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Marine Matters

Atlantic Salmon on the Brink

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Abstract

Over the past 30 years Atlantic salmon in their natural range in Eastern North America have undergone a steep decline in numbers. In spite of many steps taken to regulate the harvest, in particular a virtually complete ban of the commercial fishery, the decline has continued. In the U.S. the Department of Interior proposed on November 17, 1999 that the salmon populations in eight rivers in Maine be classified as endangered under the Endangered Species Act (ESA). The State of Maine has opposed this action. The Atlantic Salmon Federation and Trout Unlimited have jointly filed a lawsuit in Washington, DC, to force an emergency listing under the ESA that would shorten the time for corrective action to be taken. In Canada, the Department of Fisheries and Ocean has submitted a request to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that the salmon in the 33 rivers comprising the so-called Inner Bay of Fundy Rivers be listed as endangered. Unlike ESA, COSEWIC has no regulatory power to require corrective action to be taken following its listing decisions. This gap is to be addressed by proposed legislation in the Canadian Parliament of a Species at Risk Act, with regulatory powers.

The continued decline in salmon numbers appears to be caused by increased mortality in the sea. Possible anthropogenic-based explanations are depletion of the salmon's normal food source by commercial fisheries for forage fish, such as capelin, and exposure of juvenile salmon during their freshwater phase to the "endocrine disrupter" nonylphenol, which leads to mortality later in the marine phase. Interactions between wild and escaped farm-raised salmon can also be added to the suspect list. As for natural processes at work, there are several possibilities. These include predation by seals, disease, and large-scale oceanographic perturbations, in particular those involving temperature. Recent advances in acoustic telemetry, which for the first time allows the tracking of postsmolts many miles in the open ocean, hold promise for finding out where and when the as-yet unexplained increased marine mortality occurs.

The problem

Thirty years ago, about one and a half million small and large Atlantic salmon (*Salmo salar*) returned each year to spawn in their natal rivers in eastern North America (Marshall et al., 1998). Today, only about 350,000 do so. That's a reduction of more than 75 percent.

Population structure has changed too. In the 1970s, the proportion of small salmon called grilse (salmon which have spent

one year at sea [1SW]) was about 45 percent. This has risen in the past few years to about 75 percent...the wrong direction for conservation purposes since it is the large salmon, which are mostly female and 2SW or older, which possess the bulk of the eggs for the next generation. While the number of salmon of North American origin has fluctuated, the stark reality is an unmistakable downward trend (Figure 1).

The picture would look even more alarming if we had reliable historical data to start the time series earlier, say at the end of the eighteenth century. Despite limited commercial salmon fishing off Newfoundland and Labrador by early settlers and Europeans, adult salmon of North American origin were likely at a population equilibrium, numbering well over the one and a half million estimated for 1969. Then came industrial progress, and the beginning of the decline. The

