8.0 CLIMATE CHANGE

8.1 INTRODUCTION

Projected changes in the marine ecosystems off the northeastern U.S. as a result of climate-induced forcing includes alterations in water temperatures, salinity, wind stress, local precipitation patterns, and cloud cover, with potential ramifications for changes in water column structure and circulation. These, in turn, can affect many components of the marine ecosystem, beginning with the transport, production, and dynamics of planktonic communities and eventually extending through various parts of the food web. An increase in water temperatures predicted by climate change models will result in a poleward shift in the distribution of many subtropical-tropical and temperate water species in the northeast. This shift will include economically important fish and shellfish, changes in the productivity of these species, and possible increased uncertainty for the fishing industry and current resource management techniques during these periods of ecological transition (Fogarty et al. 2007).

8.2 FISH AND FISHERIES EFFECTS

Fish have complex life cycles, comprising several distinct life history stages (i.e., egg, larva, juvenile, and adult), each of which may be affected in different ways by climate change. In fish populations, climate-driven changes may result from four, often interlinked, mechanisms: (1) physiological response to changes in environmental parameters - sea surface temperature (SST), ocean circulation, and salinity patterns; (2) behavioral response - avoiding unfavorable conditions and moving into new suitable areas; (3) population dynamics - changes in the balance between rates of mortality, growth, and reproduction in combination with dispersal, which could result in the establishment of new populations in new areas, or abandonment of traditional sites; and (4) ecosystem - changes in habitat quantity and quality, productivity, and/or trophic interactions between competitors, predators, and pathogens (Lehodey et al. 2006; Rijnsdorp et al. 2009). The first three mechanisms would have a direct effect on fish populations, whereas the fourth mechanism would have an indirect effect (Brander 2010). Rijnsdorp et al. (2009) has suggested that early-life stages will be most sensitive to the effects of climate change, but the underlying mechanisms may differ among species or stocks and will depend on trophic position (Frank et al. 2007).

In addition, many other factors, including commercial fishing, biological interactions, and non-climatic environmental factors will also greatly affect the abundance and distribution of fish and may interact with the effects of climate change (Brander 2010). These changes in distributions and community structure of marine species affecting fishing activities may also have socioeconomic impacts on vulnerable coastal communities (Allison et al. 2009). Climate change will affect a range of abiotic variables that are tightly linked to the production and distribution of fish populations, while the climate-driven biotic changes will likely differ between the open ocean, shelf seas, and coastal waters (Walther et al. 2002; Lehodey et al. 2006).

Empirical and theoretical studies show that marine fish and invertebrates tend to shift their distributions according to the changing climate in a direction that is generally towards higher latitude and deeper water, with observed and projected rates of a range shift of around 30 to 130 km (16.2 to 70.2 NM) decade^{-1} towards the pole and a 3.5 m (11.5 ft) decade^{-1} to deeper waters (Perry et al. 2005; Cheung et al. 2008a; Dulvy et al. 2008; Mueter and Litzow 2008). In addition, changes in patterns of species richness may disrupt marine biodiversity and ecosystems and impact commercial fisheries (Roessig et al. 2004; Worm et al. 2006; Cheung et al. 2008b; Hiddink and Hofstede 2008). Cheung et al. (2010) projected changes in global catch potential for 1,066 species of exploited marine fish (836 spp.) and invertebrates (230 spp.) from 2005 to 2055. This study showed that climate change may lead to large-scale redistribution of global catch potential, with an average of 30 to 70% increase in high-latitude regions and a drop of up to 40% in the tropics.

8.3 NORTHEAST U.S. CONTINENTAL SHELF LARGE MARINE ECOSYSTEM

The Northeast (NE) U.S. Continental Shelf Large Marine Ecosystem (LME), a dynamic, highly productive system, has undergone sustained perturbations due to environmental and anthropogenic impacts over the last four decades, resulting in fundamental changes in its structure (Ecosystem Assessment Program 2009). Climate change may have particular impacts on the North Atlantic, because of dependence on north-south oceanic heat transfer and how any changes in SST, salinities, and ocean currents may affect both the fish and fisheries (Rose 2005). Groups of species may be expected to react differently to climate change, with species that spawn in shallow, relatively low salinity waters being most affected, while species that inhabit deeper, hydrographically more stable waters, less so. In addition, seasonal migrants that feed in the North Atlantic but spawn further south (e.g., bluefin tuna), may undergo migration shifts (Rose 2005).

