuaries, and nearshore and offshore marine environments. Substances such as sulfur dioxide, nitrogen oxide, carbon monoxide, lead, volatile organic compounds, particulate matter, and other pollutants are returned to the earth through either wet or dry atmospheric deposition. Wet deposition removes gases and particles in the atmosphere and deposits them to the earth's surface by means of rain, sleet, snow, and fog. Dry deposition is the process through which particles and gases are deposited in the absence of precipitation. Deposition of nutrients (i.e., nitrogen and phosphorous) and contaminants (e.g., polychlorinated biphenyl [PCB] and mercury) into the aquatic system are of particular concern because of the resulting impacts to fisheries and health-risks to humans.

Atmospheric inputs of nutrients and contaminants differ from riverine inputs in the following ways: (1) riverine inputs are delivered to the coastal seas at their margins, whereas atmospheric inputs can be delivered directly to the surface of the central areas of coastal seas and hence exert an impact in regions less directly affected by riverine inputs; (2) atmospheric delivery occurs at all times, whereas riverine inputs are dominated by seasonal high-flows and coastal phytoplankton activity; (3) atmospheric inputs are capable of episodic, high deposition events associated with natural or manmade phenomena (e.g., volcanic eruptions, forest fires); and (4) atmospheric inputs of nitrogen are chemically different from river inputs in that rivers are dominated by nitrous oxides, phosphorus, and silica, while atmospheric inputs include reduced and oxidized nitrogen, but no significant phosphorus or silica (Jickells 1998). While there is little information on the direct effects of atmospheric deposition on marine ecosystems, management strategies must attempt to address these variations in inputs from terrestrial and atmospheric pathways.

Nutrient loading and eutrophication

Nutrient pollution is currently the largest pollution problem in the coastal rivers and bays of the United States (NRC 2000). Nitrogen inputs to estuaries on the Atlantic and Gulf Coasts of the United States are now 2-20 times greater than during preindustrialized times (Castro et al. 2003). Sources of nitrogen include emissions from automobiles, as well as urban, industrial, and agricultural sources. Atmospheric deposition is one means of nitrogen input into aquatic systems, with atmospheric inputs delivering 20 to greater than 50% of the total input of nitrogen oxide to coastal waters (Paerl 1995). One of the most rapidly increasing means of nutrient loading to both freshwater systems and the coastal zone is via atmospheric pathways (Anderson et al. 2002).

Precipitation readily removes most reactive nitrogen compounds, such as ammonia and nitrogen oxides, from the atmosphere. These compounds are subsequently available as nutrients to aquatic and terrestrial ecosystems. Because nitrogen is commonly a growth-limiting nutrient in streams, lakes, and coastal waters, increased concentrations can lead to eutrophication, a process involving excess algae production, followed by depletion of oxygen in bottom waters. Hypoxic and anoxic conditions are created as algae die off and decompose. Harmful algal blooms associated with unnatural nutrient levels have been known to stimulate fish disease and kills. In addition, phytoplankton production increases the turbidity of waters and may result in a reduced photic zone and subsequent loss of submerged aquatic vegetation. Anoxic conditions, increased turbidity, and fish mortality may result from increased nitrogen inputs into the aquatic system, potentially altering long-term community dynamics (NRC 2000; Castro et al. 2003). Refer to the chapters on

Agriculture and Silviculture, Coastal Development, Alteration of Freshwater Systems, and Chemical Effects: Water Discharge Facilities for further discussion on impacts to fisheries from eutrophication.

The atmospheric component of nitrogen flux into estuaries has often been underestimated, particularly with respect to deposition on the terrestrial landscape with subsequent export downstream to estuaries and coastal waters (Howarth et al. 2002). The deposition of nitrogen on land via atmospheric pathways impacts aquatic systems when terrestrial ecosystems become nitrogen saturated. Nitrogen saturation means that the inputs of nitrogen into the soil exceed the uptake ability by plants and soil microorganisms. Under conditions of nitrogen saturation, excess nitrogen leaches into soil water and subsequently into ground and surface waters. This leaching of excess nitrogen from the soils degrades water quality. Such conditions have been known to occur in some forested watersheds in the northeastern United States, and streams that drain these watersheds have shown increased levels of nitrogen from runoff (Williams et al. 1996).

In one study, quantifying nitrogen inputs for 34 estuaries on the Atlantic and Gulf Coasts of the United States, atmospheric deposition was the dominant nitrogen source for three estuaries, and six estuaries had atmospheric contributions greater than 30% of the total nitrogen inputs (Castro et al. 2003). In the northeastern United States, atmospheric deposition of oxidized nitrogen from fossil-fuel combustion may be the major source of nonpoint input. Evidence suggests a significant movement of nitrogen in the atmosphere from the eastern United States to coastal and offshore waters of the North Atlantic Ocean where it is deposited (Holland et al. 1999). Nitrogen fluxes in many rivers in the northeastern United States have increased 2- to 3-fold or more since 1960, with much of this increase occurring between 1965 and 1988. Most of this increase in nitrogen was attributed to increased atmospheric deposition originating from fossil-fuel combustion onto the landscape (Jaworski et al. 1997).

Mercury loading/bioaccumulation

Mercury is a hazardous environmental contaminant. Mercury bioaccumulates in the environment, which means it can collect in the tissues of a plant or animal over its lifetime and biomagnify (i.e., increases in concentration within organisms between successive trophic levels) within the food chain. Fish near the top of the food chain often contain high levels of mercury, prompting the United States and Canada to issue health advisories against consumption of certain fish species. The US Food and Drug Administration reports certain species, including sharks, swordfish (*Xiphias gladius*), king mackerel (*Scombermorus cavalla*), and tilefish (*Lopholatilus chamaeleonticeps*), to have typically high concentrations of mercury (USFDA 2004).