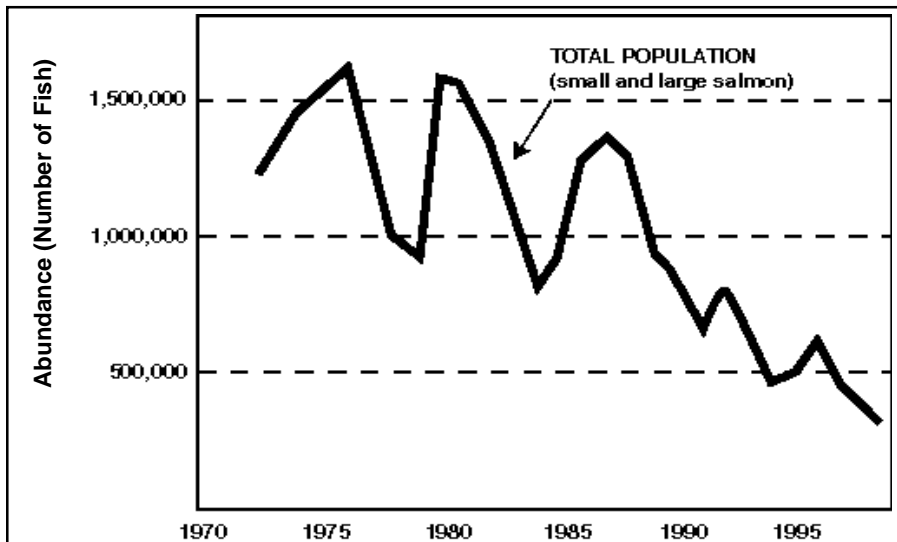


Figure 1. Numbers of Atlantic Salmon returning to North American Rivers.

early leading cause, particularly in New England, was dams that destroyed habitat, and denied access to much of whatever suitable habitat was left. A notable example was the first mainstem dam in 1794 at Hadley Falls, MA, on the salmon-prolific Connecticut River. Further depredation of the freshwater habitat followed from pollution from many sources, including industrial and municipal effluents, agriculture run-offs, forestry practices, and acid rain. The last salmon taken in Lake Ontario was in 1900. Commercial fishing by Americans and Canadians started taking its toll elsewhere in the twentieth century.

Species protection efforts

American states were forced to impose tough regulatory measures earlier than Canada. The last New England State to ban commercial salmon harvests was Maine in 1948. Regulations banning commercial salmon fishing in New Brunswick and the Gaspé region appeared in 1972. Virtually all commercial salmon nets had been lifted from the water by 1998. These regulations retired more than 10,000 licenses at a cost to federal and provincial treasuries of more than \$70 million (Cdn). Furthermore, the west

Greenland fishery, a once serious threat to salmon stocks, has been reduced to a small subsistence harvest through international treaty negotiations.

Tough regulations were applied to the recreational fishery as well. By the mid 1980s, conservation-oriented restrictions were imposed in Maine, the only state in New England where salmon angling was permitted, and all jurisdictions in Canada. These regulations included combinations of daily and seasonal bag limits, mandatory release of large salmon, and tagging retained fish to permit identification of poached salmon. By the mid 1990s, catch-and-release policies applied to all salmon caught in many areas, and a complete ban on salmon angling was imposed in other areas.

Listing

The presence of stringent conservation policies throughout the salmon's remaining range attests to the seriousness of the salmon's situation. Currently, populations in two areas are candidates for endangered species listing: the Down East region of Maine and the Bay of Fundy in Canada.

Maine

In New England, anadromous runs to

once prolific salmon rivers such as the Connecticut, Pawcatuck, and Merrimack were extirpated in the 1800s. Current runs result from restocking with hatchery fish and thus are not eligible for listing, although they are low. Despite hatchery stockings of rivers, it is possible that some remaining salmon rivers and their tributaries still contain evolutionarily unique strains of salmon. Several lower tributaries of the Kennebec and Penobscot Rivers are suspected to contain unique salmon strains. Even the main stem of the Penobscot, despite the hatchery stocking of nonnative salmon, may also contain salmon with historical genetic lineage intact. More testing, however, is required to confirm this suspicion.

There are, however, eight rivers in Maine from the lower Kennebec River to the Canadian border, whose salmon have been determined to be wild and genetically distinct enough to qualify for listing (Figure 2). They are the Dennys, East Machias, Machias, Narraguagus, Pleasant, Cove Brook (a tributary of the Penobscot), Ducktrap, and Sheepsfoot.

A relatively new environmental group, Restore the North Woods, and two other groups petitioned the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) to list Atlantic salmon as endangered under the 1973 Endangered Species Act (ESA). In 1995 the FWS and NMFS jointly conducted a review that concluded that Distinct Population Segments (DPS) of the species, as defined in the ESA, were in danger of extinction. A subsequent listing under ESA would place stringent controls on the several industries, including angling, whose activities could negatively impact the salmon's health.