In the NE LME, thermal conditions are changing due to warming of shelf and coastal waters and cooling in the northern end of the range. As a result, there has been a constriction of thermal habitats in the ecosystem with a northward shift in some fish species distributions (i.e., red hake) and shift to a warmer-water fish community (e.g., Narragansett Bay and Rhode Island Sound). The direct/indirect effects of species-selective harvesting patterns have also contributed to shifts from a demersal-dominated fish community to one now dominated by small pelagic fishes (Atlantic herring and Atlantic mackerel) and elasmobranchs (skates and small sharks) of low relative economic value. Notable changes are also evident within the benthic community with the increased abundance of the Atlantic sea scallops and American lobster and declining populations of ocean quahog and Atlantic surf clam (Weinberg 2005; Fogarty et al. 2007; Ecosystem Assessment Program 2009).

The potential importance of temperature regime and climate on fish stocks, especially those that are economically important, has been studied on relatively short temporal and spatial scales in the northwest Atlantic (Frank et al. 1990; Murawski 1993; Drinkwater et al. 2003; Hare and Able 2007). Nye et al. (2009) analyzed temporal trends of 36 fish stocks on the northeast continental shelf from 1968 to 2007 and reported that many stocks (17 of 36 or 47%) spanning several taxonomic groups, life-history strategies, and rates of fishing exhibited a poleward shift in their center of biomass, most with a simultaneous increase in depth, and a few with a concomitant expansion of their northern range. Most notable fish exhibiting a poleward shift were the alewife, American shad, and all southern populations of the silver hake, red hake, and yellowtail founder. These poleward shifts in the center of biomass and increases in depth distribution were consistent with the predicted responses to climate change that had been documented in many ecosystems (Southward et al. 1995; Parmesan and Yohe 2003; Rosenzweig et al. 2008) and in marine fishes (Holbrook et al. 1997; Perry et al. 2005; Dulvy et al. 2008). In addition, increased fishing pressure may also intensify the effects of climate change (Hsieh et al. 2008; Planque et al. 2010), especially at the southern extent of a species' range. On the eastern Scotian shelf, commercial fishing and decadal variability in water temperature appear to have shifted the fish community from a demersal- to a pelagic-dominated state (Choi et al. 2004).

With waters continuing to warm on a global scale, it is thought that the major western boundary current, the Gulf Stream, may weaken (Frank et al. 1990), resulting in fewer juvenile warm-water fishes being transported northward to temperate areas. It is also thought that the general fish assemblages of temperate estuaries may shift from more vertebrate (fish) to more invertebrate (crabs) species with increasing water temperatures (Wood et al. 2009). Collie et al. (2008) reported from 1959 to 2005 in Narragansett Bay and Rhode Island Sound that the coastal nekton community shifted progressively from vertebrates to invertebrates, and especially since 1980 from benthic to pelagic species. Demersal species (i.e., winter flounder, silver hake, and red hake) declined, while warm-water fishes (butterfish and scup) and invertebrates (American lobster, longfin inshore squid, and Atlantic rock and Jonah (*Cancer borealis*) crabs) increased with time. Triggered primarily by rising temperatures, a 1.6°C (2.9°F) increase over a 47-year period altered the trophic structure of the nekton community, resulting in a shift from benthic to pelagic consumers.

If species composition is largely driven by environmental forcing (e.g., SST and North Atlantic Oscillation [NAO]) and coastal temperatures continue to increase, it is likely that the fish community will continue to shift toward a more warm-water and pelagic community resembling those of more southern estuaries such as Chesapeake Bay and Delaware Bay, both south of Study Area (Collie et al. 2008). Rising water temperatures would favor a subtropical-tropical fauna over a temperate/boreal fauna (Oviatt 2004). Climate change-induced range shifts have been documented in the U.S. (Parker and Dixon 1998; Fodrie et al. 2010; Najjar et al. 2010) and in the northeastern Atlantic (Greenstreet and Hall 1996; Stebbing et al. 2002; Beare et al. 2004).

In conclusion, climate change has been implicated a major causes of fluctuations in marine fish diversity and abundance in both pelagic and demersal assemblages. Long-term changes in climate have also been related to changes in recruitment, growth, migration phenology, and depth and latitudinal distributions all of which will continue to be instrumental in affecting present and future fish populations and fisheries within the Study Area (Genner et al. 2010).

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