One of the most important anthropogenic sources of mercury pollution in aquatic systems is atmospheric deposition (Wang et al. 2004). The amount of mercury emitted into the atmosphere through natural and reemitted sources was estimated to be between 1500-2500 metric tons/year in the late 20th century (Nriagu 1990). Industrial activities have increased atmospheric mercury levels, with modern deposition flux estimated to be 3-24 times higher than preindustrial flux (Bindler 2003). More than half of the total global mercury emissions are from incineration of solid waste, municipal and medical wastes, and combustion of coal and oil (Pirrone et al. 1996).

Studies strongly support the theory that atmospheric deposition is an important (sometimes even the predominant) source of mercury contamination in aquatic systems (Wang et al. 2004). Mercury exists in the atmosphere predominately in the gaseous form, although particulate and aqueous forms also exist (Schroeder et al. 1991). Gaseous mercury is highly volatile, remaining in the atmosphere for more than one year, making long-range atmospheric transport a major environmental concern (Wang et al. 2004).

Concentrations of mercury in the atmosphere and flux of mercury deposition vary with the seasons, and studies suggest that atmospheric mercury deposition is greatest in summer and least in winter (Mason et al. 2000). Different, site-specific factors may influence the transport and transformation of mercury in the atmosphere. Wind influences the direction and distance of deposition from the source, while high moisture content may increase the oxidation of mercury, resulting in the rapid settlement of mercury into terrestrial or aquatic systems. Mercury that is deposited on land can be absorbed by plants through their foliage and ultimately be passed into watersheds by litterfall (Wang et al. 2004).

Mercury and other metal contaminants are found in the water column and persist in sediments (Buchholtz ten Brink et al. 1996). Mercury is toxic in any form according to some scientists, but when absorbed by certain bacteria such as those in marine sediments, it is converted to its most toxic form, methyl mercury. Methyl mercury can cause nerve and developmental damage in humans and animals. Mercury inhibits reproduction and development of aquatic organisms, with the early life-history stages of fish being the most susceptible to the toxic impacts associated with metals (Gould et al. 1994). Metals have also been implicated in disrupting endocrine secretions of aquatic organisms, potentially disrupting natural biotic properties (Brodeur et al. 1997). Direct mortality of fish and invertebrates by lethal concentrations of metals may occur in some instances. Refer to the Coastal Development and Chemical Effects: Water Discharge Facilities chapters for more information on impacts from mercury contamination.

PCB and other contaminants

PCB congeners are a group of organic chemicals which can be odorless or mildly aromatic and exist in solid or oily-liquid form. They were formerly used in the United States as hydraulic fluids, plasticizers, adhesives, fire retardants, way extenders, dedusting agents, pesticide extenders, inks, lubricants, cutting oils, manufacturing of heat transfer systems, and carbonless reproducing paper. Most uses of PCB were banned by the US Environmental Protection Agency in 1979; however this persistent contaminant continues to enter the atmosphere mainly by cycling from soil to air to soil again. PCB is also currently released from landfills, incineration of municipal refuse and sewage sludge, and improper (or illegal) disposal of PCB-contaminated materials, such as waste transformer fluid, to open areas (USEPA 2005a).

PCB compounds are a mixture of different congeners of chlorobiphenyl. In general, the persistence of PCB increases with an increase in the degree of chlorination. Mono-, di- and trichlorinated biphenyls biodegrade relatively rapidly, tetrachlorinated biphenyls biodegrade slowly, and higher chlorinated biphenyls are resistant to biodegradation. If released to the atmosphere, PCB will primarily exist in the vapor-phase and have a tendency to become associated with the particulate-phase as the degree of chlorination of the PCB increases. Physical removal of PCB from the atmosphere is accomplished by wet and dry deposition (USEPA 2005b).

Although restrictions were first placed on the use of PCBs in the United States during the 1970s, lipid-rich finfish and shellfish tissues have continued to accumulate PCBs, dichlorodiphenyl trichloroethane (DDT), and chlordane from the environment (Kennish 1998). PCB congeners are strongly lipophilic and accumulate in fatty tissues including egg masses, affecting the development of fish as well as posing a threat to human health through the consumption of contaminated seafood. Refer to the chapters on Coastal Development and Chemical Effects: Water Discharge Facilities for more additional information on PCB contamination.

Alteration of ocean alkalinity

The influx of acid to the aquatic environment occurs through the atmospheric precipitation of two predominant acids, sulfuric acid and nitric acid, making up acid rain (i.e., pH less than 5.0). Sulfur dioxide is produced naturally by volcanoes and decomposition of plants, while the main anthropogenic source is combustion, especially from coal-burning power plants. In eastern North America, acid rain is ubiquitous because of the presence of coal-burning power plants (Baird 1995). Other sources of sulfuric acid in the atmosphere include oil refinement, cleaning of natural gas, and nonferrous smelting. Affects on biological life depend strongly on soil composition. Granite and quartz have little capacity to neutralize acid, while limestone or chalk can efficiently neutralize acids. Under acidic conditions, aluminum is leached from rocks. Both acidity and high concentrations of dissolved aluminum are responsible for decreases in fish populations observed in many acidified water systems (Baird 1995).

