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Restoring Atlantic salmon (*Salmo salar*) to New England

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Atlantic salmon (*Salmo salar*) is an anadromous salmonid distributed in the North Atlantic Ocean. 'Anadromous' fish are species that begin life in freshwater, migrate to the ocean during a juvenile stage, grow and mature in the ocean, and migrate back to the freshwater of origin to spawn. Atlantic salmon may survive spawning and return to the ocean to recondition and return for subsequent spawning seasons, unlike the Pacific salmon, which all die after spawning. Atlantic salmon most likely navigate through ocean currents offshore via innate behavior that is genetically regulated. However, they are able to home to their natal streams via learned behavior: the 'imprinting' to chemical properties of natal streams to which they may 'home' years later. The life cycle of Atlantic salmon in most of New England is typically two years in freshwater and two years in saltwater but the duration of these phases is highly variable both within New England and throughout the species' range. A more detailed overview of the species' life history can be found in Scott and Crossman (1973).

In North America, the species' native range extended from Ungava Bay in Northern Quebec south to the Housatonic River in Connecticut. Major North American salmon rivers included the Moise, Restigouche, Miramichi, Margaree, St. John, Penobscot, Kennebec, Androscoggin, Saco, Merrimack, and Connecticut. Salmon were also found in the Shetucket and Quinebaug rivers, two major tributaries of the Thames River, which flows past Connecticut College. In Europe, the species' native range extended from the Pechora River in Siberia, Russia, west across Norway and down the coast to northern Portugal. Salmon were also found in streams flowing into the Baltic Sea, the British Isles, and Iceland. Major European salmon rivers included the Tenno, Alta, Vistula, Rhine, Thames, Seine, Loire, and Bush. The drainages around the North Atlantic Ocean that supported native Atlantic salmon corresponded to the land that was glaciated, with the southern extent of the range (Long Island Sound to the west and mid-Portugal to the east) representing the southernmost extent of the glaciers. A more detailed overview of the world distribution of this species can be found in MacCrimmon and Gots (1979).

The connection to glaciated streams is the species' need for gravel/cobble streambeds in which to spawn. Salmon lay their eggs in gravel nests in the streambed. Non-glaciated streams to the south (like the Hudson, Potomac, Cape Fear, and Pee Dee) are mud/silt streams with no gravel. Even large New England rivers like the Connecticut do not have gravel near their mouths and salmon needed to reach the headwaters in the mountains (in the case of the Connecticut River, in Vermont and New Hampshire) or in the steeper lower tributaries (in the case of the Connecticut River, the Salmon, Farmington, Westfield, or Deerfield rivers).

The Decline of Salmon in the U.S.

The more rugged terrain of glaciated New England provided more lucrative mill sites than more southern drainages. Dams were built atop waterfalls and rapids of various heights to power mills of the Industrial Revolution. Mill villages sprang up at these sites, such as the Connecticut villages of Seymour, Westville, Collinsville, Tariffville, Moodus, Chester, Greeneville, Jewett City, Danielson, and Putnam as well as Lowell, Holyoke, and Turners Falls, MA; Manchester and Hooksett, NH, and Lewiston, Rumsford, Dover-Foxcroft, and Millinocket, ME. These dams blocked the migration of Atlantic salmon and often prevented them from reaching critical spawning habitat in the headwaters. Where the dams were close to tidewater (e.g. Greeneville in Norwich, CT), the entire run of salmon was extirpated. Where dams were upstream of some spawning habitat (e.g. on the Penobscot River in Bangor, ME) or where the dams were very low and salmon could leap over them (e.g. the Narraguagus River in Cherryfield, ME), small remnant populations of salmon persisted into the 20th Century. Over-harvesting of salmon, pollution, and other types of habitat degradation also contributed to the decline of Atlantic salmon but in the U.S., the construction of dams was the most important and consistent cause for the extirpation/decline of salmon. All salmon runs south of mid-coast Maine had totally disappeared by 1960 and only a handful of the runs north of that (mostly in Washington County, ME near the Canada border) survived. Parrish *et al.* (1998) provide a detailed summary of the status of Atlantic salmon stocks worldwide and provide some information regarding the causes of declines and threats.

