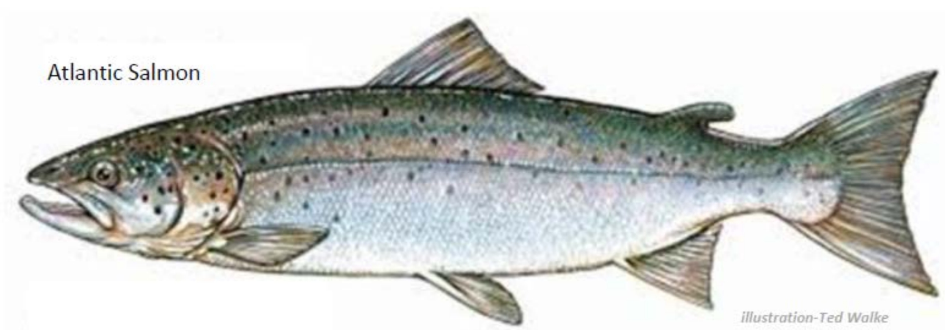
Minnesota Department of Natural Resources
Special Publication 185, December 2019

DEPARTMENT OF NATURAL RESOURCES

Atlantic Salmon Management in the Minnesota Waters of Lake Superior, 1980-1998

prepared by

Donald R. Schreiner
and
Mary T. Negus



Minnesota Department of Natural Resources
Division of Fish and Wildlife
Section of Fisheries
Lake Superior Fisheries Area
5351 North Shore Drive
Duluth, MN 55804

Table of Contents

Abstract

The Atlantic Salmon *Salmo salar* is native to the North Atlantic Ocean and was found as far inland in North America as Lake Ontario. The Atlantic Salmon is an anadromous fish which spawns in freshwater streams. To diversify the fishery and respond to angler requests, the Minnesota Department of Natural Resources (MNDNR) began an experimental Atlantic Salmon stocking program for Lake Superior in 1980. Atlantic Salmon from Maine's Grand Lake strain were stocked in the French and the Split Rock Rivers and a captive broodstock was established to secure eggs for the program. Poor return to the angler and low angler interest over the first 10 years stimulated the MNDNR, Section of Fisheries to critically review the program. In the winter of 1991-1992, following a series of public input meetings, the MNDNR decided to eliminate the Atlantic Salmon broodstock, stock the remaining hatchery fish, and monitor the fishery to provide the option for reestablishing the program if returns to the angler and angler interest increased substantially over the next two years. A reestablished program would have originated with gametes collected from Atlantic Salmon returning to the French River trap. The eggs would then have been used to rear yearlings for stocking. In 1992, the angler catch of Atlantic Salmon was relatively high compared to previous years and returns to the French River trap increased to an all-time high. The 1993 angling season was monitored through a special Atlantic Salmon creel survey, charter fishing reports and routine spring and summer creel surveys. All data indicated that the catch of Atlantic Salmon showed a large decline when compared to 1992, and interest in the fishery continued to be low among all but a few avid anglers. In the fall of 1993, after further discussions with anglers, the MNDNR, Section of Fisheries discontinued the Atlantic Salmon program, with no plans to reestablish it. This report provides a summary of the management actions and results of the Atlantic Salmon program in Minnesota's portion of Lake Superior from 1980-1998.

Introduction

Atlantic Salmon *Salmo salar* are native to the Atlantic Ocean with the original range extending from the Iberian Peninsula in Europe, north to Russia and Scandinavia, west to Iceland and the Canadian Maritime Provinces, and south to New England (Thorstad et al. 2011). In North America, they are highly prized for their fighting ability, willingness to take a fly, and high quality table fare. Atlantic Salmon were also native to Lake Ontario, the most eastern of the Great Lakes. In Lake Ontario they were considered a land-locked indigenous form and supported a large and popular fishery until the late 1800s, but overharvest decreased the population to extinction by 1896 (Huntsman 1944). They were considered a top predator in the early Lake Ontario fish community, mentioned in historical accounts more often than Lake Trout *Salvelinus namaycush* (Smith 1995).

Much of the work with Atlantic Salmon in the Great Lakes has focused on restoring the native stocks in Lake Ontario, with a few attempts to introduce them to the upper lakes. Agencies on Lakes Huron and Superior introduced Atlantic Salmon to develop a diverse fishery and address angler desires to establish an Atlantic Salmon fishery. The most consistent Great Lakes program outside of Lake Ontario is in the St. Marys River where a put-grow-take fishery has been developed for Atlantic Salmon. This program has established a small, but popular fishery, that attracts both local and outstate anglers. Based on the success of the St. Marys River Atlantic Salmon fishery, the Michigan Department of Natural Resources (MIDNR) recently initiated an experimental Atlantic Salmon stocking program in the northern main basin of Lake Huron.

In 1980, the Minnesota Department of Natural Resources (MNDNR) began an experimental program to establish Atlantic Salmon in Lake Superior and address angler desires for a more diverse fishery. This report is a summary of the management actions and results of the Atlantic Salmon program in Minnesota. The objectives for the report are to: 1) Describe the general life history characteristics of Atlantic Salmon in the Great Lakes, 2) Provide a brief overview of Atlantic Salmon management in the Great Lakes, 3) Discuss the reasons the Minnesota program was initiated, 4) Consolidate and summarize the results of the Minnesota program, and 5) Provide justification for discontinuation of the program.

General Life History Attributes of Landlocked Atlantic Salmon

The Atlantic Salmon has a complex life cycle, much of which is common to the family Salmonidae (Figure 1). Salmon in their native range are anadromous, with part of their lives spent in fresh water streams, and part in the ocean (or lake for landlocked populations). In most cases, Atlantic Salmon demonstrate high fidelity to their natal streams (Fay et al. 2006). The life cycle of the Atlantic Salmon in the Great Lakes is called potamodromous because it is confined to fresh water throughout its life. For lake-run Atlantic Salmon in the Great lakes, adults enter streams to spawn from late summer to late fall depending on the location. The female chooses a gravel-bottomed riffle above or below a pool, digs a nest, or redd, and lays eggs in this depression while the male simultaneously releases sperm. When completed, the female pushes gravel back over the eggs where they incubate for 6-8 months. After spawning, adults may rest in the river for a time and then return to the lake, or the male may remain in the river all winter.

In general, only about 5-20% of fertilized eggs survive to develop over the winter and, depending on temperature and other stream conditions, usually hatch in April. Most sac-fry or “alevins” remain buried in redds for up to another month depending on water temperatures, and feed exclusively off their yolk sacs. Normally, by mid-May the yolk sacs are largely depleted and the alevins leave the redds to “swim up” and fill their swim bladders. Once “swim up” has occurred, the young fish are referred to as “fry” and begin to feed on insect larvae, zooplankton, and other invertebrates. As the fry mature they develop small red spots along their sides, from which dark vertical stripes descend to form camouflage. At this stage, they are referred to as “parr.” They normally remain in their natal streams, feeding on insect larvae, worms, small fish and invertebrates for 2-3 years before they smolt and emigrate to the lake at about 6 in, usually in late spring of their second or third year (Michigan Department of Natural Resources 2014).