The freshwater environment does not have the buffering capacity of marine ecosystems, so acidification has serious implications on riverine habitat. Low pH (below 5.0) has been implicated with osmoregulation problems (Staurnes et al. 1996), pathological changes in eggs (Peterson et al. 1980; Haines 1981), and reproduction failure in Atlantic salmon (Watt et al. 1983). Cumulative, long-term deposition of acid into the aquatic environment can hinder the survival and sustainability of fisheries by disrupting and degrading important fish and shellfish habitat. Refer to the Coastal Development and Chemical Effects: Water Discharge Facilities chapters for additional information on the affects of acidification of aquatic habitats.

Conservation measures and best management practices for atmospheric deposition

1. Install scrubbers for flue-gas desulfurization in electricity generating powerplants, oil refineries, nonferrous smelters, and other point sources of sulfur dioxide emissions.
2. Use integrated, gas-scrubbing systems on municipal waste combustion units.
3. Reduce sulfur dioxide emissions by substituting natural gas or low-sulfur coal for high-sulfur coal at power plants.
4. Encourage renewable energy generation using wind, solar, and geothermal technologies.
5. Encourage the use of fuel-efficient vehicles and mass transportation systems.
6. Encourage the separation of batteries from the waste stream to reduce the release of mercury vapors through waste incineration.
7. Lower volatization and/or erosion and resuspension of persistent compounds through remediation at waste sites.

Military/Security Activities

The operations of the US military span the globe and are carried out in coastal, estuarine, and marine habitats. Military operations have the potential to adversely impact fish habitat through training activities conducted on land bases as well as in coastal rivers and the open ocean. Military operations also impact fish habitat and larger ecological communities during wars (Literathy 1993).

Because many military bases and training activities are located in coastal areas and oftentimes directly on shorelines, they can cause impacts similar to those mentioned in other parts of this document (e.g., coastal development, dredging, sewage discharge, road construction, shoreline protection, over-water structures, pile driving, port and marina operations, and vessel operations). In addition to these conventional activities, the military often stockpiles and disposes of toxic chemicals on base grounds. Toxic dumping on base grounds has led to the contamination of groundwater at Otis Air National Guard Base on Cape Cod, MA, (NRDC 2003) and in Vieques, Puerto Rico.

The United States Navy also uses sonar systems that create large amounts of noise in ocean waters. The Surveillance Towed Array Sensor System (SURTASS) low frequency active sonar produces extremely loud low frequency sound that can be heard at 140 dB from 300 miles away from the source (NRDC 2004). Sixty percent of the US Navy's 294 ships are equipped with mid-frequency sonar devices that can produce noise above 215 dB (NRDC 2002). The intensity of these noises in the water column can cause a variety of impacts to fish, marine mammals, and other marine life such as behavior alterations, temporary and permanent impairments to hearing, and mortality. Other sources of underwater noise from military activities may include explosive devices and ordnances during training exercises and during wartime. Refer to the Ocean Noise section in this chapter for more information on impacts associated with sonar, as well as the Marine Transportation and Coastal Development chapters for information related to blasting impacts.

Natural Disasters and Events

Introduction

Natural events and natural disasters of greatest concern for the northeastern United States include hurricanes, floods, and drought. These events may impact water quality, alter or destroy habitat, alter hydrological regimes, and result in changes to biological communities. Natural disasters have the potential to impact fishery resources, such as displacing plankton and fish from preferred habitat and altering freshwater inputs and sediment patterns. While these effects may not themselves pose a threat to coastal ecosystems, they may have additive and synergistic effects when combined with anthropogenic influences such as the release of agricultural and industrial pollutants in storm water.

Water quality impacts

Water quality degradation by hurricanes can be exacerbated by human activities. Hurricanes and posthurricane flooding have been known to result in large freshwater inputs and high concentrations of nutrients into river and estuarine waters, causing reductions in water quality and massive fish kills (Mallin et al. 1999). For example, when Hurricane Fran struck North Carolina in the Cape Fear River area in 1996, the following impacts were reported as a result of the hurricane: (1) power failures caused the diversion of millions of liters of raw and partially treated human waste into rivers when sewage treatment plants and pump stations were unable to operate; (2) dissolved oxygen concentrations decreased in parts of the Cape Fear River for more than three weeks following the hurricane; (3) ammonium and total phosphorous concentrations were the highest recorded in 27 years of monitoring in Northeast Cape Fear River following the hurricane and; (4) sediment-laden waters flowing into Cape Fear River increased turbidity levels (Mallin et al. 1999).

Generally, high rates of flushing and reduced water residence times will inhibit the formation of algal blooms in bays and estuaries. However, the input of large amounts of human and animal waste can greatly increase the biological oxygen demand and lead to hypoxic conditions in aquatic systems. In addition to the diversion of untreated waste from sewage treatment plants during Hurricane Fran, several swine waste lagoons were breached, overtopped, or inundated, discharging large quantities of concentrated organic waste into the aquatic environment (Mallin et al. 1999). Other sources of nutrient releases during storms and subsequent flooding events include septic systems on private residences built on river and coastal floodplains.

Natural disasters, such as hurricanes, may also put vessels (e.g., oil tankers) and coastal industrial facilities (e.g., liquefied natural gas [LNG] facilities, nuclear power plants) at risk of damage and contaminant spills. Tanker ship groundings generally occur during severe storms, when moorings are more susceptible to being broken and the control of a vessel may be lost or compromised. The release of toxic chemicals from damaged tanks, pipelines, and vessels threaten aquatic organisms and habitats.

