Potential Impacts of Global Warming on Diadromous Fishes of Connecticut

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As climate change occurs in Connecticut, there will be impacts to the flora and fauna of the region. It is instructive to consider the likely impacts to *diadromous* fishes, a group of species that have been important to humans since the time we arrived in the area. 'Diadromous' refers to fish that migrate back and forth between saltwater and freshwater to reproduce. There are two groups of diadromous fishes. *Anadromous* species begin life in freshwater and after a juvenile phase, migrate to saltwater to feed, grow and mature. They migrate back to freshwater (usually the same water body of their origin) to spawn. *Catadromous* species begin life in the ocean and migrate to freshwater to feed, grow and mature. They migrate back to saltwater to spawn. In Connecticut, we have 13 species of anadromous fish: sea lamprey, shortnose sturgeon, Atlantic sturgeon, Atlantic salmon, sea-run trout, rainbow smelt, American shad, alewife, blueback herring, gizzard shad, hickory shad, striped bass, and white perch. We have one catadromous species: the American eel. Each one of these species has evolved complex life histories and migratory strategies to adapt to both the freshwater habitat in Connecticut and the oceanic habitats both near and distant to Connecticut. All of these species have had value to humans from the earliest times. Some still support important commercial or recreational fisheries. They also are important components to complex ecosystems that include not just coastal areas but even distant mountainous areas beyond Connecticut (due to the long freshwater migration of some species). Their ecological value is not limited to aquatic species but also extends to terrestrial species such as birds and mammals due to predator-prey relationships. While it is not the intent of this paper to fully describe the life history and ecological relationships of these diadromous species, it is important to understand the importance and wide-range of the species to appreciate the scale of potential impacts from climate change.

Anadromous fish evolved their unique reproductive strategy to take advantage of higher productivity in the ocean relative to the freshwater habitats in which they originated. Because of this, the majority of anadromous fish evolved in temperate latitudes, particularly where the landmass had been glaciated and the freshwater habitats exhibited low productivity. Concurrently, the adjacent ocean habitats had very high productivity. This differential favored the development of anadromous fish that could migrate to the ocean and grow faster and compete better with other species that stayed in freshwater streams. In warmer, more tropical areas, the freshwater habitats are more productive than the adjacent ocean habitats and therefore there was no evolutionary pressure to migrate to the ocean to grow. However, such a differential favored the development of catadromous species, and the American eel, which hatches in the Sargasso Sea east of the Caribbean Sea, could grow faster by colonizing freshwater habitats, some quite distant from the Sargasso. In a broad sense, any climate change that changes the productivity of these two habitats threatens to disrupt the driving mechanism that helped develop anadromy and catadromy. For example, if freshwater lakes and streams in Connecticut become much more productive due to warming and eutrophication, there will be less advantage for fish to migrate to Long Island Sound and the Atlantic Ocean. Similarly, if the lower productivity of the Atlantic Ocean at lower latitudes creeps northward and diminishes the productivity of the ocean off New England, there will be less advantage to anadromy. Since the Sargasso Sea will remain in an area of lower productivity and the productivity of the freshwater habitats along the East Coast—and Connecticut, specifically—will continue to increase, it does not appear that the driving mechanism for catadromy by American eel will diminish.