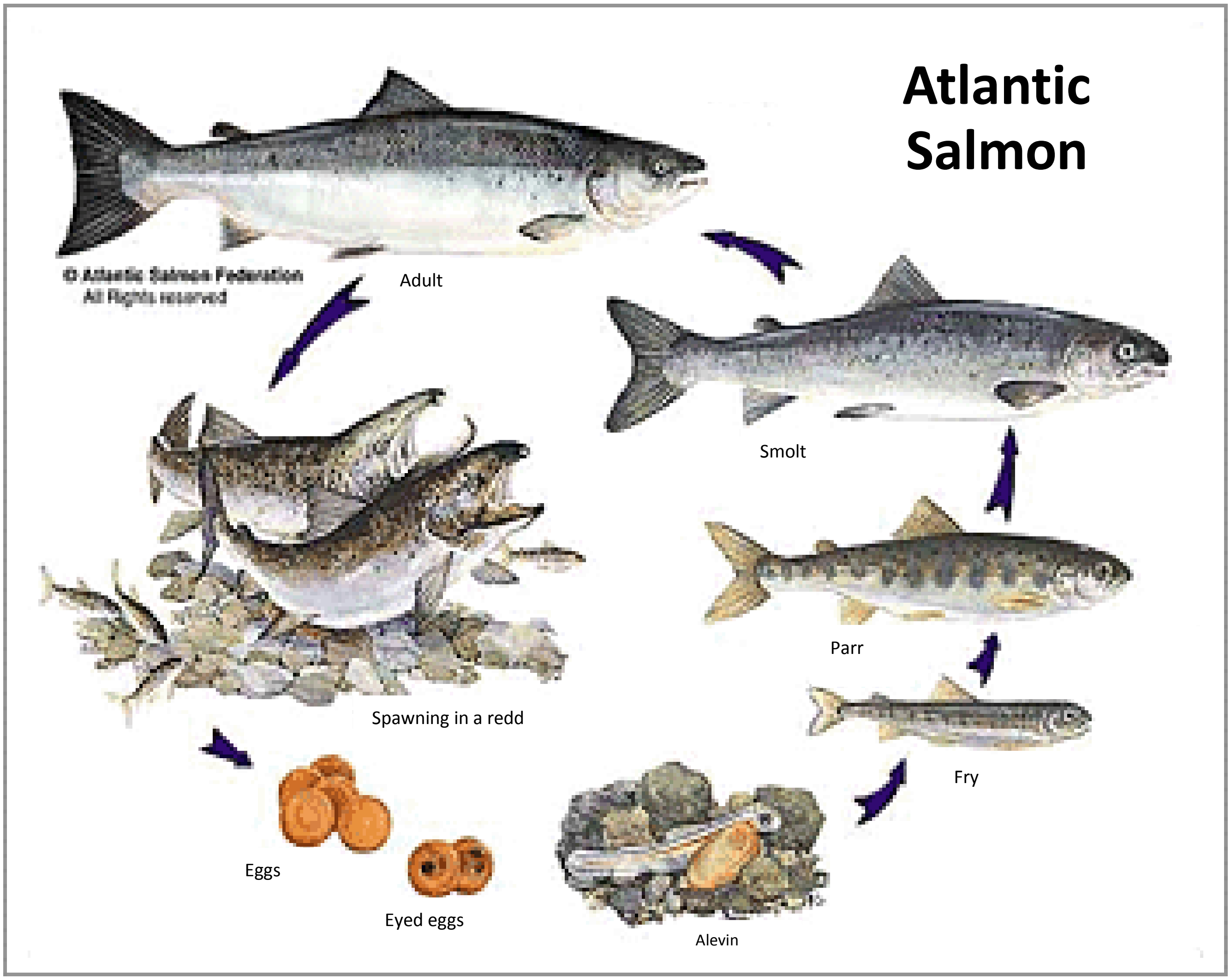


FIGURE 1. Life cycle of Atlantic Salmon.

Once in the lake, given adequate prey, smolts can grow rapidly, feeding in the Great Lakes on terrestrial insects, aquatic invertebrates, Rainbow Smelt *Osmerus mordax*, Alewife *Alosa pseudoharengus* and other small fish. They normally reach maturity in 2-3 lake years, returning to their natal streams to spawn, usually in mid-late fall, starting the cycle once again. Once at full maturity, Atlantic Salmon can range in weight from 3-10 lb. After maturity, growth is relatively slow unless prey is abundant. Few Atlantic Salmon grow to over 10 lb in the Great Lakes, especially Lake Superior, but some fish up to 20 lb have been reported. Unlike Pacific Salmon, Atlantic Salmon do not routinely die after spawning (Michigan Department of Natural Resources 2014).

Overview of Atlantic Salmon Programs in the Great Lakes

Lake Ontario

In the Great Lakes, the Atlantic Salmon was only indigenous to Lake Ontario. However, by 1896 they were considered extinct in Lake Ontario (Huntsman 1944) and are now formally listed as "extirpated" according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010). In 2003, initial research was undertaken to determine the feasibility of restoring Atlantic Salmon to Lake Ontario through a partnership between the province of Ontario and New York State. Following this research, the

Lake Ontario Atlantic Salmon Restoration Program (LOASRP) was launched in 2006, bringing together the Ontario Ministry of Natural Resources and the Ontario Federation of Anglers and Hunters (de Guzman et al. 2014). The program has a website called "Bring Back the Salmon". The recent completion of LOASRP - Phase I in 2011 was deemed a success, as wild Atlantic Salmon were recorded in one of the target tributaries for the first time in over 150 years.

Phase II of LOASRP, which began in 2012, faces several key challenges, the dominant one being widespread habitat degradation in streams and human-caused development in many watersheds. The prey base in Lake Ontario is dominated by Alewives, a thiaminase-rich species, resulting in thiamine deficiencies in Atlantic Salmon as well as altered competition and predation. Thiamine deficiencies greatly reduce or impede egg development in Atlantic Salmon similar to Early Mortality Syndrome (EMS) in Lake Trout. This is a major obstacle to overcome if Atlantic Salmon are to become self-sustaining (de Guzman et al. 2014). Competition for spawning habitat with naturalized Chinook Salmon *Oncorhynchus tshawytscha*, was also cited as a major obstacle in reestablishing Atlantic Salmon in Lake Ontario. It has been found that Chinook Salmon provoke agonistic behavior in Atlantic Salmon, thereby wasting critical stores of energy that would otherwise be used for reproduction (Jones and Stanfield 1993; Scott et al. 2003). This results in subsequent delays in nesting and disadvantaged juveniles that arrive at forage sites later than other competitive species. To a lesser extent, there is evidence that both stocked and naturalized juvenile Steelhead may compete with juvenile Atlantic Salmon for food and cover in streams when both are limited (Hearn and Kynard 1986; Volpe et al. 2001; Scott et al. 2005; Dietrich et al. 2008).

Overcoming these many challenges will take time. Anglers will have to be patient, and may have to give up other productive fishery programs that they presently enjoy if Atlantic Salmon stocks are to be restored. This will no doubt cause some controversy among the various user groups. A description of the science involved with Atlantic Salmon restoration in Lake Ontario along with potential solutions and recommendations has been summarized in two recent publications that discuss attempts to overcome many of the challenges faced in this restoration effort. One summary is entitled *Assessing the Challenges of Reintroducing Atlantic Salmon (Salmo salar) to Lake Ontario* (de Guzman et al. 2014) and the other is the *Proceedings of the Lake Ontario Atlantic Salmon Restoration Science Workshop Feb. 18-20, 2014, Allston, Ontario* (Stewart et al. 2014). In addition, citizen efforts and outreach on various projects can be found on the "Bring Back the Salmon" website (Bring Back the Salmon 2013). Results of the major efforts currently underway to rehabilitate Atlantic Salmon in Lake Ontario will likely influence how agencies proceed with Atlantic Salmon management in the upper Great Lakes.

Lakes Huron and Michigan

The State of Michigan stocked over 250,000 landlocked Atlantic Salmon in several large inland lakes and in rivers that are tributary to lakes Michigan and Huron from 1972-1982. Several land-locked strains including Quebec, Gullspang (from Norway), Sebago and Penobscot (from Maine), and a Vermont strain were used for these introductions (Johnson 2012). Survival was generally below 1% in Lakes Huron and Michigan, but higher in the two inland lakes, Gull Lake and Higgins Lake (Galbraith and Schneider 1983; Dexter 2004). Evaluation was hampered by a lack of systematic creel surveys, and was dependent principally upon angler reports. Mature fish returning to Lake Michigan tributaries were commonly in poor health and egg quality was poor; most fry resulting from these eggs died shortly after hatching (Johnson 2012). Many locations were stocked with yearlings that were too small to smolt in the year of stocking and many stocked fish remained in the stocked tributaries during the ensuing summer, resulting in decreased survival (Galbraith and Schneider 1983). As in Lake Ontario, Atlantic Salmon in Lakes Michigan and Huron are vulnerable to thiamine deficiency, especially following heavy predation on Alewives (Fisher et al. 1996; Brown et al. 2005; Werner et al. 2006). It is likely that thiamine deficiency may have contributed to the lower performance of Great Lakes stockings of Atlantic Salmon by causing low egg survival from returning fish and poor health and mortality of the adults (Brown et al. 2005).

The most successful program to establish Atlantic Salmon in either Lake Michigan or Lake Huron is the St. Marys River program where Atlantic Salmon have been stocked to provide a put-grow-take fishery, and potentially establish a naturalized population. Lake Superior State University (LSSU), under a Memorandum of Agreement with the MIDNR, has stocked Atlantic Salmon in the St. Marys River since 1987. The fish are raised at the LSSU Aquatic Research Laboratory (ARL). The LSSU ARL is a cooperative venture with the Cloverland Electric Cooperative and allows LSSU to raise the fish adjacent to the St. Marys River and use water from the river for their culture operations. From 1995–2008 LSSU has stocked an average of 36,771 spring yearlings annually that average approximately 7.0 in in total length at stocking (Johnson 2012). Fish are stocked when the temperature of the upper St. Marys River approaches 46.5^{O}F, usually about June 1. The return to creel from this program has been stable and relatively high, averaging approximately 2% from 1997-2007. Annual average return rates increased to approximately 6% between 2008 and 2011 despite the Alewife collapse in Lake Huron, and possibly benefitting from the decline in Chinook Salmon (Johnson 2012). The highest return rates resulted by rearing Atlantic Salmon smolts in the hatchery for 1.5 years before direct release into the St. Marys River (Tucker et al. 2014).

A number of Atlantic Salmon strains were used as a source of gametes in the St. Marys River program from 1985-2003, with the West Grand Lake (Maine) strain being the most productive (Johnson 2012). Beginning in 2004, the LSSU Atlantic Salmon program has collected enough eggs from returning, spawning-phase adults to supply all the eggs required for culture operations. In most years at least 100 pairs have been captured and used as broodstock to perpetuate the program. The first naturally reproduced Atlantic Salmon were discovered in the St. Marys River in 2012 when 21 larvae were collected over three sampling dates in June. This was the first evidence of natural reproduction by Atlantic Salmon in the upper Great Lakes (Tucker et al. 2014).