The State of Maine countered by developing a recovery plan through an Atlantic Salmon Task Force. The Task Force consisted of representa-

tives from agriculture, aquaculture, forestry, recreational fishing, the University of Maine, and the Penobscot First Nation. The plan was ambitious. It called for stream management and habitat improvement in both tidal and uplands sections of the rivers. Aquaculture, agriculture and forest management were charged with ensuring adherence to management practices designed to have minimum ecological impact upon Atlantic salmon. The plan was sufficiently impressive to persuade the FWS and NMFS to accept the state's management plan in lieu of proposed protection under the ESA as a threatened DPS for Maine salmon in seven rivers, with the eighth added later.

Early in 1999 a public hearing was held to consider progress over the past two years on the state's conservation plan. This formed the basis for a required progress report to the FWS and NMFS. Critics, including the Atlantic Salmon Federation, which was represented on the Task Force, concluded that while the conservation plan was a good blueprint for recovery, it was not meeting its objectives. Criticism focussed on inadequate funding by the state, and unsatisfactory implementation of several key elements of the plan, in particular measures to minimize potential adverse affect from the blueberry and aquaculture industries. ASF and Trout Unlimited (TU) decided to take drastic action. In August 1999, both jointly filed a lawsuit in Washington, D.C., to force the federal government immediately to protect Maine's Atlantic salmon under the ESA.

In October 1999, the FWS and NMFS issued an exhaustive 225-page biological status review report that agreed the recovery plan was flawed (FWS 1999 [a]). Like ASF and TU, it expressed serious concern that potential negative impacts of commercial aquaculture were not being adequately addressed. The report con-

cluded by reiterating the Services' 1995 observation that the Atlantic salmon in the rivers eligible for listing were in danger of extinction. Actually, the salmon themselves told the story. In 1995 as many as 500 salmon were estimated to have returned to the eight rivers in question. By 1999, this had plummeted to less than 50.

On November 17, 1999, the Department of Interior formally announced in the Federal Register its intention to list salmon in the eight rivers as endangered, an upgrade from its earlier proposal for a threatened classification (FWS, 1999 [b]). Governor King of Maine expressed strong opposition to the proposal. The FWS and NMFS are required to hold public hearings on the issue (scheduled for January, 2000), and subject the announcement to a 90-day comment period before a final decision can be made. If the Services decide to list the DPS salmon as endangered as expected, however, the ESA requires the Services to develop a recovery plan with all stakeholders involved. This listing process could take another 12 to 18 months to complete. This lengthy timeline was unacceptable to ASF and TU. The jointly-filed lawsuit to force an emergency listing, which would require a much shorter process, is still in progress.

Bay of Fundy
Atlantic salmon in

the Bay of Fundy, like their counterparts in the contiguous marine ecosystem of the Gulf of Maine, are also showing signs of extreme ecological stress (Amiro 1999). Within the Bay of Fundy there are two distinct groups of Atlantic salmon. The first group are from rivers ranging from the Saint John River westward to the Saint Croix River, the international border between Maine and New Brunswick. This area is known as the Outer Bay of Fundy rivers which contain a mix of 1SW and 2SW salmon which migrate to the North Atlantic Ocean, as far north as west Greenland for 2SW salmon. The salmon populations in these rivers are not in good health.

It is the second group of salmon in the Inner Bay of Fundy (IBOF) rivers—the 33 rivers extending clock-