Each of the 13 anadromous fish species has habitat preferences that include thermal tolerances. Some, such as striped bass and blueback herring have larger populations along the southern portion of the East Coast. Others, such as Atlantic salmon and rainbow smelt are found only in the northern portion of the East Coast. In fact, Atlantic salmon was never found farther south than Connecticut. It seems logical to conclude that as climate change warms aquatic habitats, there will be some winners (southern species) and some losers (northern species). This appears to have already begun. Gizzard shad were not found in Connecticut historically but entered rivers in states south of New England. A few gizzard shad appeared in Connecticut in the 1970s and by the 1990s, the species was firmly established in Connecticut rivers through natural range extension. It appears the same may be true of hickory shad, although this estuary-spawning species is harder to document as an established species. Conversely, up until the 1960s, there were many abundant runs of rainbow smelt in the state, in places like the Saugatuck, Hammonassett, Connecticut (and tributaries), Niantic, Thames, and Mystic rivers. A survey by a University of Connecticut graduate student in 2005 failed to document any smelt runs in Connecticut and the species is now listed as ‘State threatened’ and there is support for changing that to ‘State endangered’. There is reason to fear that Connecticut is become less hospitable for Atlantic salmon, as well, but that picture is confounded by the fact that salmon were extirpated from the state by the late 1700s due to the construction of barrier dams and the present-day salmon run into the Connecticut River and its tributaries is being maintained by a restoration program in which government agencies stock millions of young salmon into the system annually.

A simple understanding of how temperature drives freshwater productivity may lead us to the conclusion that there will be more fish. Warmer streams in the south (e.g. the Susquehanna, Shenandoah, Roanoke, Cape Fear) have higher productivity and *generally* more fish per acre than the colder rivers of the north (e.g. Merrimack, Kennebec, Penobscot, St. John). For species that tolerate warmer temperatures (e.g. American shad), it is possible that there will be a trend of more fish. It is also true that coastal habitats have been alternately warming and cooling through the millennia as glaciers have been advancing and retreating. As the ice sheet moved south, diadromous species were excluded from northern rivers but some southern river became hospitable so they colonized them. As the ice retreated northward and northern river once again ‘opened up’, the fish re-colonized them. As the same time, some of those southern rivers may have become too warm and the runs of some species disappeared. In a sense, the current climate change is not much different than what these species have been experiencing for thousands of years. However, the past climate changes have been relatively slow and have allowed ample time for populations to spread and allow evolution to adapt the species to the new regions. The current human-driven climate change is very rapid and it is uncertain how quickly the species can evolve/adapt to ‘keep up’ with the changes. Furthermore, by this time in history, most of the populations have been impacted by humans. Pollution, habitat degradation, and over-harvest are things that have reduced the size of the populations and—more importantly—the genetic variability of these populations. This is a technical but important point. Historically, a healthy run of fish would have lots of different genes, including some uncommon genes found only in some individuals. However, these uncommon genes may have coded for traits that were not important at the time but could be important in the future. One example is thermal tolerance. There is a gene in Atlantic salmon that appears to allow salmon to tolerate warmer water temperatures. As long as such a gene is present in a population, if climatic conditions change, evolution can help the population adapt to the new conditions. But if the gene is lost from the population due to over fishing, the only way that the population may be able to adapt to changing conditions would be a serendipitous mutation—when a new gene randomly arises. The important point is that diadromous fish populations of the 1600s (prior to humans' impact) were genetically better suited to adapt to climate change than the populations of the early 21st Century.

Life history strategies of these species are much more complicated than a simple model of higher temperatures means more young fish. For example, all shad south of the Cape Fear River in North Carolina die after they spawn. Shad entering rivers north of the Cape Fear can survive spawning to a varying degree. The farther north the river, the more individuals survive spawning. In the Connecticut River, traditionally about one-third of the run is comprised of ‘repeat spawners’ (fish that entered the river in previous years). In Maritime Canada, that percentage is even higher. Some may spawn two or three times before they die. How many fish survive a spawning migration in a particular river is likely a function of water temperature and the fish's energy expenditures. Interestingly, the fecundity (number of eggs per individual female fish) is higher in the southern rivers than the northern rivers. Apparently, nature has developed a system where the lack of repeat spawning in the south is compensated by more eggs being produced during the one spawning run. This phenomenon evolved in the species over thousands of years. It is likely that rapid warming of coastal waters will result in rapid reduction of survival of post-spawned shad but it is unclear if the compensatory trait of higher fecundity could evolve in these streams fast enough to keep the species from declining.