Based on the positive results of the St. Marys River program, and the dramatic changes in the Lake Huron fish community over the last 10 years, the MIDNR has begun an experimental Atlantic Salmon program in the main basin of Lake Huron. Experimental stocking began in 2013 with approximately 100,000 Atlantic Salmon yearlings reared at the Platte River Hatchery using culture techniques acquired from the St. Marys River program. Unfortunately, due to warmer water at the Platte River Hatchery, yearlings cannot be reared as long, and have been stocked at a much smaller size than those in the St Marys River. There is guarded optimism that with the dramatic decline in Alewives and Chinook Salmon in Lake Huron, the Atlantic Salmon program may experience positive results. However, there is also concern that the St. Marys River is unique and that the main basin of Lake Huron will not be as hospitable for hatchery-reared Atlantic Salmon. Advantages of the St. Marys River program include: 1) the LSSU hatchery is located on the St. Marys River, uses St. Marys River water, and fish are stocked directly into the river without additional transport, resulting in increased homing and greatly reduced hauling stress; 2) the St. Marys River has abundant forage (larval Rainbow Smelt and Cisco *Coregonus artedi*) and stocking can be timed so receiving temperatures are ideal for survival; 3) over 80% of the Atlantic Salmon are caught in the St. Marys River indicating a high degree of homing behavior that makes the fish more vulnerable to anglers; and 4) the St. Marys River is cool and large, allowing spawning phase Atlantic Salmon to begin migration as early as June and July, while many smaller streams do not take runs until the mid-late fall season (Behmer et al. 1993).

To date, returns from the Lake Huron program have been disappointing, but the long-term success of the experimental stocking program is still a work in progress. Many anglers and the MIDNR support continuing the experiment because Lake Huron may be able to support an Atlantic Salmon fishery, increasing the diversity of the fishery for anglers.

Lake Superior

Wisconsin - The Wisconsin Department of Natural Resources (WIDNR) was the first agency to experiment with establishing an Atlantic Salmon fishery in Lake Superior. In 1972, 20,000 Atlantic Salmon were obtained from a private hatchery in Quebec and transported to the Bayfield hatchery. The 20,000 fish were composed of 8,000 age-3 fish at approximately 8 fish/lb and 12,000 age-2 fish at approximately 12 fish/lb. The cost of age-2 fish was $0.85/fish and age-3 fish was $1.00/fish. Half the fish from each size group were exposed to a morpholine drip for approximately 12 days before release into Pike's Creek in an effort to enhance imprinting. In 1973, 20,000 age-2 (11 fish/lb) Atlantic Salmon pre-smolts were acquired from the Gaspe Peninsula area of New Brunswick, exposed to morpholine for imprinting in the Bayfield Hatchery, and released into Pikes Creek (WIDNR files). No further stocking was reported by the WIDNR.

Only three verified Atlantic Salmon from the two years of stocking were harvested by anglers and all were taken in the vicinity of Marquette, MI. No Atlantic Salmon were reported returning to Pikes Creek. Growth in the first year after stocking averaged about 13 inches and second year growth averaged only 4 in. The fish ranged in size from 19 in to 27 in. The 27 in fish weighed 4 lb 7 oz. and was very slender (WIDNR files). Growth of these fish is of interest since Rainbow Smelt populations were at all-time highs during this period, suggesting that prey was not limiting. When compared to the recent size of Atlantic Salmon captured in the St. Marys River (8-18 lb at 3-4 years old) (Lake Superior State University 2014), the growth rates of Atlantic Salmon from the WIDNR program appear very slow, suggesting that colder water temperatures in Lake Superior may have affected growth more than prey availability. The WIDNR discontinued the Atlantic Salmon stocking program in 1973 with no plans to reestablish the program.

Minnesota - In the 1970's, the MNDNR investigated the suitability of a number of salmon and trout species for introduction into Lake Superior (Woods 1970). Non-indigenous Salmonids were introduced to create and/or diversify the Lake Superior fishery after the invasion of Sea Lamprey and ultimate collapse of Lake Trout stocks in Minnesota (Schreiner et al. 2015). The Atlantic Salmon was one of many species considered for introduction.

Various criteria were investigated for each species before introductions were initiated (Woods 1970). Woods (1970) hypothesized that Atlantic Salmon were adaptable to a wide range of water temperatures and could potentially inhabit the deeper cold water habitat of Lake Superior, as well as the warmer surface waters. Atlantic Salmon consume a wide range of food items, from smaller invertebrates and insects to Sculpins (*Cottus*), Cisco and the extremely abundant (in the 1970's) Rainbow Smelt (Woods 1970). After spending 1-3 years in Lake Superior, adult Atlantic Salmon would use the streams to spawn in the fall, where juveniles would develop into smolts over 2-4 years. Atlantic Salmon have an advantage over Pacific Salmon because adults do not die after spawning and presumably will continue to contribute to the fishery. In addition to the potential survival attributes, Atlantic Salmon might provide anglers with a late summer and early fall fishery for a species that could be harvested from shore or boat, had a reputation as an exciting fish to catch, and was known for its high quality table fare.

In the late 1970s, the MNDNR made the decision to begin an experimental Atlantic Salmon program in Lake Superior. Eggs were procured from Maine, a stocking program began in 1980, and a broodstock was established for future egg takes within the state. Regulations were enacted to protect the species from overharvest and both angler creel surveys and migratory fish traps were used to monitor the results of the stocking program. The remainder of this report will discuss the specific aspects of the management program including stocking, harvest regulation and monitoring; the results of the program as measured by return to the angler, return to migratory fish traps, and population dynamics of Atlantic Salmon in Minnesota; the overall cost of the program; why the program was discontinued; and how environmental conditions in Lake Superior and recent changes in the Lake Superior fish community may decrease the success of any future reestablishment of an Atlantic Salmon program in Minnesota.

Management Actions

Stocking

Hatchery Program - The first Atlantic Salmon eggs for the Minnesota stocking program were obtained from the Grand Lake Strain in Maine in 1979. In 1980, 7,584 yearlings that were reared at the St. Paul Hatchery were stocked into the French River. The remaining eggs were reared to adults to be used as a captive broodstock for the Atlantic Salmon program. In subsequent years additional year classes were added to the broodstock to increase diversity. The broodstock was reared at the St. Paul Hatchery for over 12 years. Production of gametes from the captive broodstock never reached the levels anticipated and for about the first four years, egg production was supplemented with additional eggs from the Grand Lake strain in Maine. The captive broodstock performed poorly for a variety of reasons. The adults were extremely sensitive to handling, with few surviving after the initial spawn take. Density levels of the broodstock in ponds had to be kept much lower than originally planned, decreasing the number of fish that could be held in the hatchery. In addition, water temperature for egg development was too warm in the spring, but too cold once fry hatched for optimum growth of yearlings (Personal Communication, Donn Schrader, St. Paul Hatchery Supervisor, MNDNR).

Starting in 1982, gametes were taken from mature adult Atlantic Salmon that returned to the French River trap to supplement the production of the captive broodstock. The adults were captured, stripped of their gametes and returned to the lake. Many of the eggs taken from the French River feral broodstock were shipped to the St. Paul and Peterson hatcheries to be reared to the yearling and fingerling life stages. Most of the yearlings for the Atlantic Salmon program were reared in St. Paul. However, in 1988 and 1989 repairs and updates to the St. Paul Hatchery were required and fewer yearlings were produced. Both fry and fingerlings were stocked these years because of insufficient space to rear fish to yearling size. To overcome the production bottleneck in St. Paul, fingerling production was split between the St. Paul and Peterson hatcheries in an attempt to increase both numbers and size of fingerlings stocked.

In some years, fertilized eggs from the French River spawning run were also reared at the French River Cold Water Hatchery (FRCWH). Fertilized eggs were incubated over the winter in heath trays, and sac-fry were transferred to nursery tanks in February to rear to fingerling size. Fingerlings were transferred to raceways, reared for an additional year, and stocked as yearlings into Lake Superior at approximately 6 in total length. A more detailed description of Minnesota's Atlantic Salmon hatchery production techniques can be found in Appendix 1.

Stocking Locations and Numbers - The French and Split Rock rivers were chosen as stocking sites for the experimental Atlantic Salmon program in Minnesota (Figure 2). French River was chosen as the primary stocking site (Table 1, Appendix 2) because a fish trap operated by the MNDNR is located just upstream from the mouth of the river. The plan was to stock yearlings in the French River and to capture the adults when they returned to spawn, to be used as feral broodstock. Ideally, a successful program would yield enough mature Atlantic Salmon to provide sufficient eggs for future stocking. In 1986, annual stocking of Atlantic Salmon yearlings began in the Split Rock River (Table 1, Appendix 3). The Split Rock River was selected because it had a relatively long reach below the first natural barrier to upstream migration, providing space for potential natural reproduction and an extended area for anglers to fish.