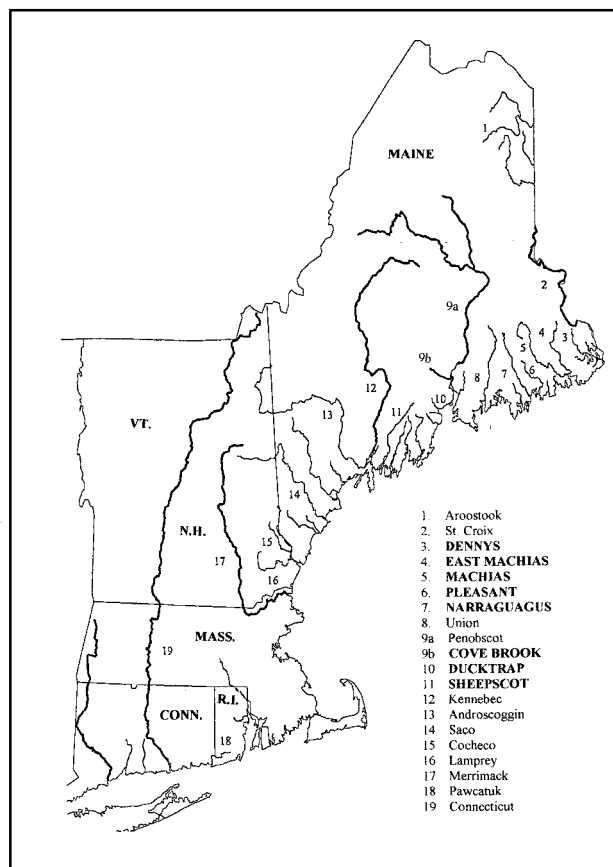


Figure 2. New England Atlantic salmon rivers highlighting eight in Maine (bold print and caps) whose salmon runs are proposed for ESA listing as Endangered (adapted from FWS 1999 [a]).

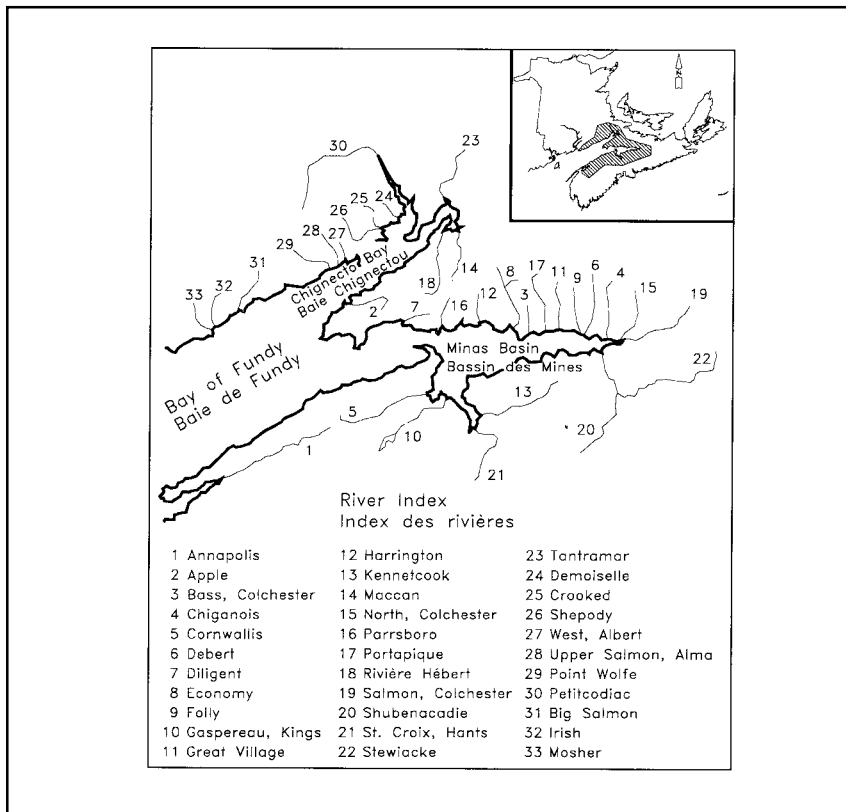


Figure 3. Map showing the Inner Bay of Fundy Rivers whose salmon runs may be listed as endangered.

wise from, but not including, the Saint John River in New Brunswick to the Annapolis River in Nova Scotia—that are being targeted for listing as endangered under Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Figure 3). The basis for concern is plain enough (Kenchington 1999). As recently as the mid 1980s, salmon runs in the IBOF rivers were as high as 40,000. The subsequent decline in salmon runs was so drastic that all fishing in IBOF rivers was banned after 1990. **By 1999 only a few hundred salmon returned, a decline of more than 99 percent in fifteen years.** As in the U.S., an essential factor supporting listing is a unique genetic make up of the population. Results from allozyme, microsatellite and mitochondrial DNA testing show that IBOF salmon have a distinct evolutionary lineage making them separate from other North American populations, including the Outer Bay of

Fundy rivers.