Another life history strategy is the relative inactivity of juvenile Atlantic salmon in New England streams during the winter. Throughout much of Northern New England, streams are completely frozen over with a two to three foot deep snow cover. Since most precipitation events are snow, the streams are relatively stable and calm throughout the winter. Young salmon are mostly dormant, feeding very little but they don't need to feed much because with diminished flow and lack of predators, they are safely tucked away for the winter. However, this winter freeze-up is less common in southern New England and becoming less common throughout New England with global warming. Some streams may stay unfrozen all winter and subject to highly fluctuating flow levels as winter rainstorms pass through. Such increases in flows and vulnerability from predators means that young salmon much expend more energy and therefore feed more. Yet it is still winter with less food (aquatic insects) available. It is believed that these conditions result in increased over-winter mortality.

Climate change in Connecticut will probably be more than just warmer temperatures. In fact, it remains to be seen if New England experiences the same uniform warming as many parts of the world. With the Arctic Ice Cap melting, the south-flowing Labrador Current will run colder (ice melt) and that might actually cool the landmasses of Maritime Canada and New England. In any case, climatologists believe that New England will see greater annual rainfall and more severe weather. Adult fish can adapt to changing water flows. If a flood occurs when they are trying to move upstream, they can pause either in Long Island Sound, the estuary, or a deep section of the stream to wait for the freshet to subside. Eggs and larvae are less adaptable. If heavy rains and flooding occurs when young shad, alewife, and blueback herring are hatching and beginning to feed, the survival rate will be much lower. Such events have occurred in the past and have resulted in a weak year class—part of the natural ups and downs wild animal populations exhibit. However, if the frequency of storms increases in Connecticut, the likelihood that one such storm will occur during the critical hatch-out stage will increase and there will be more frequent ‘year class failures’ than we now see.

Severe weather, including powerful hurricanes, have always occurred in Connecticut but in the past the environment has been more natural, healthy, and protected. Naturally vegetated riverbanks with functioning riparian wetlands mitigate the effects of storms. However, we have destroyed many riparian wetlands, we have cleared forests, paved a large portion of the state, we have active erosion sites that turn rivers brown when it rains. We have built dams that have accumulated huge amounts of sediment behind them. When storms occur now, it is much more likely that deleterious substances (sand, oil, plastics, sewage) will wash into the streams and degrade the fish habitat. Some of the events can be catastrophic. We have thousands of dams in Connecticut, all holding back years and years of sediment accumulations. If a flood breaches a poorly maintained, ‘orphan’ dam, there will be a huge destructive wave of water that goes downstream, destroying riparian habitat, followed by a deluge of sand and silt that will bury important gravel beds where fish need to spawn. The likelihood of such an event increases with the more severe weather predicted with climate change as well as the deterioration of aging dams that were built in the 1800s.

Experience indicates that warmer climates are more susceptible to the invasion of non-native species of plants and animals. One reason for this is that there are more species at the equator than the poles and more niches for species in warmer climates. As Connecticut gets warmer, more non-native species may become established and they may stress native diadromous fish species. Such species will not be limited to other fish species like flathead catfish or (heaven help us) Asian carp. Zebra mussels, Chinese mitten crabs, *Hydrilla*, and water chestnut have the potential to alter the ecosystem to the detriment of native fish.

Migratory species are the most difficult to manage, protect, conserve and restore due to the added complexity of the need to migrate. For example, a young salmon can migrate to sea only during a brief springtime window when its body is physiologically adapted to saltwater due to the influence of water temperature and daylength. If it arrives too early or too late, it will not survive the transfer to saltwater. Moreover, there are patterns in streamflow and the arrival of predators that challenge the migration. Young salmon arrive in the ocean with the need to begin feeding immediately. If young smelt or sandlance are not present, the salmon will starve. The timing of the migration of salmon (as well as every other diadromous species) is synchronized with the migration of other species and environmental patterns to ensure the survival of the species as well as the greater ecosystem of which it is an important part. All of these things co-evolved, historically, in a system of gradual change. It is unclear whether there will be an 'uncoupling' if rapid climate change due to human activities and the well-synchronized system descends into chaos in which interdependent species diverge.