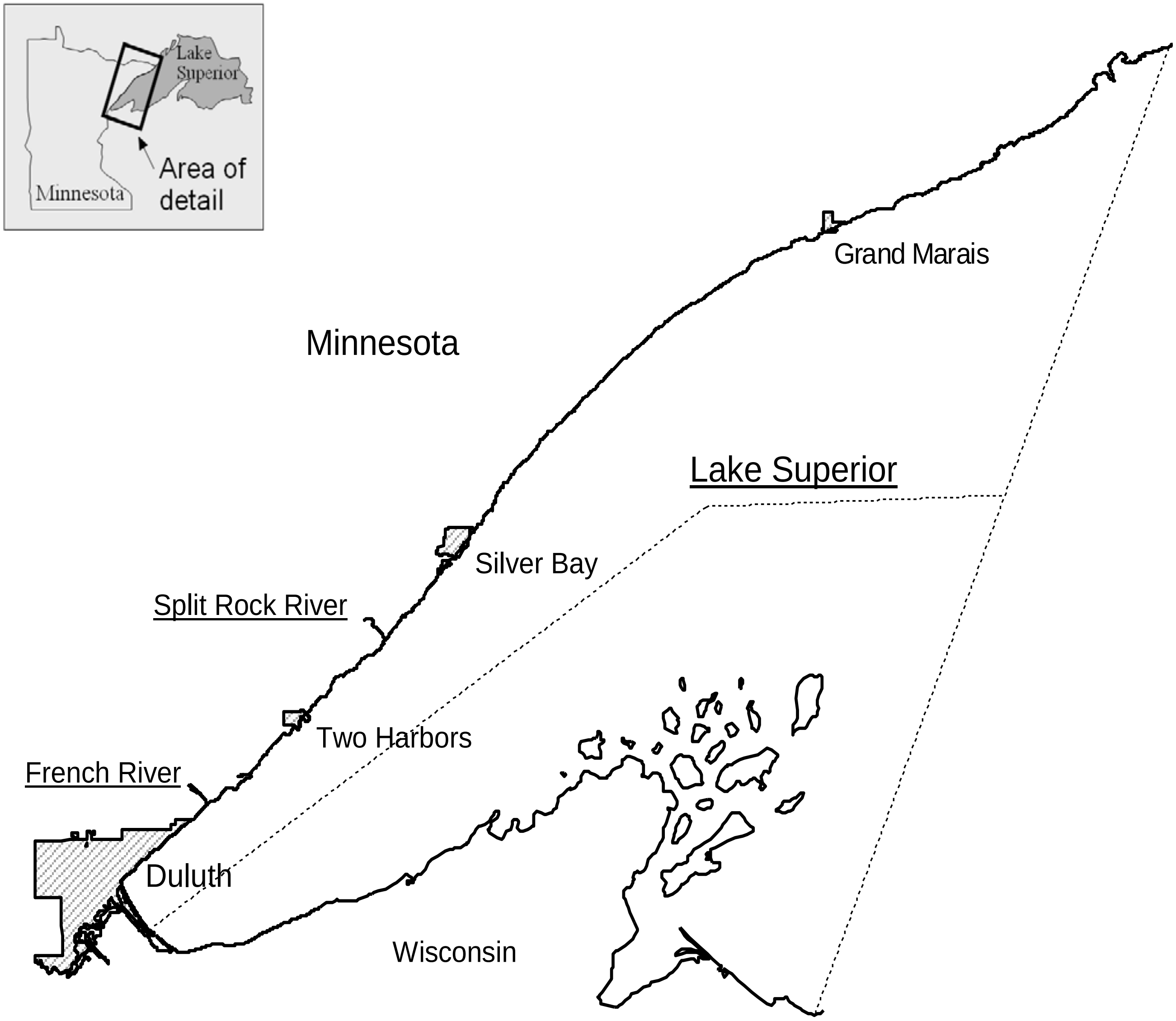


FIGURE 2. The French and Split Rock rivers were selected as the primary stocking locations for Atlantic Salmon in Minnesota's portion of Lake Superior.

TABLE 1. Numbers and sizes of Atlantic salmon stocked into the French and Split Rock rivers, Minnesota, summarized by life stage. Life stages include: Fgl = fingerlings; Yrl = yearlings, Adl = adults. See Appendices 2 and 3 for stocking details.

		French River		Split Rock River		
Year Stocked	**Life Stage**	**Number**	**Avg. Rate (number/lb)**	**Number**	**Avg. Rate (number/lb)**	**Total**
1980	Yrl	7,584	3.2			7,584
1982	Yrl	17,952	8.0			17,952
	Adl	234	0.3			234
1983	Yrl	11,025	9.8			11,025
	Adl	323	0.2			323
1984	Yrl	11,866	9.1			11,866
1985	Yrl	25,154	7.4			25,154
1986	Yrl	28,634	7.9	9,521	13.3	38,155
	Fgl			3,876	40.8	3,876
1987	Yrl	50,120	5.4	22,138	6.7	72,258
	Fgl			6,048	48.0	6,048
1988	Yrl	21,061	9.7	9,880	7.9	30,941
	Fgl	19,976	64.4	92,951	63.3	112,927
	Fry	60,291				60,291
1989	Yrl	20,930	10.6	10,321	6.8	31,251
	Fgl	111,616	104.0			111,616
1990	Yrl	29,469	6.3	76,278	11.8	105,747
	Fgl			67,955	319.0	67,955
1991	Yrl	20,282	6.3	68,294	13.9	88,576
1992	Yrl	30,492	5.8	67,037	12.6	97,529
	Adl	738	0.55	753	0.55	1,491

Four other streams, the Lester, Gooseberry, Two Island and East Split Rock, were stocked with Atlantic Salmon fry as part of a research project from 1984-1986 (Table 2). The goal of the research project was to examine the role of habitat, and interspecific competition between Atlantic Salmon, Rainbow Trout *Oncorhynchus mykiss* and Chinook Salmon as factors limiting abundance of juvenile salmonids in North Shore streams (Close et al. 1989). In other years small numbers of fry or fingerlings were occasionally stocked in these streams, likely to distribute excess hatchery production to a convenient location (Table 2).

TABLE 2. Atlantic Salmon stocked into various north shore streams in Minnesota. Life stages include: Fgl = fingerlings; Fry=fry.

Year Stocked	Life Stage	Lester River	Gooseberry River	Two Island River	East Split Rock River	Total
1983	Fgl	5,286				5,286
1984	Fgl	2,463				2,463
	Fry	12,470	4,800	3,600	9,000	29,870
1985	Fry	16,417	4,850	3,731	8,954	33,952
1986	Fry	20,513	5,000			25,513
1987	Fry	15,000	5,000		9,000	29,000
1990	Fry				21,680	21,680

The annual stocking goal for Atlantic Salmon in Lake Superior was 100,000 yearlings, once the broodstock in St. Paul and a natural spawning run at the French River were developed to produce adequate gametes. Unfortunately, this goal was approached only from 1990-1992 (Table 1). Approximately 150,000 eggs were needed from the French River trap to raise 100,000 yearlings in the hatchery, and this quantity was reached only three times in ten years (Table 3). Lower than expected egg takes were a result of low returns of feral broodstock to the French River trap, and poor egg production from the St. Paul hatchery captive broodstock.

Cost of Stocked Fish - During fiscal year 1989 (July 1, 1988 - June 30, 1989), the St. Paul Hatchery produced 8,247 pounds of Atlantic Salmon yearlings at a cost of $14.80 per pound, which excludes costs for rearing broodstock and stocking. Production costs were not available for Peterson Hatchery for fiscal year 1989 because they did not begin raising Atlantic Salmon until January, 1989. During fiscal year 1990 (July 1, 1989 - June 30, 1990), the St. Paul Hatchery produced 8,379 pounds of yearling Atlantic Salmon at a cost of approximately $17.00 per pound. During the same fiscal year, Peterson Hatchery produced 3,709 pounds of Atlantic Salmon yearlings at a cost of approximately $7.20 per pound. In addition to Atlantic Salmon, Peterson Hatchery also produced Lake Trout, Rainbow Trout, and Brown Trout *Salmo trutta* so an exact cost by species was not possible to calculate, and combining species may have lowered the actual cost to rear Atlantic Salmon. The cost figures given above exclude costs associated with rearing broodstock and stocking. The increase in production cost at the St. Paul Hatchery in fiscal year 1990 arose from rearing fish at a lower density, which produced larger and higher quality fish. In general, Atlantic Salmon cost more to produce than domestic strains of trout, and about the same as producing other "specialty" fish such as “wild” Steelhead smolts.

TABLE 3. Number of Atlantic Salmon eggs taken and females spawned that returned to the French River trap, 1982-1991.

Year of egg take	Number of females spawned	Total number of eggs	Number of eggs /female
1982	41	154,504	3,768
1983	34	142,087	4,179
1984	46	200,010	4,348
1985	26	125,852	4,840
1986	23	112,985	4,912
1987	59	185,222	3,139
1988	22	55,744	2,534
1989	10	48,232	4,823
1990	22	81,999	3,727
1991	3	4,584	1,528
Total	286	1,111,219	-
Mean	29	111,122	3,780
Median	24.5	119,419	3,974

Regulations

The goal of the experimental program was to establish a self-sustaining population of Atlantic Salmon and to diversify angling opportunities. Harvest was restricted to only one fish per day with a minimum size of 10 in, in an attempt to spread the catch among more anglers and also protect enough fish to create spawning populations if the program was successful. Anglers understood these objectives and the relatively restrictive regulations were well accepted. These regulations stayed in place throughout the life of the program and are still in place to regulate potential harvest of any stray Atlantic Salmon that may find their way into Lake Superior from the lower lakes.

Monitoring

Return of Atlantic Salmon to the angler was monitored by using a variety of creel surveys. The traditional summer creel survey targeted the catch of Atlantic Salmon in the boat and shore fishery from Memorial weekend through September 30th (MNDNR Lake Superior Area files). The spring creel survey monitored the shore and stream angler catch of Atlantic Salmon during the traditional spring Rainbow Trout run (MNDNR Lake Superior Area files), while the fall creel survey, which was conducted intermittently, targeted both Pacific and Atlantic Salmon from September through early November (MNDNR Lake Superior Area files). In 1993, a dedicated creel survey was conducted to target mostly Atlantic Salmon in an attempt to get the best information possible to assist in determining the fate of the program (Jones 1993).