Similar to the situation in the U.S., interactions among wild salmon and escaped farmed salmon from the Canadian Bay of Fundy aquaculture industry were an issue. Here, however, the magnitude of the interactions, and potential impacts, were clearer because of scientific research programs which had documented the number of wild fish, and escaped farmed fish, entering and spawning in rivers (Carr et al., 1997).

In October 1999, the Department of Fisheries Oceans submitted a recommendation to COSEWIC that Atlantic salmon in the IBOF rivers be listed as endangered. Federally, Canada, however, has no formal endangered species statute legislation at this time. COWESIC, while funded in part by government, has no mandate, much less regulatory ability, to force corrective action to be taken. In contrast, some provinces do. New Brunswick has had an Endangered

Species Act since 1974 (revised in 1996). Nova Scotia enacted its first endangered species legislation in 1998. Rarely in Canada, however, have the powers in provincial statutes been invoked to rescue endangered species. This may change soon.

Since 1996, Canada's Wildlife Ministers have been considering the establishment of federal endangered species legislation. Previous attempts to enact legislation died in Parliament. A new accord was finally reached in 1999 for the establishment of a Species at Risk Act (SARA). It is expected to be brought before Parliament early in February, 2000. It is assumed that it will contain regulatory powers that will place it in the same league as ESA in the U.S. ASF has urged the Minister of Canada's Environment Department to place the IBOF Atlantic salmon stocks on the national strategic priority list for endangered species under SARA at its first reading.

Meanwhile, a special measure to save the IBOF salmon runs is underway. Wild parr from three-year classes—1996, 1997, and 1998—were collected from the Big Salmon River in New Brunswick and the Stewiacke River in Nova Scotia, for hatchery rearing. They will be cultured to the adult stage as broodstock, with the first batch of eggs expected in 2000. The purpose of this live gene-bank program is to preserve the genome of the IBOF rivers. Only two of the 33 IBOF rivers are involved in the program, but it is a start. These fish are so valuable that they likely will be cultured throughout their development stages in a freshwater hatchery to prevent contagion from marine-borne diseases so difficult to protect against in a sea-cage setting, even with use of vaccines.

Understanding the problem

Commercial fishing

It was widely accepted in Canada that

wild Atlantic salmon stocks would recover naturally. This assumption drove the often unpopular, conservation-oriented fishery regulations imposed by government. An important source of support for the lifting of the commercial nets was ASF's advocacy efforts. Additionally, the Canadian salmon aquaculture industry provided fresh salmon year-round, keeping the price of wild salmon from escalating in times of scarcity. The industry's success made it financially feasible for the provincial and federal governments in Canada to buy out commercial fishermen at a cost of more than \$70 million (Cdn). A significant rebound was predicted to occur after the closure of the entire insular Newfoundland fishery in 1992. Not only did this not happen (Figure 1), but the downward spiral continued, although probably not as drastically as would have been the case if the regulatory measures had not been introduced. The question is why?

There is some evidence that the principal problems are not in the freshwater development stage (Hawkins 1999). Smolt production as a function of spawning escapement has remained reasonably constant where this has been measured. This does not mean that improvements in the quality of the freshwater habitat are impossible or unnecessary; it simply means that barring further evidence the cause for the observed increase in mortality lies, by default, in the marine phase.