Changes to community composition

Major storm events may impact benthic communities through a variety of mechanisms, including increased sedimentation, introduction of contaminants, reduction in dissolved oxygen, short-term changes in salinity, and disturbance from increased flow. Monitoring of environmental impacts following Hurricane Fran in 1996 indicated that significant declines in benthic organism abundance were observed up to three months after the storm. However, significant declines in benthic abundance generally did not occur in areas where levels of dissolved oxygen recovered quickly after the storm (Mallin et al. 1999). Poorly flushed bays and inland river floodplains are areas that typically exhibit greater magnitude and duration of storm-related impacts.

Loss/alteration of habitat

The rate of accretion and erosion of coastal areas is influenced by wave energy impacting the shoreline, and natural events such as hurricanes will accelerate this process. Erosion may occur as a function of hydraulic scour produced by hurricane overwash and offshore-directed wave energy. Accretion of materials resulting from overwash deposition may result in subsequent flood tidal delta development. Extreme climatic events, such as hurricanes and tsunamis, can have large-scale impacts on submerged aquatic vegetation communities (Orth et al. 2006). Loss or alteration of coastal habitat as a result of storms may be exacerbated by the effects of shoreline development and erosion control measures. For example, the creation of hardened shoreline structures (e.g., seawalls, jetties) and storm-water control systems can focus storm energy and redirect storm water to wetlands, resulting in increased erosion and habitat loss in productive fishery habitat.

Alteration of hydrological regimes

Hurricane and flood events result in large volumes of water delivered to the watershed in a relatively short period of time. These events can alter the hydrology of wetlands, streams, and rivers by increasing erosion and overwhelming flood control structures. Freshwater flows into rivers draining into Charleston Harbor in South Carolina increased as much as four times the historical average after Hurricane Hugo in 1989 (Van Dolah and Anderson 1991). Reduced dissolved oxygen concentrations were observed in all portions of the Charleston Harbor estuary following Hurricane Hugo, with hypoxic conditions in some of the rivers in the watershed. The decomposition of vegetation and the failure of septic and sewer systems overflowing into the watershed as a result of this hurricane was identified as the primary cause of the high organic loads (Van Dolah and Anderson 1991). At the other extreme, drought will result in reduced run-off and low flows in streams and rivers that drain into estuaries and bays. Low freshwater input resulted in dramatic reductions in phytoplankton and zooplankton in San Francisco Bay, CA, reducing pelagic food for fish populations (Bennett et al. 1995). Larval starvation may limit recruitment. During low-flow years, toxins from agricultural and urban runoff are less diluted which can also harm fish.

Conservation measures and best management practices for natural disasters and events

1. Require backup generating systems for publicly owned waste treatment facilities.
2. Prohibit development of high-risk facilities, such as animal waste lagoons, storage of hazardous chemicals within the 100-year floodplain.
3. Ensure that all industrial and municipal facilities involving potentially hazardous chemicals and materials have appropriate emergency spill response plans, including emergency notification systems and spill cleanup procedures, training, and equipment.
4. Encourage the protection and restoration of coastal wetlands and barrier islands, which buffer the affects of storm events by dissipating wave energy and retaining floodwaters.
5. Discourage new construction and development in or near coastal and riparian wetlands.
6. Discourage the use of "hard" shoreline stabilization, such as seawalls and bulkheads.
7. Limit emergency authorizations (e.g., federal Clean Water Act permits) for reconstruction projects to replacing structures that were in-place and functional at the time of the natural disaster/event and do not include the expansion of structures and facilities.

Electromagnetic Fields

Anthropogenic activities are responsible for the majority of the overall electromagnetic fields (EMF) emitted into the environment, with natural sources making up the remainder. Levels of EMF from anthropogenic sources have increased steadily over the past 50-100 years (WHO 2005). Anthropogenic sources of EMF include undersea power cables, high voltage power lines, radar, FM radio and TV transmitters, cell phones, high frequency transmitters for atmospheric research, and solar power satellites. The EMF created by undersea power cables may have some adverse affect on marine organisms. Undersea power cables transfer electric power across water, usually conducting very large direct currents (DC) of up to a thousand amperes or more. It has been inferred that undersea cables can interfere with the prey sensing or navigational abilities of animals in the immediate vicinity of the sea cables (See also the Cables and Pipelines section of the Energy-related Activities chapter). Few published, peer reviewed scientific articles on the environmental effects of electromagnetic fields on aquatic organisms exist. However, the World Health Organization cosponsored an international seminar in October 1999 entitled "Effect of Electromagnetic Fields on the Living Environment" to focus attention on this subject. A review of the information presented at the seminar was prepared by Foster and Repacholi (2000).

Electromagnetic fields are the product of both natural and artificial sources. Natural sources of EMF include radiation from the sun, the earth's magnetic fields, the atmosphere (e.g., lightning discharges), and geological processes (WHO 2005). Marine animals are also exposed to natural electric fields caused by sea currents moving through the geomagnetic field. Examples of anthropogenic sources of EMF include undersea power cables and US Navy submarine communication systems (Foster and Repacholi 2000). Mild electroreception by teleost (bony) fishes occurs through external pit organs that interpret minute electrical currents in the water (Moyle and Cech 1988). However, elasmobranches (i.e., sharks, skates, and rays) are unique in that they possess well-developed electroreceptive organs, called Ampullae of Lorenzini, that enable them to detect weak electric fields in the surrounding seawater as low as 0.01 μV/m (Kalmijn 1971). Elasmobranchs are able to receive information about the positions of their prey, the drift of ocean currents, and their magnetic compass headings from electric fields in their surrounding environment.