The French River trap was used to monitor Atlantic Salmon returns to a specific stocked stream. The trap information was essential to monitor the return rates of Atlantic Salmon, collect biological information from individual fish, and assist in determining the cost: benefit of the experimental program. In addition to monitoring Atlantic Salmon runs, the French River trap was used to capture feral broodstock, an important aspect of the overall Atlantic Salmon program if it were to succeed. The French River trap has been operated in both spring and fall seasons since the mid-1970s to monitor a variety of migratory fish populations. Annual trap reports include detailed information on both the biology and behavior of many trout and salmon species that include Rainbow, Brown, and Brook Trout *Salvelinus fontinalis*; Chinook, Coho *Oncorhynchus kisutch* and Pink Salmon *Oncorhynchus gorbuscha* and Atlantic Salmon (MNDNR Lake Superior and Duluth Area files). In 1994, a smolt trap was added to the adult trap on the French River (Dexter and Schliep 2007) making it an ideal experimental stream to test management alternatives on a variety of migratory species and a unique tool for Lake Superior fisheries management.

Results of the Program

Return to the Angler

Atlantic Salmon returns to the angler were monitored by three different creel surveys in Minnesota's portion of Lake Superior (spring, summer and fall). Because the minimum harvest size for Atlantic Salmon was 10 in, anglers were required to release fish less than 10 in. Creel clerks reported that in some years, a small group of anglers routinely practiced their fly fishing techniques on recently stocked Atlantic Salmon yearlings. Therefore, in this report, all creel survey results are reported as harvest of legally caught fish, because including the high catches of recently stocked sub-legal Atlantic Salmon could significantly inflate the number of legal fish caught in some years.

Spring Creel - The spring creel targets the Rainbow Trout spawning run from early April to late May, and has been conducted in most years since 1980. Incomplete trip interviews are conducted with both shore and stream anglers. Although Atlantic Salmon spawn in the fall, some adults routinely enter streams and congregate off river mouths in the spring when the stream water warms, becoming vulnerable to anglers. Expanded harvest estimates were only made if at least 5 fish were encountered by creel clerks during the spring creel survey, which occurred only in 1990 and 1992, when estimated harvest was 62 and 141 fish respectively (Figure 3, Appendix 4). Anglers harvested less than 0.001 fish per angler hour or less than 1 fish per 1,000 hours of fishing in 1990 and 1992.

Fall Creel - The fall creel survey was established to monitor angler catch of Pacific Salmon, but it was also useful to monitor catch of Atlantic Salmon during their spawning run. Unfortunately, the fall creel was only conducted in nine out of the 18 years that the Atlantic Salmon program was monitored. The estimated angler harvest of Atlantic Salmon in the fall fishery ranged from 14 to 173 fish with a mean of 40 fish and a median of 24 fish between 1985 and 1994 in years when the creel was conducted (Figure 3, Appendix 4). An important observation made by both creel clerks and anglers was that many of the Atlantic Salmon returned relatively late in the fall, much later than expected and long after the time when most anglers had discontinued fishing and switched to hunting activities. Similar to the spring creel estimates, overall average harvest rate by anglers in the fall creel was less than 0.001 fish per angler hour or less than 1 fish per 1,000 hours of fishing.

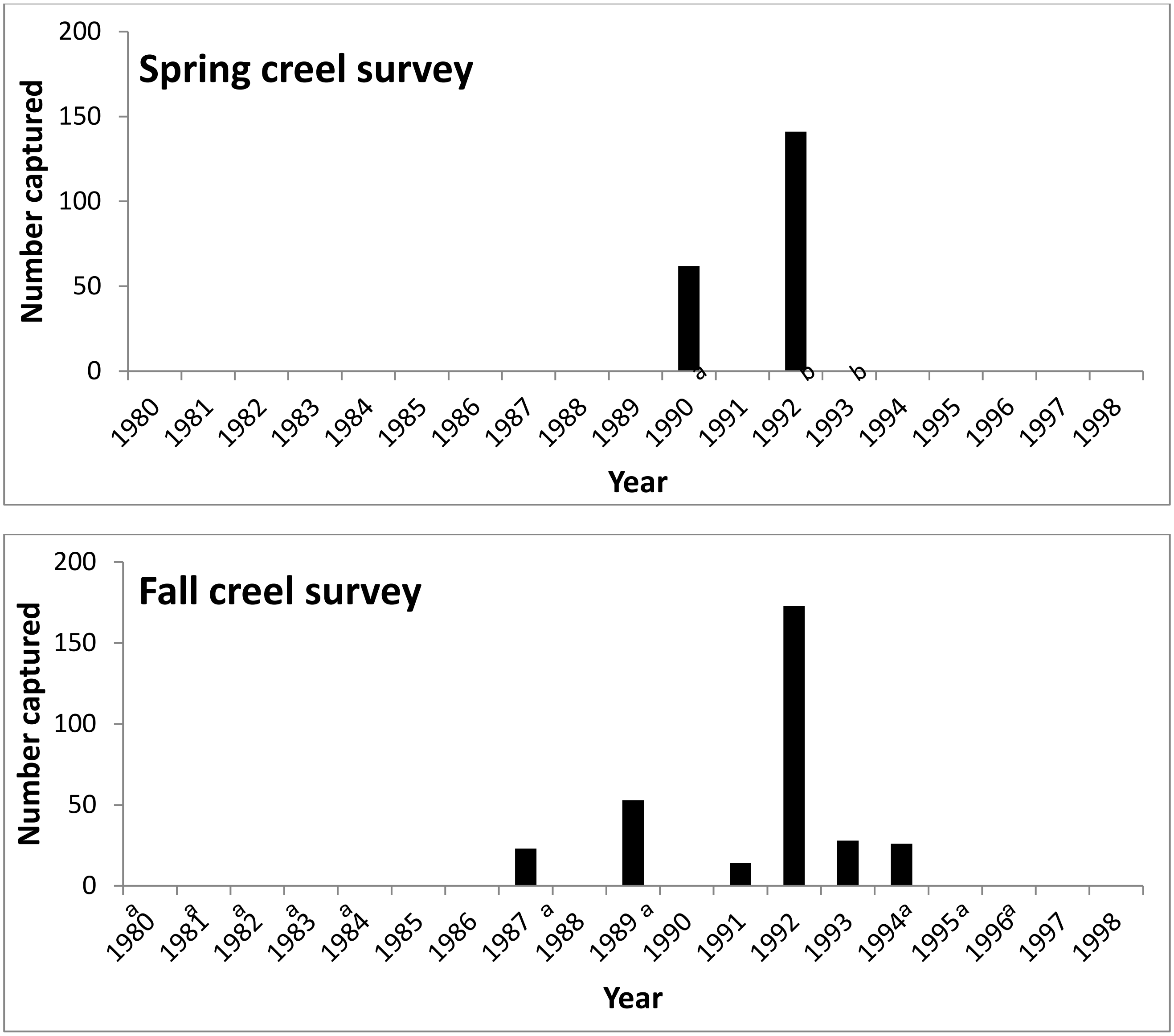
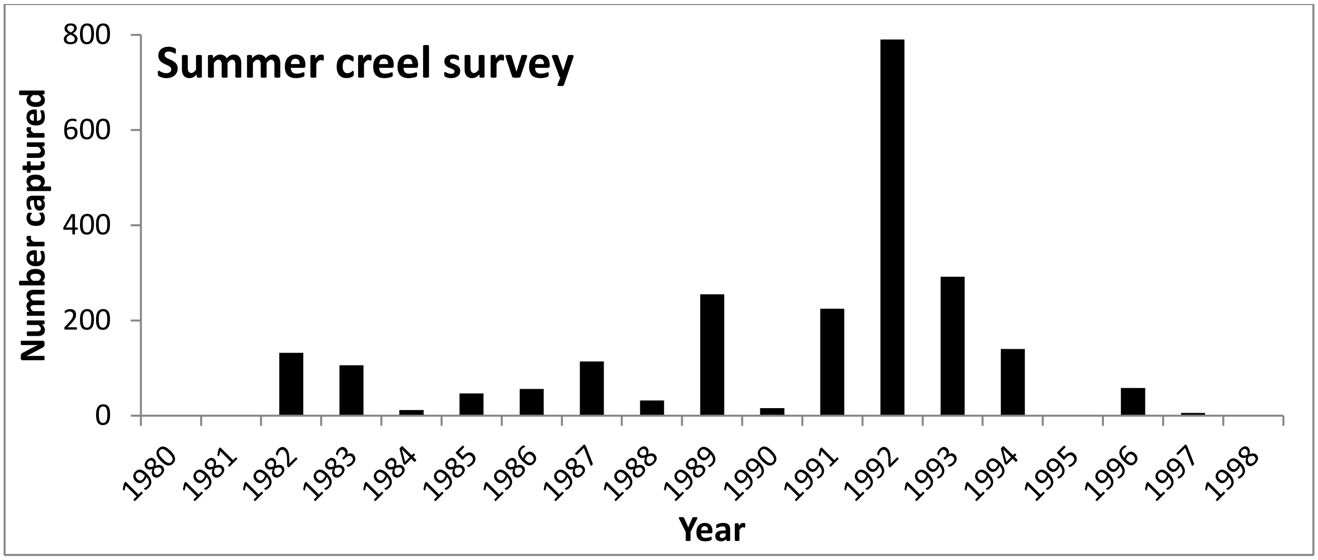


FIGURE 3. Estimated harvest of Atlantic Salmon in spring and fall creel surveys. Superscripts on year: [a] indicates that no creel survey was conducted; [b] indicates that too few (<5) Atlantic Salmon were observed to calculate an estimate. No Atlantic Salmon were observed in years without symbols.