Other anthropogenic causes

Overfishing, particularly by the commercial fisheries, has been a major cause for the salmon's population decline over the last few decades. But regulations governing harvesting, and stock- and habitat-improvement programs, have not covered all the possible anthropogenic causes.

First, industrial fisheries threaten salmon's food source. More than 90

percent of the salmon's diet during its marine phase is fish, mostly pelagic, of which a large fraction is represented by "forage fish," so called because they are at the bottom of the food chain (Hislop and Shelton 1993). Two species, capelin (*Mallotus villosus*) and sandeels (*Ammodytidae*), have come in for special attention. They form the basis of "industrial fisheries" for the production of fishmeal, and oil, used for, among other things, fuel in power plants. It is possible these industrial fisheries adversely affect survival of salmon postsmolts by significantly reducing their food source, but hard evidence is lacking. Testing such a hypothesis is difficult because there are many potential prey species for the salmon in the ocean, and the hypothesis has to deal with biological logic. Salmon are opportunistic feeders, so that should the abundance of a prey species decrease, for whatever reason, salmon would naturally turn to another food source. Whether these alternate prey are abundant enough, and at the right place at the right time to meet the needs of the salmon, are open questions.

Another possible anthropogenic, and unconventional, cause for salmon's increased marine mortality has recently been proposed (Fairchild 1999). Nonylphenols are a class of chemicals that have estrogen-mimicking effects on animals, hence the popular name "endocrine disrupter." A second look at data from the 1970s and 1980s suggests that exposure of Atlantic salmon juveniles to minute quantities of nonylphenol, used in an insecticide sprayed to control a forest pest in New Brunswick, resulted in poor marine survival of postsmolts from the Miramichi River. Because of its suspected effect on salmon, the formulation of the insecticide has since been changed to remove the nonylphenol. Nevertheless, this chemical is a popular surfactant

added to detergents to lower surface tension and, therefore, must be in most waterways receiving domestic and industrial effluents. Thus, this unexpected insecticide story may have opened a whole new line of investigation.

Natural causes

Fluctuations in abundance of all living things are, of course, a natural norm. It is plausible that natural forces account for what has been happening to Atlantic salmon during its marine phase. A popular hypothesis centers on seal predation. In the Northwest Atlantic there are six species of seals, of which the Harp seal (*Phoca groenlandica*) is by far the most numerous.

The Harp seal, as are all seals, is a prodigious and opportunistic eater of fish. The likelihood of a seal encountering salmon in the sea, as opposed to other species, notably cod, is statistically remote. Therefore, seals are unlikely to pose a serious threat to salmon populations in the ocean. Analyses of thousands of seal stomachs confirms this assertion: salmon are found in the stomach with a frequency less than 1 in 10,000 (Beck and Hammill, 1993). Seals may still affect salmon population, however, by eating large numbers of the salmon's food source, in particular capelin.

Disease is another possible natural cause of a decrease in marine survival. In the late 1960s, a disease decimated salmon populations in Ireland. *Columnaris*, a myxobacterium species carried up rivers by returning adult salmon, was involved but the etiology was never fully understood (Brown 1966). The disease gradually disappeared, and has not returned since. Recently a virus causing infectious salmon anemia (ISA), which has been a scourge to Atlantic salmon aquaculture operations on both sides of the North Atlantic, was found in

wild salmon in Canada and Scotland. The Davis Strait area off west Greenland is a common feeding ground for 2SW Atlantic salmon from North America and much of Europe. At the time of writing planning is underway to include tissue samples for ISA testing in an international program monitoring salmon caught in the Greenland subsistence fishery.

Another possible explanation invokes a major climatic event affecting the marine environment. Two environmental factors, temperature and salinity, are prime candidates as provocative agents in oceanographic perturbations affecting the life history of Atlantic salmon...as well, undoubtedly, as other species. The problem for investigators has been trying to obtain enough data over such a vast expanse as the North Atlantic, and on a timely basis. Research vessels, and

ships of opportunity, can sample only a small fraction of the ocean, and even then over relatively long time periods. Satellites, however, can cover huge areas, providing data to researchers continuously. They provide some hope for unraveling the Gordian knot as to what is happening to salmon in the sea.