Conservation Efforts

Efforts to conserve and restore runs of salmon to New England began in the 1860s but were suspended throughout most of the region by the early 1900s due to lack of success. Efforts have continued at some level ever since in Maine, particularly on the Penobscot River. Modern efforts at Atlantic salmon restoration began in 1963 when Congress passed the Anadromous Fisheries Restoration Act that provided federal funding for interstate, cooperative efforts. Restoration programs began on the Penobscot River in 1965, on the Connecticut River in 1967, on the Merrimack River in 1969, and on the Pawcatuck and other rivers in subsequent years. Adult returns from the ocean slowly began to increase. The first adults returned to the Connecticut River in 1974; 90 returned in 1978; 529 in 1982; but by the 1990s, the run size to the Connecticut and all salmon rivers were declining, despite increased stocking and effort. Returns back to the last surviving native runs in Washington County, ME dwindled to single figures. In 2000, the species in these last native runs were listed as 'endangered' under the federal Endangered Species Act. For more information about the listing, see http://www.nmfs.noaa.gov/pr/species/esa/.

Currently, there are two major initiatives for Atlantic salmon in New England: restoring extirpated populations (e.g., the Connecticut River program) and recovering listed populations (e.g. the Narraguagus River in Maine). The activities associated with both initiatives are similar but how these activities are managed varies among the programs. The activities of the Connecticut River program described here are as typical of these programs.

The program is managed by the Connecticut River Atlantic Salmon Commission (CRASC), which was authorized by an act of Congress. It consists of the top fisheries agency commissioner from each of the four states on the river, the Regional Directors from the U.S. Fish & Wildlife Service (USFWS) and the National Marine Fisheries Service, and one private citizen appointed by each governor of the four states. The CRASC sets policy and general direction of

the restoration program. It relies on its Technical Committee to make science-based technical decisions and manage the workload on a day-to-day basis. The Technical Committee is composed of senior fisheries biologists from each State and federal agency represented on the CRASC. The Technical Committee has sub-committees that help develop work plans and review programs. These subcommittees include Salmon Studies, Genetics, Fish Culture, and Smolt Advisory. The sub-committees may include members who are not members of the Technical Committee but are other staff from member agencies.

Once decisions and plans have been made on how to work toward restoration, activities are carried out in the four states by the appropriate agencies by their staff. For example, all juvenile salmon released in Connecticut are stocked by staff from the CTDEP/Inland Fisheries Division. Fishways at Massachusetts dams are planned and constructed by the MA Division of Inland Fisheries and Wildlife. Adult salmon migrating up Vermont rivers are tracked by staff of the VT Fish and Wildlife. The USFWS operates three salmon hatcheries and a salmon holding facility in MA and VT. The juvenile salmon produced in the federal hatcheries are stocked in all four states. The states of Connecticut and Massachusetts also operate salmon hatcheries and all of those juvenile salmon are stocked into streams in the appropriate states.

Planning

State biologists surveyed the streams in their states that flow into the Connecticut River to determine where suitable Atlantic salmon habitat still exists. In CT, it was determined that only three tributary drainages still possessed significant amounts of high quality habitat suitable for supporting Atlantic salmon: the Farmington River (entering at Windsor), the Salmon River (entering at East Haddam), and the Eightmile River (entering at Lyme). These tributaries have many sub tributaries that possess good salmon habitat. All suitable streams were surveyed and measured to calculate the amount of juvenile salmon that each could support. All migratory barriers (e.g. dams) were documented within this critical habitat. Various plans were developed: stocking plans (how many fry are stocked within each stream), fish passage plans (how to get fish upstream and downstream around barriers), and general habitat plans (identify land that should be acquired for preservation or habitat restoration).

Stocking

Early stocking of juvenile salmon consisted entirely of hatchery-reared smolts. Eggs from Canada and, later, Maine were incubated and hatched in hatcheries within the basin and raised initially for two years but subsequently one year until they reached the smolt stage in the spring. Smolts were trucked from the hatcheries and stocked into tributaries to which they could return and spawn. This practice slowly began to generate adult returns back to the river. Experimental stocking of fry (less than one month old) began in the mid-1980s and showed great promise. The decision was made in 1994 to emphasize fry stocking as the major stocking strategy as a way to minimize artificial selection that inevitably occurs in hatcheries. Due to space limitations, the smolt-rearing program was eliminated at that time. It was resurrected in a different hatchery in 2000 and the first significant return of hatchery-reared smolts since that time occurred in 2006. Fry stocking continued at the same level. The two life phases that were stocked at the same time are not competitive. Fry are stocked in all suitable rearing habitat (including that upstream of the dams) and need to live and feed there for about 2 years before leaving for the sea. Smolts are stocked in non-rearing habitat, often below the dams and only need to stay in the river for about a month prior to leaving for the sea.