Summer Creel and Charter Fishery - The Lake Superior summer creel survey in Minnesota targets Lake Trout and Salmon during the open water season. Interviews in this creel survey are mainly from boat anglers, but some shore anglers are also interviewed at the busier shore fishing locations. Annual estimates of Atlantic Salmon harvest in the summer creel survey ranged from 12 to 790 fish, with a mean of 170 fish and a median of 114 fish per year from 1982-1994 (Figure 4, Appendix 4). The harvest from the charter fishery is monitored and included in the total harvest for the summer creel survey, so they are not additive. Actual harvest records from the charter fishery are reported monthly during the season by charter captains. Atlantic Salmon harvest as reported by charter captains ranged from 12 to 200 fish, with a mean of 44 fish and a median of 16 fish from 1985–1994 (Figure 4, Appendix 4). As expected, charter harvest roughly followed the pattern observed in the summer creel survey. Prior to 1985, no charter license was required to fish Lake Superior in Minnesota so reports were not filed.



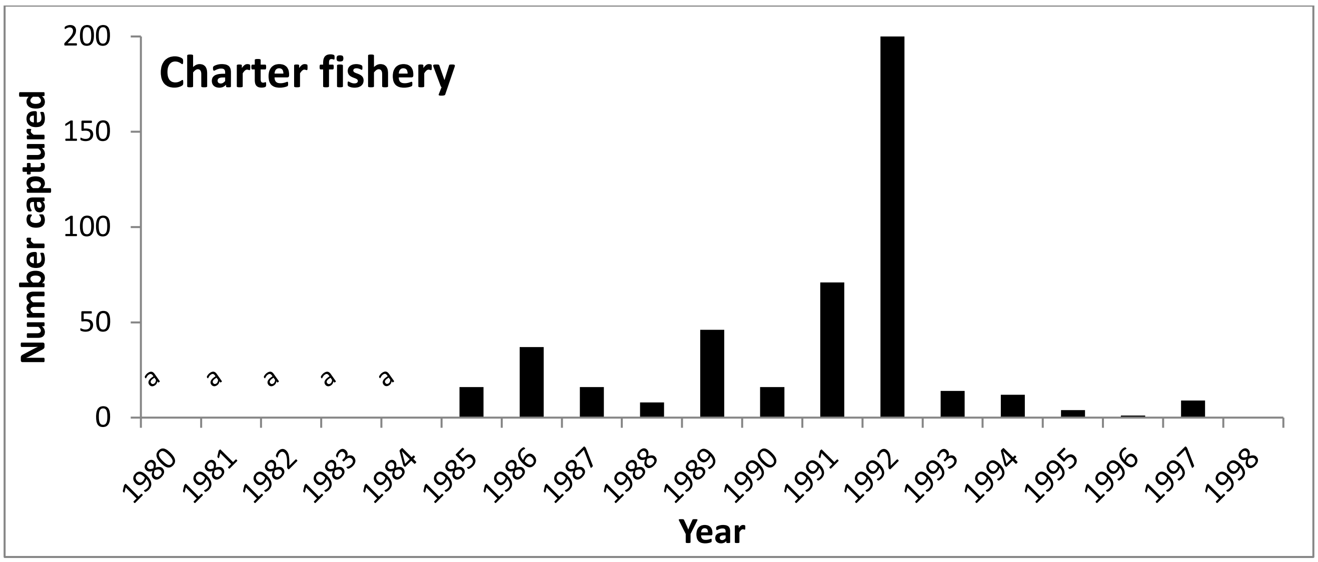


FIGURE 4. Estimated harvest of Atlantic Salmon in summer creel surveys and charter fishery. Superscript on year: [a] indicates that no charter reports were required from 1980 - 1984.

Atlantic Salmon harvest rate from 1982-1994 in the summer creel ranged from a high of 0.0035 fish/angler hour in 1992 to a low in 1984 of < 0.0001 fish per angler hour, with an overall average harvest rate of less than 0.001 fish per angler hour. This reflects a fishing rate that ranged from approximately 282 hours per fish in 1992 to 19,688 hours per fish in 1984 with a mean of 1,540 angler hours expended to harvest one fish in the summer creel survey (Table 4). Based on the total number of yearlings stocked from 1980-1992 and total estimated catch from 1982-1994, the overall average return rate to the angler in the summer creel was 0.43%. The average return rate was not calculated for the spring or fall creels since there were many years when a creel survey was not conducted or Atlantic Salmon harvest was so low that estimates could not be determined.

TABLE 4. Return of Atlantic Salmon to summer creel, 1982-1998.

Year of creel survey	Total pressure (hours fishing)	Number of fish harvested	Harvest rate (fish/hr)	Fishing rate (hr/fish)	Average weight per fish (lb)
1982	297,905	132	0.0004	2,256.9	4.9
1983	451,905	106	0.0002	4,263.3	3.2
1984	236,252	12	0.0001	19,687.7	3.3
1985	194,842	47	0.0002	4,145.6	3.8
1986	288,811	56	0.0002	5,157.3	5.4
1987	212,994	114	0.0005	1,868.4	n/a
1988	332,825	32	0.0001	10,400.8	4.3
1989	280,078	255	0.0009	1,098.3	5.2
1990	276,529	16	0.0001	17,283.1	3.8
1991	239,645	225	0.0009	1,065.1	3.9
1992	222,625	790	0.0035	281.8	4.3
1993	213,476	292	0.0014	731.1	5.2
1994	165,939	140	0.0008	1,185.3	4.6
1995	176,811	0			
1996	180,892	65	0.0004	2,783.0	4.5
1997	155,477	6	0.0000	25,912.8	3.2
1998	142,596	0			

Special Atlantic Salmon Creel - In spring 1993 a special creel survey was conducted that mainly targeted Atlantic Salmon (Jones 1993). Despite being fall spawners, stream and shore anglers harvested many Atlantic Salmon in the spring, with some anglers reporting their highest catches in late May and June. This survey was designed to provide new information on late spring harvest, and given the relatively high angler returns in 1992, conduct a thorough assessment of Atlantic Salmon harvest in 1993. The estimated harvest of Atlantic Salmon in the special 1993 creel survey was 166, similar to that recorded in the 1992 spring creel survey, which excluded late May and June. The harvest rate in the special creel survey was 0.06 fish per angler hour. In addition, important information was collected on angler attitudes toward Atlantic Salmon, with about half the anglers interviewed targeting both Atlantic Salmon and Lake Trout, but only one angler exclusively targeting Atlantic Salmon. Along with harvest statistics, biological information on the fish harvested was also recorded and analyzed (Jones 1993).

Returns to the French River Trap

The total number of Atlantic Salmon returning to the French River adult trap was monitored from 1980–1998 during both the spring and fall seasons. Returns of Atlantic Salmon from 1981–1995 ranged from 8 to 624 fish, with a mean of 133 fish and a median of 94 fish per year. From 1982-1995 the total annual returns of Atlantic Salmon were fairly stable, ranging between 100 to 200 fish, except in 1992 when 624 fish returned. The 1989 year class comprised all the Atlantic Salmon returns in 1992 and over 95% of the returns in 1993, excluding recently released broodstock, and was the strongest year class represented over the length of the program (Figure 5).

Return rates by year class (number caught/number stocked in a given year) to the French River trap were based only on the number of yearlings stocked in or near the French River (Table 5). Return rates are likely inflated in some years because only yearlings were used in the calculation, but a limited number of the fry and fingerlings stocked also contribute to the adult returns. In addition, some unmarked fish from all size groups stocked in the Split Rock River may have strayed back to the French River, which would also inflate actual return rates. Return rates to the French River trap were only calculated for all, or a portion of 8 year classes. All yearlings stocked in 1980 were given a distinct fin clip so the 1979 year class could be tracked upon return. Atlantic Salmon stocked from 1981-1984 were not aged upon return, so return by year class could not be determined. Fish stocked from 1985-1988 were not marked, but beginning in 1988 all returning fish were aged using scales, so return rate by year class to the French River trap could be estimated. Paired experimental stocking was conducted for the 1989-1991 year classes to determine if size at stocking and imprinting influenced return rate. Individual yearling lots were given distinct marks, except for 10,047 fish stocked in 1990. Return rate based on specific marks were determined for these 3 year classes. Six distinct return rates for the 1989-1991 year classes could be calculated, because two different groups of fish were stocked in each year (Table 5).

From 1981-1995 return rates by year class varied from a low of 0.02% for the 1988 and 1990 year classes to a high of 3.56 % for the 1979 year class with a mean of 0.45% and a median of 0.26% (Table 5). In general, it appears that larger yearlings had higher return rates (Table 5: Figure 6). This was especially true for the 1979 year class stocked at a size of 3.2 fish/lb, and a portion of the 1989 year class that was stocked at 3.9 fish/lb. Unfortunately, there were only two years when fish larger than 4.0 fish/lb (~ 9 in) were stocked. However, two stocking events used fish at sizes 4.4 and 4.6 fish/lb, only about 0.5 in smaller in length (~8.5 in), which demonstrated a 10-fold reduction in return rate when compared to fish larger than 4.0/lb. Given the major difference in return rate, over a very narrow size range, it is likely that environmental factors, in addition to size at stocking, may have influenced return rate for these year classes. However, the general trend that larger yearlings return at higher rates is consistent with observations by other agencies when stocking Atlantic Salmon (Johnson 2012; Tucker et al. 2014) and has also been observed for returns of stocked Rainbow Trout in Minnesota (Negus et al. 2012).