Most aquatic organisms emanate low-frequency electric fields that can be detected by fish, such as skates and rays, through a process known as “passive electrolocation” or “passive electroreception.” Passive electroreception allows animals to sense electric fields generated in the environment, thereby allowing predators to detect prey by the electric fields that individual fauna emanate. Elasmobranchs have demonstrated during controlled experiments the ability to detect artificially created electric fields (1-5 μA) that are similar to those produced by prey (Kalmijn 1971). The other form of electroreception is “active electroreception” and occurs when an animal detects changes in their own electric field caused by the electric field produced by prey in the vicinity. This ability to detect disturbances to an individual’s own electric field is rare, occurring only in a few families of weakly electric fish, none of which are found in the Northwest Atlantic Ocean.

There is evidence that elasmobranches also use their ability to detect electric fields for the purpose of navigation. For example, blue sharks (*Prionace glauca*) have been observed migrating in the North Atlantic Ocean maintaining straight courses for hundreds of kilometers over many days (Paulin 1995). The two modes of detection used for navigation are: (1) passive detection (when an animal estimates its drift from the electrical fields produced by interactions of tidal and wind-driven currents and the vertical component of the earth’s magnetic field); or (2) active detection (when the animal derives its magnetic compass heading from the electrical field it generates by its interaction with the horizontal component of the earth’s magnetic field) (Gill and Taylor 2001).

Changes in migration of marine organisms

Anthropogenic sources of EMFs may affect social behavior, communications, navigation, and orientation of those animals that rely on the earth’s magnetic field. Certain fish rely on the natural (geomagnetic) static magnetic field as one of a number of parameters believed to be used as orientation and navigational cues. For example, stingrays have demonstrated their ability during training experiments to orient relative to uniform electric fields similar to those produced by ocean currents (Kalmijn 1982). In addition, the small-spotted catshark (*Scyliorhinus canicula*) and the thornback skate (*Raja clavata*) have shown a remarkable sensitivity to electric fields (Kalmijn 1982). However, studies demonstrating an impact on the ability of marine organisms to migrate because of anthropogenic sources of EMFs have not been found. Foster and Repacholi (2000) noted the sensitivity of sharks to low frequency electric fields and a potential mechanism for adverse effects from DC fields but made no mention of adverse effects from EMFs.

Changes to feeding behavior

Electric or magnetic fields near sea cables may affect prey sensing of electrically or magnetically sensitive species. Submarine cables may attract species when the field intensity approximates that of their natural prey. Smooth dogfish (*Mustelus canis*) and the blue shark have been observed to execute apparent feeding responses to dipole electric fields designed to mimic prey (Kalmijn 1982). Less is known about how elasmobranches respond in the presence of stronger EMFs that exist closer to the cable. Depending on the presence and strength of electric fields, the feeding behavior of elasmobranches could be altered by submarine cables.

The possible affects of exposure to EMF depend on a coupling between the external field and the body of the animal and the biological response mechanisms. The size of the animal, frequency of the field, and whether the pathway of exposure is via air or water will determine effects to the animal. It has been suggested that monopolar power links are more likely to affect aquatic animals than bipolar links do because they produce perceptible levels of fields over larger distances from the cables (Kalmijn 2000). Sea cables are isolated from the surrounding water by layers of insulation and metal sheathing, yet electric fields that can exceed natural ambient levels remain detectable (Foster and Repacholi 2000). The flow of seawater past the cables can create electric fields by magnetic induction. The resulting field strength in the seawater can exceed naturally occurring levels and depends on the flow velocity, whether or not the observer is moving with respect to the water, and on the electrical conductivity of nearby surfaces (Foster and Repacholi 2000).

Further directed research should be conducted to examine the effect of EMFs from underwater transmission lines on marine organisms. Increased understanding is needed about the effects of cable burial within different substrata and the range of frequencies and sensitivities of electric fields that marine species are capable of detecting.

Conservation recommendations and best management practices for electromagnetic fields

1. Map proposed submarine cable routes with marine resource utilization in a geographic information system database to provide information on potential interference with elasmobranch fishes and other organisms. Particular attention should be paid to known nursery and pupping grounds of coastal shark species.
2. Bury submarine cables below the seafloor to potentially reduce possible interference with the electroreception of fishes. However, the benefits of cable burial to minimize potential impacts to elasmobranchs should be weighed with the adverse effects associated with trenching on the seafloor.
3. Place new submarine electric transmission lines within existing transmission corridors to minimize the cumulative effect of transmission lines across the ocean bottom to the extent practicable.

References for Global Effects and Other Impacts

Anderson DM, Glibert PM, Burkholder JM. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25(4b):704-26.

Baird C. 1995. Ground-level air chemistry and air pollution. In: Environmental Chemistry. New York (NY): W. H. Freeman and Company. p 90-9.

Bennett WA, Ostrach DJ, Hinton DE. 1995. Larval striped bass condition in a drought-stricken estuary: evaluating pelagic food-web limitation. Ecological Applications 5(3):680-92.

Bigford TE. 1991. Sea-level rise, nearshore fisheries, and the fishing industry. Coastal Management 19:417-37.

Bindler R. 2003. Estimating the natural background atmospheric deposition rate of mercury utilizing ombrotrophic bogs in southern Sweden. Environmental Science and Technology 37:40-6.