Seldom does the environment itself directly kill organisms capable of movement, but variations in climatological factors, such as temperature, could nonetheless indirectly affect the ability of an animal to survive. About 80 percent of Atlantic salmon in the sea occur within temperature bounds of 4°-11°C (Reddin and Friedland 1993). The location and size of areas with the "preferred" marine temperature for salmon has been shown by sea-surface temperature satellite data to vary among seasons annually, and

among years. Such variability could affect such things as migration routes, and the distribution of food resources and/or predators. Farming can be used as an analogy. As the number of cows that can be raised in a field is a function of the size of the fenced-in field used for grazing, so in nature the number of salmon that can be grown in the ocean depends on the size of the "grazing grounds" as determined by thermal boundaries.

These large-scale variations in temperature are thought to be driven by the so-called North Atlantic Oscillation (NAO), caused by atmospheric pressure differences between a low near Iceland, produced by westerly winds moving counter-clockwise, and a high near the Azores, produced by westerly winds moving clockwise. Physical oceanographers are attracted by the idea that one of their icons, NAO, may be playing an important role in the life of Atlantic salmon. Biologists are interested in satellite data because it allows them to test the hypothesis that the size and location of preferred habitat in the North Atlantic for Atlantic salmon are key determinants in the salmon's marine survival.

Information gaps

The analogy has often been used that there are black holes in the ocean into which salmon disappear. It would help enormously in our understanding of the salmon's marine life if we had some idea where these black holes are (i.e. where and when the unexplained mortality is occurring). Recent advances in tracking technology hold promise for identifying the black holes. Miniature electronic sonic transmitters with unique codes, surgically implanted in the peritoneal



Figure 4. Atlantic salmon (*Salmo salar*), courtesy of Atlantic Salmon Federation.

cavity of salmon smolts, have recently undergone a major improvement in performance. Previously these transmitters allowed the tracking of seaward migrating smolts in rivers, but never far past the estuary into the open ocean. New transmitters have been developed with a life span of two or more months.

Also, newly improved automated receivers suspended in the water column from surface buoys can detect a tagged salmon within a half-mile range. Tagged smolt were released in 1999 from the Big Salmon River in New Brunswick and were successfully tracked across the Bay of Fundy a distance of 26 miles (Lee 1999). This is the longest by far for small fish in the open ocean.

Plans now call for a large-scale monitoring of post-smolt movement through the Bay of Fundy and perhaps out into the Gulf of Maine using the receivers in strategically deployed detection barriers. Tracking itself will not likely reveal why mortality occurs, but it should indicate where and when it occurs. Knowing the "scene of the crime" should then allow different questions to be asked directed at the cause of mortality. This advanced telemetry will also allow investigations on the effect on smolt in the sea of certain pre-smolt treatments, such as exposure to the endocrine disrupter, 4-Nonylphenol.

Conclusions

While the Atlantic salmon's current trouble appears to manifest itself during its marine phase—which does not preclude initiation of causal events in

the freshwater phase—it is unlikely there is a single cause-and-effect vector at play. Some investigators point out that since the late 19th century, when reasonably accurate fishery and physical oceanographic records began to be kept, there is evidence that oscillations in abundance of Atlantic salmon were matched by oscillations in large-scale oceanographic data, in particular temperature (Dunbar 1993). If naturally occurring oceanographic perturbations are in any way involved in the present condition of salmon, the bad news is that not much can be done about it. There is good news, however, in the thought that cyclical oscillations imply peaks and valleys, and perhaps an upturn in the ecosystem favoring salmon is next. But this time nature may not be able to do it on her own. Every effort needs to be taken to ensure that endangered populations of Atlantic salmon do not become extinct because of a failure to take corrective action.

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