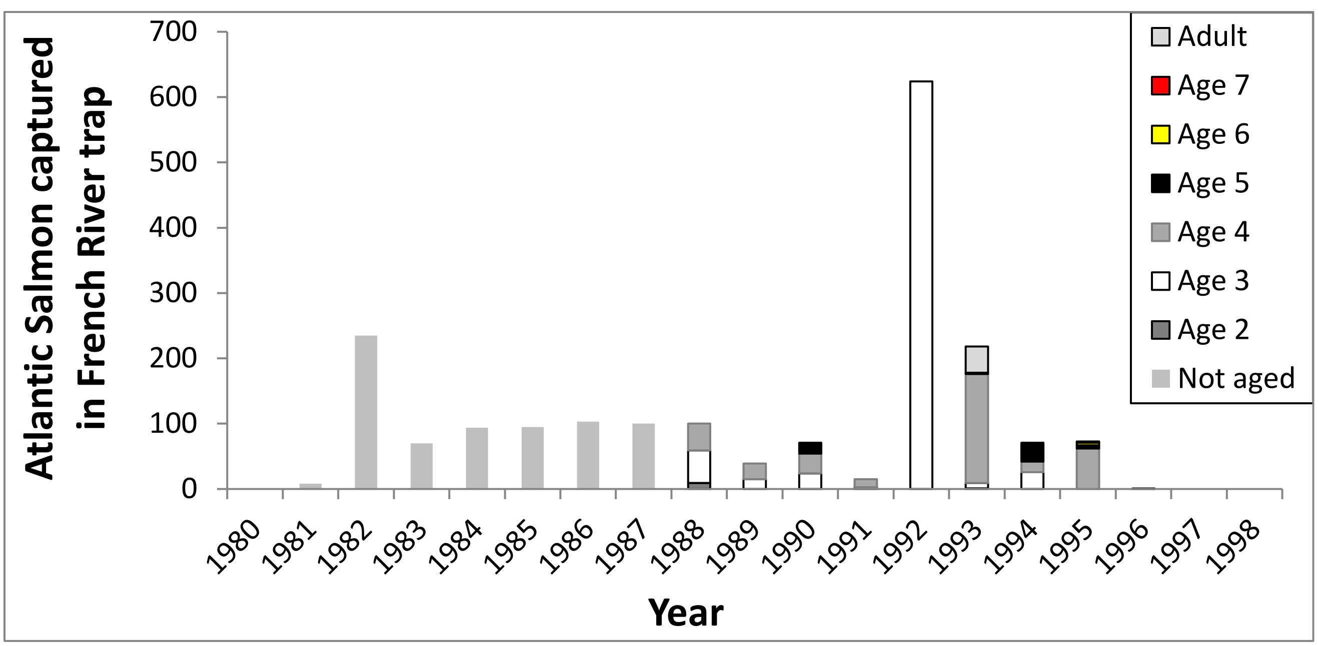


FIGURE 5. Number and age of Atlantic Salmon captured in the French River trap by year. Fish were not aged prior to 1988.

TABLE 5. Return rate of Atlantic Salmon yearlings by year class and size at stocking to the French River trap.

Year class[a]	Year stocked	Number stocked	Rate (yearlings/lb)	Adults returned	Percent return
1979	1980	7,584	3.2	270	3.56%
1985	1986	28,634	7.9[b]	89	0.31%
1986	1987	50,120	5.4[b]	54	0.10%
1987	1988	21,061	9.7[b]	28	0.11%
1988	1989	20,930	10.6[b]	5	0.02%
1989	1990	9,558	3.9	318	3.33%
1989	1990	9,864	16.1	11	0.11%
1990	1991	10,355	4.4	27	0.26%
1990	1991	9,927	11.2	2	0.02%
1991	1992	14,961	6.9	47	0.31%
1991	1992	15,498	4.6	42	0.27%

[a] 1981 to 1984 year classes were not aged.
[b] Rate represents an average rate of several groups stocked from these year classes.

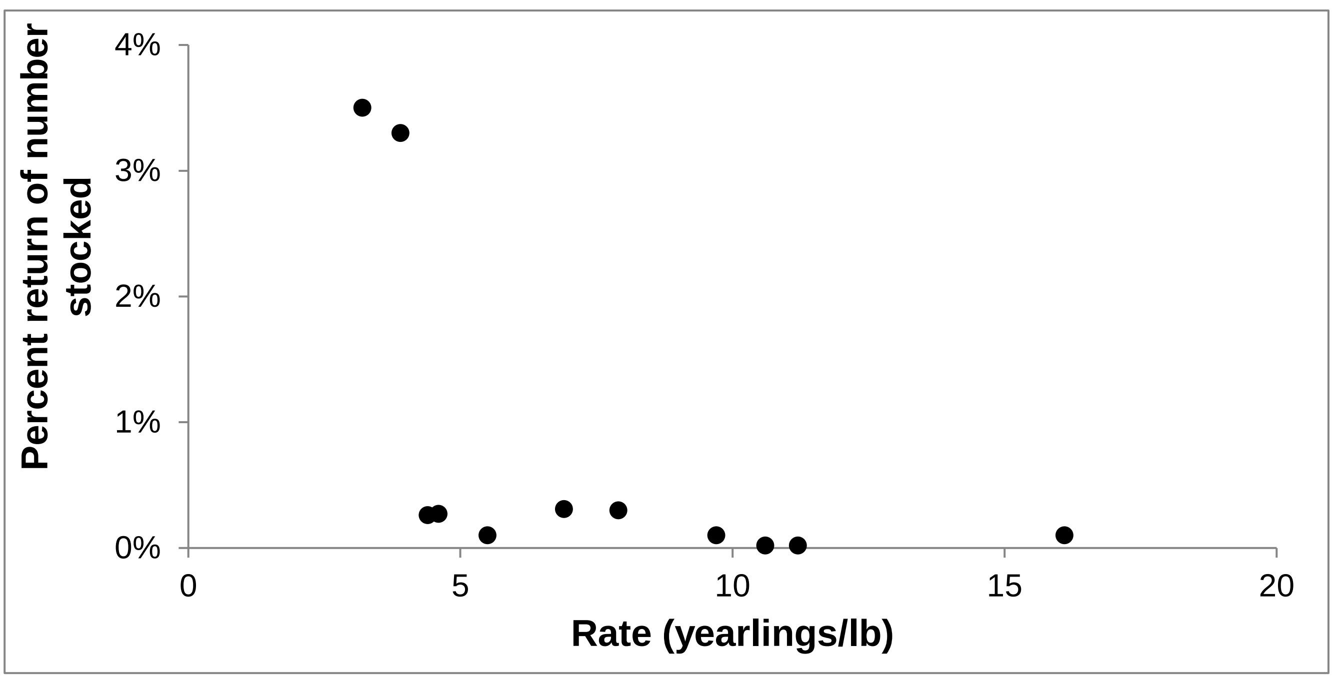


FIGURE 6. Size of yearlings at stocking (rate; number/lb) versus percent return of adult Atlantic Salmon captured in the French River trap.

In addition to being a valuable monitoring tool, the French River trap has also been used as an egg take station for feral broodstock. During the Atlantic Salmon program, gametes were taken at the trap from 1982-1991. The number of females spawned over this 10 year period ranged from 3 to 59 fish, with a mean of 29 fish. The number of eggs taken per year averaged approximately 111,122 eggs and the average number of eggs per female was approximately 3,780 eggs (Table 3). Eggs collected at the French River trap were either transferred to the St. Paul Hatchery for rearing to various life stages or were reared at the French River Hatchery and stocked back into Lake Superior.

Population Dynamics

No population estimates for Atlantic Salmon in Lake Superior were made during the life of the program. However, population size of a given year class could be estimated based on number stocked and assumed mortality rates. Total annual mortality rates between years based on scale ages and fin clips were estimated as 0.9 for stocked age-1 to age-2; 0.5 from age-2 to age-3; 0.8 from age-3 to age-4; and 0.9 for each year after age-4 (Negus 1992; Negus 1995).

Atlantic Salmon returning to the French River trap from 1988-1995 ranged in age from 2-7 based on scales and fin clips (Table 6). The most common age of fish in the spawning run from 1988-1995 was age 3+ at 64.2%, followed by age-4+ at 30.1% (Figure 5; Table 6). Most of the age-3+ returning fish were from the very strong 1989 year class, which greatly influenced the age structure of returns to the French River trap. Average weight at age was determined from adults returning to the French River trap (Table 7).

TABLE 6. Ages of recaptured Atlantic Salmon in the French River trap.

Year captured	Not aged	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Stocked Adults
1980	0							
1981	8							
1982	235							
1983	70							
1984	94							
1985	95							
1986	103							
1987	100							
1988		9	50	41				
1989			15	24				
1990			24	30	15	2		
1991			3	12				
1992			624					
1993		1	8	167	2			40
1994			26	16	25		2	2
1995				62	5	4		2
1996					1			
1997	0							
1998	0							
Total	705	10	750	352	48	6	2	44
% at age		0.9%	64.2%	30.1%	4.1%	0.5%	0.2%	

TABLE 7. Average weight at age for Atlantic Salmon returning to the French River trap.

Age	Weight (lb)	Increment (lb)
1	0.13	
2	2.00	1.90
3	3.30	1.30
4	4.90	1.60
5	5.70	0.83

Weight at age-1 was the average weight of the stocked yearling, with other weights at age determined by averaging returns to the French River trap during the fall spawning runs (Negus 1992: Negus 1995). As expected, the largest growth increment occurred between age-1 and age-2, with the lowest occurring in the older fish once maturity had been reached. Atlantic Salmon returning to the French River trap averaged about 4.3 lb and were generally smaller, and grew slower than Atlantic Salmon in Lake Ontario that averaged 6-8 lb per returning spawner or those in the Atlantic Ocean which averaged 8-12 lb per returning spawner, depending on the stream (Fay et al. 2006).