Brodeur JC, Sherwood G, Rasmussen JB, Hontela A. 1997. Impaired cortisol secretion in yellow perch (*Perca flavescens*) from lakes contaminated by heavy metals: *in vivo* and *in vitro* assessment. Canadian Journal of Fisheries and Aquatic Sciences 54 (12):2752-8.

Buchholtz ten Brink MR, Manheim FT, Bothner MH. 1996. Contaminants in the Gulf of Maine: what's there and should we worry? In: Dow D, Braasch E, editors. The health of the Gulf of Maine ecosystem: cumulative impacts of multiple stressors. Hanover (NH): Dartmouth College, Regional Association for Research on the Gulf of Maine (RARGOM) Report 96-1. p 91-5.

Castro MS, Driscoll CT, Jorden TE, Reay WG, Boynton WR. 2003. Sources of nitrogen to estuaries in the United States. Estuaries 26(3):803-14.

Cloern J. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210:223-52.

Edwards M, Richardson A. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430(7002):881-4.

Engås A, Lokkeborg S, Ona E, Soldal AV. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences 53:2238-49.

Fernandez A, Edwards JF, Rodriguez F, Espinosa De Los Monteros A, Herraez P, Castro P, Jaber JR, Martin V, Arbelo M. 2005. ‘‘Gas and fat embolic syndrome’’ involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. Veterinary Pathology 42:446-57.

Foster KR, Repacholi MH. 2000. Environmental impacts of electromagnetic fields from major electrical technologies. In: Matthes R, Bernhardt JH, Repacholi MH, editors. Proceedings of the international seminar on effects of electromagnetic fields on the living environment; 1999 Oct. 4-5; Ismaning, Germany. Munich (Germany): International Commission on Non-Ionizing Radiation Protection. World Health Organization (WHO). 17 p.

Frumhoff PC, McCarthy JJ, Melillo, SC, Moser SC, Wuebbles DJ. 2007. Confronting climate change in the U.S. Northeast: science, impacts, and solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge (MA): Union of Concerned Scientists (UCS). 146 p.

Gill AB, Taylor H. 2001. The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes. University of Liverpool: Research project for Countryside Council of Wales. CCW Science report No. 488. 73 p.

Gould E, Clark PE, Thurberg FP. 1994. Pollutant effects on dermersal fishes. In: Langton RW, Pearce JB, Gibson JA, editors. Selected living resources, habitat conditions, and human perturbations of the Gulf of Maine: environmental and ecological considerations for fishery management. Woods Hole (MA): NOAA Technical Memorandum NMFS-NE-106. p 30-41.

Greene CH, Pershing AJ. 2007. Oceans: climate drives sea change. Science 315:1084-5.

Gutierrez BT, Williams SJ, Thieler ER. 2007. Potential for shoreline changes due to sea-level rise along the U.S. mid-Atlantic region. [Internet]. Reston (VA): US Geological Survey Open-File Report 2007-1278. [cited 2008 July 28]. 26 p. Available from: http://pubs.er.usgs.gov/usgspubs/ofr/ofr20071278.

Haines TA. 1981. Acidic precipitation and its consequences for aquatic ecosystems: a review. Transactions of the American Fisheries Society 110(6):669-707.

Hanson J, Helvey M, Strach R. editors. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. Long Beach (CA): National Marine Fisheries Service (NOAA Fisheries) Southwest Region. Version 1. 75 p.

Hastings MC, Popper AN. 2005. Effects of sound on fish. Sacramento (CA): Jones & Stokes. CADOT Contract No. 43A0139, Task Order 1. 82 p.

Heathershaw AD, Ward PD, David AM. 2001. The environmental impact of underwater sound. Proceedings of the Institute of Acoustics 23(4).

Hildebrand J. 2004. Sources of anthropogenic sound in the marine environment. [Internet]. In: Vos E, Reeves RR, editors. Report of an international workshop: policy on sound and marine mammals; 2004 Sep 28-30; London, England. Bethesda (MD): Marine Mammal Commission. [cited 2008 Jul 21]. 129 p. Available from: http://www.mmc.gov/sound/internationalwrkshp/pdf/hildebrand.pdf.

Hodgkins GA, Dudley RW. 2005. Changes in the magnitude of annual and monthly streamflows in New England, 1902-2002. Denver (CO): US Department of the Interior, US Geological Survey. Scientific Investigations Report 2005-5135. 23 p. plus appendices.

Holland TA, Dentener FJ, Braswell BH, Sulzman JM. 1999. Contemporary and pre-industrial global reactive nitrogen budgets. Biogeochemistry 46:7-43.

Howarth RW, Sharpley A, Walker D. 2002. Sources of nutrient pollution to coastal waters in the United States: implications for achieving coastal water quality goals. Estuaries 25(4b):656-76.

Hubbs CL, Rechnitzer AB. 1952. Report on experiments designed to determine effects of underwater explosions on fish life. California Fish and Game 38:333-66.

[IPCC] Intergovernmental Panel on Climate Change. 2007a. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Internet]. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. New York (NY): Cambridge University Press. [cited 2008 Jul 9]. 996 p. Available from: http://www.ipcc.ch.

[IPCC] Intergovernmental Panel on Climate Change (IPCC). 2007b. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Internet]. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. New York (NY): Cambridge University Press. [cited 2008 Jul 9]. 976 p. Available from: http://www.ipcc.ch.