Fish Passage

Reintroducing fish back into the habitat will not achieve restoration if the original problem of barrier dams is not addressed. CRASC partners have strategically targeted barriers within the designated restoration rivers for fish passage—which could mean total removal or the construction of fishways. Large hydroelectric dams cannot practically be removed but need to be licensed by the Federal Energy Regulatory Commission (FERC). CRASC and its partners intervened in the re-licensing procedures and FERC required the licensees to build state-of-the-art fish passage facilities to pass salmon (and other migratory species). At smaller and non-licensed dams, CRASC partners pursue fish passage through other approaches. Facilities are needed not just to get adult salmon upstream but also to allow juvenile smolts downstream, safely, around turbines and other threats. Traps designed to safely capture returning adults were installed within fishways at the dams that adult salmon first encounter as they swim upstream from the ocean.

Fish Breeding

The overall strategy is to breed returning salmon with each other to eventually create a new stock of salmon comprised entirely of fish that have returned from the ocean to the Connecticut River. It is believed that natural selection will have occurred in fish coming back to the river and the stock will slowly evolve into a unique, adapted strain that is suitable for the Connecticut River and different from the original stock from Maine. However, when the run back to the river was less than 20 fish each year, there were not enough eggs to continue the stocking. Therefore, eggs were continually imported from Maine. To augment the program's egg production, a line of 'domestic' broodstock was created by raising in a hatchery some eggs all the way to mature adults (thus completing the life cycle completely inside the hatchery.) These eggs came from parents that returned to the river from the ocean. The eggs from this broodstock are hatched and the fry and smolts are stocked into the river along with the offspring from the sea- returned adults. By 1994, the program was producing enough eggs to meet its initial targets and the importation of eggs from Maine was terminated. All juveniles that are now stocked are either 'children' (from sea-run broodstock) or 'grandchildren' (from domestic broodstock) from salmon that have returned to the Connecticut River. Recent genetic comparisons between the Connecticut River and Penobscot River stocks show that there is an increasing difference between the two stocks, indicating that natural selection is occurring.

One of the reasons that fry stocking was emphasized was to maximize the time that natural selection can be applied to the salmon. Hatchery-reared smolts are protected from natural selection during the first portion of their lives whereas stream-stocked fry spend most of their lives in natural habitat, being subjected constantly to natural selection. Natural selection during the juvenile life phase will allow future generations of salmon to be better adapted to living in natural habitat within the Connecticut River watershed.

Results

The numbers of returning adults increased during the 1970s and 1980s but began declining during the 1990s (Figure 1). Declines in adult returns have been seen in most rivers in North America and many in Europe during the same time period and it was this downturn that resulted in the last remaining native runs in the U.S. being listed under the federal Endangered Species Act. Investigations have concluded that the major driving forces behind the decline are occurring

in the ocean, which all river populations have in common. However, the identity of the causes are yet unknown. Coordinated marine research on Atlantic salmon under the name SALSEA is being planned for the next few years.

International Efforts

River programs like the Connecticut River work at a local level to restore local salmon runs. But highly migratory species like the Atlantic salmon leave their natal rivers and migrate through other political jurisdictions. The cooperation of all such jurisdictions (e.g., states and nations) is required to achieve restoration and recovery. Closing down fisheries in the Connecticut River watershed, stocking millions of fish, and tearing down dams will not be successful if the surviving adults are netted in distant fisheries in other countries. The North Atlantic Salmon Conservation Organization (NASCO) is an international organization created by a treaty among all North Atlantic Ocean nations in 1983 and given the charge for conserving salmon in the ocean. After setting progressively more restrictive quotas in interceptory fisheries for years, NASCO finally shut down all significant fisheries in 2003 (http://www.nasco.int/greenlandmeasures.htm). The run sizes have continued to decline, however, demonstrating that marine factors other than fisheries are more to blame for the decline. NASCO is now focusing on SALSEA and best management practices to re-build salmon populations.

Literature Citied and Other Resources

Atlantic Salmon Federation: http://www.asf.ca/

Connecticut River Coordinator's Office- U.S. Fish & Wildlife Service: http://www.fws.gov/r5crc/index.html

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Figure 1. Returns of Atlantic Salmon to the Connecticut River