Perhaps the greatest unknown threat to diadromous species is the changes to the ocean. We know that anadromous species find their way home from coastal waters using their sense of smell to recognize natal freshwater habitats. However, we don't know how some species get back to coastal waters—such as the Atlantic salmon that travels to West Greenland, 3,000 miles from Old Saybrook, CT. It is suspected that they use ocean currents to guide them. Currents that have been stable and predictable (like the Gulf Stream and the Labrador Current) can be used to navigate and the species can evolve traits through natural selection to adapt to them. The American eel clearly uses the Gulf Stream to travel north from the mid-Atlantic to distribute itself along the East Coast. How the larvae leave the Gulf Stream and enter coastal waters like Long Island Sound is poorly understood. However, such currents are maintained by temperature and salinity gradients. There is a huge deepwater current from north to south that acts like a conveyor belt and provides the energy to drive various currents. As the waters to the north warm, the gradient between the Arctic waters and the tropical waters decreases and so does the strength of the conveyor belt and associated currents. With less energy, the direction of the currents can also vary, perhaps analogous to the wobbling of a slowing top. Many researchers fear that the currents have already been impacted by climate change and the decline of long distance migrants like Atlantic salmon and American eel are due to this phenomenon. The fish either cannot find their way to productive habitats or the habitat to which they are guided are no longer productive. Coastal migrants like sturgeon and striped bass may be less vulnerable to such changes.

Up to this point, I have focused on biological/ecological threats of climate change to diadromous fish. However, socio-political impacts from climate change may pose additional threats. Sad but true, most diadromous fish now rely on human intervention to maintain healthy runs of the East Coast of the United States. Government agencies, conservation groups, harvesters, anglers, and volunteers all work within a system of hatcheries, fish ladders, regulations, and habitat management to create a system that allows the fish to survive in an ecosystem dominated by food- and energy-demanding human beings. Much of this system requires money. With climate change will come enormous challenges to the infrastructure of Connecticut and the United States. If the prediction of a 20-foot sea level rise is realized by 2040, many of us will live to see massive changes. If we expect to maintain parts of Stamford, Bridgeport, New Haven, and New London, massive public works projects similar to the Netherlands will need to be initiated. However, it is not simple to wall off large areas of land because when it rains, rainfall inside the walls collects and flows toward the sea in streams that must reach rivers and Long Island Sound. The mouths of these streams inside a dike system may be lower than the sea level and the run-off will have to be pumped up to the sea. This is currently done in Hartford and East Hartford when the Connecticut River is in flood and the gates to the dike must be closed. With sea level rise, those existing dikes of Hartford and East Hartford will have to be raised, probably by more than 20 feet when you consider increased frequency of severe floods. The dikes will have to be expanded to the north and south to either save communities like Windsor, South Windsor, Glastonbury, and Rocky Hill or wall them out. What we will do with continuous coastal communities like Branford east to Old Saybrook is unimaginable. With increased flooding comes risks from scores of dams. The State may no longer be able to wait for private dam owners with modest means to perform needed repairs. To protect the public, government may have to step in and remove or repair dams. Existing infrastructure such as sewer outfalls, water mains and treatment plants, utilities, and transportation corridors will need to be replaced or modified. In the process of all of this activity, new barriers to diadromous fish migration and new degradation to diadromous fish habitat will be created. New technologies to get fish past dikes, pumps, and tide gates will be needed. These public works projects will cost billions of dollars and will become a top priority along with the need to maintain traditional social services. It will become increasingly challenging to secure funding to ensure that healthy fish runs are maintained into the future.