Jasny M, Reynolds J, Horowitz C, Wetzler A. 1999. Sounding the depths: supertankers, sonar, and rise of undersea noise. Los Angeles (CA): Natural Resources Defense Council. Marine Mammal Protection Project. 38 p.

Jaworski NA, Howarth RW, Hetling LJ. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the northeast United States. Environmental Science and Technology 31:1995-2004.

Jickells TD. 1998. Nutrient biogeochemistry of the coastal zone. Science 281(5374):217-22.

Kalmijn AJ. 1971. The electric sense of sharks and rays. Journal of Experimental Biology 55:371-83.

Kalmijn AJ. 1982. The electric and magnetic field detection in elasmobranch fishes. Science 218(4575):916-18.

Kalmijn AJ. 2000. Detection and processing of electromagnetic and near-field acoustic signals in elasmobranch fishes. Biological Sciences 335(1401):1135-41.

Karl TR, Knight RW. 1998. Secular trends in precipitation amount, frequency, and intensity in the United States. Bulletin of the American Meteorological Society 79(2):231-41.

Keevin TM. 1998. A review of natural resource agency recommendations for mitigating the impacts of underwater blasting. Reviews in Fisheries Science 6(4):281-313.

Keevin TM, Gaspin JB, Gitschlag GR, Hempen GL, Linton TL, Smith M, Wright DG. 1999. Underwater explosions: natural resource concerns, uncertainty of effects, and data needs. In: Proceedings of the twenty-fifth annual conference on explosives and blasting technique; 1999 Feb 7-10; Nashville, TN. Cleveland (OH): International Society of Explosive Engineers. p 105-16.

Kennedy VS, Twilley RR, Kleypas JA, Cowan JH, Hare SR. 2002. Coastal and marine ecosystems and global climate change: potential effects on U.S. resources. Arlington (VA): Pew Center on Global Climate Change. 51 p.

Kennish MJ, Ruppel BE. 1998. Organochlorine contamination in selected estuarine and coastal marine finfish and shellfish of New Jersey. Water, Air, and Soil Pollution 101(1-4):123-36.

Linton TL, Landry AM Jr, Buckner JE Jr, Berry RL. 1985. Effects upon selected marine organisms of explosives used for sound production in geophysical exploration. The Texas Journal of Science 37(4):341-53.

Literathy P. 1993. Considerations for the assessement of environmental consequences of the 1991 Gulf War. Marine Pollution Bulletin 27:349-56.

Mallin MA, Posey MH, Shank GC, McIver MR, Ensign SH, Alphin TD. 1999. Hurricane effects on water quality and benthos in the Cape Fear watershed: natural and anthropogenic impacts. Ecological Applications 9(1):350-62.

Mason RP, Lawson NM, Sheu GR. 2000. Annual and seasonal trends in mercury deposition in Maryland. Atmospheric Environment 34:1691-701.

Mountain DG. 2002. Potential consequences of climate change for the fish resources in the Mid-Atlantic region. In: McGinn NA, editor. Fisheries in a changing climate. Bethesda (MD): American Fisheries Society, Symposium 32.

Mountain DG, Murawski SA. 1992. Variation in the distribution of fish stocks on the northeast continental shelf in relation to their environment, 1980-1989. ICES Marine Science Symposia 195:424-432.

Moyle P, Cech J. 1988. Fishes: an introduction to ichthyology. Englewood Cliffs (NJ): Prentice-Hall. 559 p.

[NOAA] National Oceanic and Atmospheric Administration. 2005. Final environmental impact statement for minimizing impacts of the Atlantic herring fishery on essential fish habitat. Gloucester (MA): National Marine Fisheries Service, Northeast Regional Office. 274 p.

[NRC] National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Washington (DC): National Academy Press. 405 p.

[NRDC] Natural Resource Defense Council. 2002. Federal court blocks full deployment of navy low frequency active sonar system. [Internet]. NRDC Press Archive, October 31, 2002. [cited 2007 Dec 21]. Available from: http://www.nrdc.org/media/pressreleases/021031.asp.

[NRDC] Natural Resource Defense Council. 2003. Above the law? The Pentagon is taking aim at America's public health and environmental protections. [Internet]. NRDC Backgrounder, March 12, 2003. [cited 2007 Dec 21]. Available from: http://www.nrdc.org/media/pressreleases/030312.asp.

[NRDC] Natural Resources Defense Council. 2004. Coalition warns navy over destructive use of mid-frequency sonar. [Internet]. NRDC Press Archive, July 15, 2004. [cited 2007 Dec 21]. Available from: http://www.nrdc.org/media/pressreleases/040715.asp.

Nedeau E. 2004. Effects of climate change on the Gulf of Maine region. [Internet]. Gulf of Maine Council on the Marine Environment. [cited 2008 Jul 9]. 12 p. Available from: http://www.gulfofmaine.org/summit/ClimateChangeKbase.pdf.

Nriagu JO. 1990. Global metal pollution. Poisoning the biosphere? Environment 32:7-33.

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesikan A, Gruber N, Ishida A, Joos F, and others. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681-6.

Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck KL Jr, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, and others. 2006. A global crisis for seagrass ecosystems. Bioscience 56(12):987-96.

Paerl HW. 1995. Coastal eutrophication in relation to atmospheric nitrogen deposition: current perspectives. Ophelia 41:237-59.

Paulin MG. 1995. Electroreception and the compass sense of sharks. Journal of Theoretical Biology 174(3):325-39.

Perry AL, Low PJ, Ellis JR, Reynolds JD. 2005. Climate change and distribution shifts in marine fisheries. Science 308:1912-5.

Peterson RH, Daye PG, Metcalfe JL. 1980. Inhibition of Atlantic salmon (*Salmo salar*) hatching at low pH. Canadian Journal of Fisheries and Aquatic Sciences 37:770-4.

Pirrone N, Keeler GJ, Nriagu JO. 1996. Regional differences in worldwide emissions of mercury to the atmosphere. Atmospheric Environment 30:2981-7.

Richardson A, Schoeman D. 2004. Climate impact on plankton ecosystems in the Northeast Atlantic. Science 305(5690):1609-12.

Riebesell U. 2004. Effects of CO_2 enrichment on marine phytoplankton. Journal of Oceanography 60:719-29.

Rogers PH, Cox M. 1988. Underwater sound as a biological stimulus. In: Atema J, Fay RR, Popper AN, Tavolga WN, editors. Sensory biology of aquatic animals. New York (NY): Springer-Verlag. p 131-49.

Scavia D, Field JC, Boesch DF, Buddemeier RW, Burkett V, Cayan DR, Fogarty M, Harwell MA, Howart RW, Mason C, and others. 2002. Climate change impacts on U.S. coastal and marine ecosystems. Estuaries 25(2):149-64.

Schneider D. 1998. The rising seas. Oceans; Scientific American Quarterly 9(3):28-35.

Scholik AR, Yan HY. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. Environmental Biology of Fishes 63:203-9.

Schroeder WH, Yarwood G, Niki H. 1991. Transformation processes involving mercury species in the atmosphere-results from a literature survey. Water, Air, and Soil Pollution 56:653-66.

Short FT, Neckles HA. 1999. The effects of global climate change on seagrasses. Aquatic Botany 63 (3-4): 169-96.

Staurnes M, Hansen LP, Fugelli K, Haraldstad O. 1996. Short-term exposure to acid water impairs osmoregulation, seawater tolerance, and subsequent marine survival of smolts of Atlantic salmon (*Salmo salar* L.). Canadian Journal of Fisheries and Aquatic Sciences 53(8):1695-704.

Stocker M. 2002. Fish, mollusks and other sea animals' use of sound, and the impact of anthropogenic noise in the marine acoustic environment. Journal of Acoustical Society of America 112(5):2431.

Teleki GC, Chamberlain AJ. 1978. Acute effects of underwater construction blasting on fishes in Long Point Bay, Lake Erie. Journal of the Fisheries Research Board of Canada 35:1191-8.

[USEPA] US Environmental Protection Agency. 2005a. Technical factsheet on polychlorinated biphenyls (PCBs). [Internet]. Washington (DC): US EPA. [updated 2006 Nov 28; cited 2007 Dec 21]. Available from: http://www.epa.gov/safewater/dwh/t-soc/pcbs.html.

[USEPA] US Environmental Protection Agency (USEPA). 2005b. Consumer factsheet on polychlorinated biphenyls (PCBs). [Internet]. Washington (DC): US EPA Office of Groundwater and Drinking Water. [updated 2006 Nov 28; cited 2007 Dec 21]. Available from: http://www.epa.gov/OGWDW/dwh/c-soc/pcbs.html.

[USFDA] US Food and Drug Adminstration. 2004. What you need to know about mercury in fish and shellfish. [Internet]. Washington (DC): US Department of Health and Human Services and US Environmental Protection Agency. EPA-823-R-04-005. [cited 2008 Jul 28]. Available from: http://www.cfsan.fda.gov/~dms/admehg3.html.

[USGS] US Geological Survey. 2005. Streamflow trends in the United States. Reston (VA): US Department of the Interior, US Geological Survey. USGS Fact Sheet 2005-3017. 3 p.

Van Dolah RF, Anderson GS. 1991. Effects of Hurricane Hugo on salinity and dissolved oxygen conditions in the Charleston Harbor estuary. Journal of Coastal Research Special Issue 8:83-94.

Wang Q, Kim D, Doinysiou DD, Sorial GA, Timberlake D. 2004. Sources and remediation for mercury contamination in aquatic systems-a literature review. Environmental Pollution 131(2004):323-36.

Watt WD, Scott CD, White WJ. 1983. Evidence of acidification of some Nova Scotia rivers and its impact on Atlantic salmon, *Salmo salar*. Canadian Journal of Fisheries and Aquatic Sciences 40:462-73.

Williams MW, Baron JS, Caine N, Sommerfield R, Sanford RJ. 1996. Nitrogen saturation in the Rocky Mountains. Environmental Science and Technology 30:640-6.

[WHO] World Health Organization. 2005. Electromagnetic fields and public health: Effects of EMF on the environment. [Internet]. Munich (Germany): WHO. Fact sheet No. 296. 2005 Dec. [cited 2008 Jul 28]. Available from: http://www.who.int/mediacentre/factsheets/fs296/en/.

Wright DG. 1982. A discussion paper on the effects of explosives on fish and marine mammals in the waters of the Northwest Territories. Winnipeg (Manitoba): Western Region, Department of Fisheries and Oceans. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1052. 16 p.

Zervas C. 2001. Sea level variations of the United States 1854-1999. [Internet]. Silver Spring (MD): National Ocean Service. NOAA Technical Report NOS CO-OPS 36. [cited 2008 Aug 12]. 66 p. Available from: http://tidesandcurrents.noaa.gov/publications/techrpt36doc.pdf.