In the fall, most spawning fish returned between September and mid-November, with the majority returning from mid-October thru early November (Figure 7; Appendix 5). The range of return dates are only presented for 1992 and 1993 since those were the years that had the highest returns and spanned the longest time period. However, in general, return dates were later as the program progressed (MNDNR French River Trap Reports, Lake Superior and Duluth Area Files).

Limited information is available on the diet of Atlantic Salmon in Lake Superior. However, as anticipated when the program began, Atlantic Salmon fed predominately on Rainbow Smelt (Conner et al. 1993; Negus 1995; MNDNR Lake Superior Files). Negus (1995) created five diet categories for top Lake Superior predators in Minnesota. Using these categories, Atlantic Salmon diet by weight was composed of approximately 80% Rainbow Smelt, 5% Coregonids, 5% insects, 10% crustaceans (predominately Mysids), with < 1% made up of other fish species.

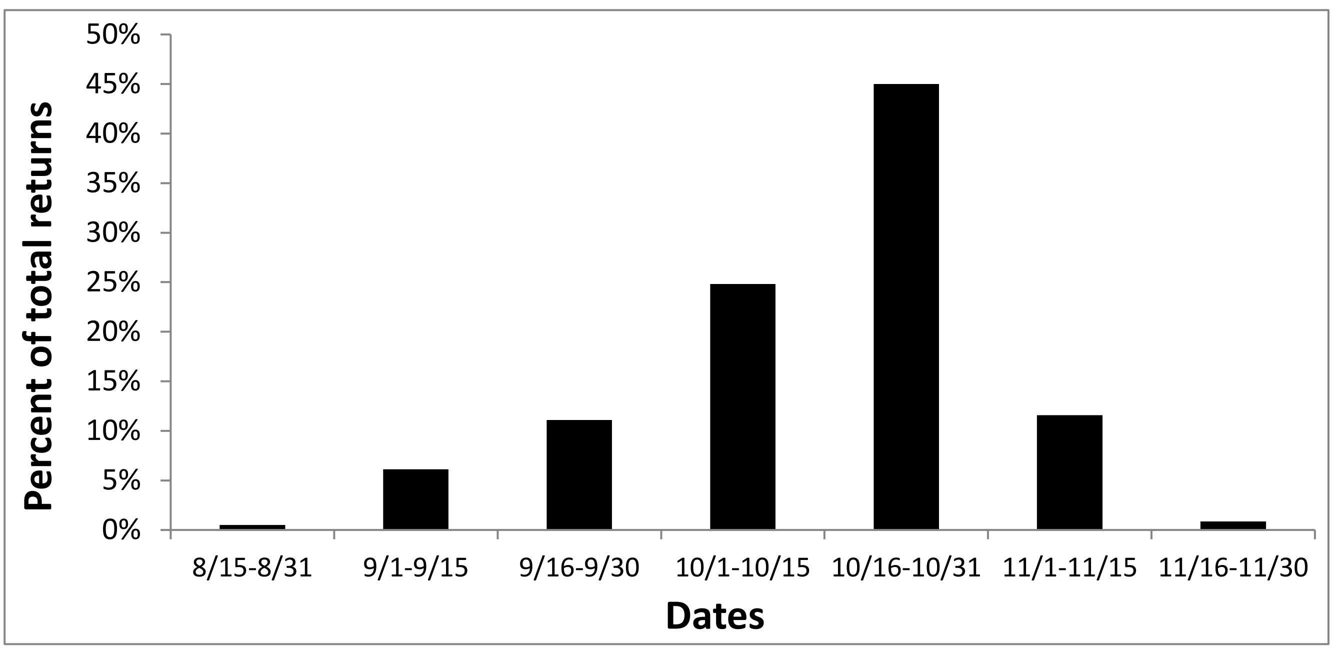


FIGURE 7. Percent of Atlantic Salmon that returned as adults to the French River trap by date interval in 1992 and 1993.

Overall Atlantic Salmon Program Costs

The overall cost of the Atlantic Salmon program is difficult to calculate, but general estimates can be made based on both cost of fish produced and cost of fish returned to the angler. Cost of fish produced is greatly influenced by the hatchery where the fish were reared, and if the gametes came from a captive or feral broodstock. As an example, in 1989 the cost to produce one pound of Atlantic Salmon yearlings at the St. Paul Hatchery was approximately $17.00/lb, while the cost of producing the same product at the Peterson Hatchery was approximately $7.20/lb. Neither of these cost estimates included broodstock maintenance, or stocking costs which would increase the costs even further. Two major factors increase the cost of producing Atlantic Salmon yearlings above those of most other salmonids. First, they must be reared in the hatchery for at least 1.5 years before stocking since they are fall spawners. Second, they do not thrive when crowded, so the need for greater raceway space makes the total production program less efficient than for other salmonids. The average estimated production cost from all hatcheries per Atlantic Salmon yearling/fingerling stocked from 1988-1992 was approximately $1.80 per fish (Schreiner 1995). The cost/fish stocked for yearlings only would have been much higher.

The cost of fish returned to the angler can be calculated by dividing the total cost of fish stocked by the number of fish returned to the angler. Although the cost to produce an Atlantic Salmon was relatively stable over the years the program was conducted, the harvest by anglers was extremely variable and had a large impact on the cost of fish caught. The average cost of Atlantic Salmon caught from 1988-1994 in the Lake Superior fishery from all sources was approximately $720.00 per fish (Schreiner 1995). This calculation includes the extremely high catches experienced in 1992.

The estimated average annual cost of the entire Atlantic Salmon program from 1980–1992 was approximately $200,000.00. The average angler harvest of Atlantic Salmon from 1981-1998 combining all creel surveys is estimated at 265 fish/year. This would result in a cost per fish harvested of $755.00, very similar to the estimate given in the 1995 Fisheries Management Plan for the Minnesota Waters of Lake Superior (Schreiner 1995). If the average return of Atlantic Salmon to the French River trap over this same period is added to the average creel return, the cost estimate decreases to approximately $500.00 per fish. Given the effects of compounding inflation over the last 20 years, costs to produce Atlantic Salmon in 2015 would likely double when compared to historical calculations.

Factors Influencing Atlantic Salmon Survival

A combination of factors influenced the survival of Atlantic Salmon in Minnesota's portion of Lake Superior. As is normally the case in biological systems, a combination of these factors, rather than one specific factor, affected survival of Atlantic Salmon. However, the relative importance of individual factors varied over time. In a hatchery-based program some of these factors can be controlled, but once stocked, natural environmental conditions dominate to control survival.

In a hatchery based program managers have some influence over the attributes of the fish they produce. Managers for the Atlantic Salmon hatchery program made decisions on strain, size at stocking, time of stocking, and to a lesser extent imprinting. One factor that appears to have influenced Atlantic Salmon survival in Minnesota was size at stocking, with larger fish surviving better than smaller fish. Survival of fry and fingerlings was extremely poor, while the size of yearlings stocked appeared to influence survival, with yearlings larger than 4/lb (> 9.0 in) surviving almost 10-fold better than yearlings smaller than 4/lb (< 9.0 in) (Figure 6). This relationship was largely driven by the 1979 year class stocked at 3.2 fish/lb (3.56% return rate) and a portion (32.4%) of the 1989 year class that was stocked at 3.9 fish/lb (3.33% return rate) (Table 5, Appendix 2). Interestingly, a portion of the 1990 Atlantic Salmon year class stocked at 4.4 fish/lb and a portion of the 1991 year class stocked at 4.6 fish/lb had much lower return rates (0.26 and 0.27% respectively), despite being only about 0.5 in smaller than the portion of the 1989 year class monitored (Table 5, Appendix 2).

Return rates to both the French River trap and the fishery of the 1989 Atlantic Salmon year class stood out as unusually high. The total return of the 1989 Atlantic Salmon year class to the French River trap from 1992-1995 was 820 fish (Table 6). The total return of yearlings stocked into the French River in 1990 at 3.9 fish/lb was 318 or about 39% of the total return to the French River trap of the 1989 year class. The portion of the 1989 year class stocked into the French River in 1990 at 16.1 fish/lb contributed only 11 fish to the total return or 1.3%. The remainder of the 491 fish were not marked, but were aged and likely came from a combination of returns that originated from the 10,047 yearlings stocked in the French River at 6.4 fish/lb in 1990, the 111,616 fingerlings stocked in the French River in 1989 at 101.7 fish/lb (Appendix 2) or were strays from the 76,278 yearlings stocked in the Split Rock River at 11.8 fish/lb in 1990 (Table 1; Appendix 3). The number of yearling stocked in the Split Rock River in 1990 was about six times greater than the number of yearlings that had normally been stocked in the Split Rock River since 1986. The high returns of the 1989 year class to both the French River trap and the fishery were likely due to the combination of the relatively high number of yearlings stocked in both the French and Split Rock rivers in 1990 (105,747), a sub-group of relatively large yearlings stocked in the French River, an unusually high number of fingerlings stocked in the French River (111,616), and favorable environmental conditions in the lake in 1990. Negus et al. (2012) noted that relatively warm Lake Superior water temperatures in the summer of 1990 positively influenced the survival of Rainbow Trout, while below average lake temperatures in 1992 and 1993 had a negative influence on Rainbow Trout survival. These same conditions also may have influenced return rates of Atlantic Salmon in those years.

Rearing fish to a very large size may increase survival, but it can also negatively affect homing, because rearing fish past smolt size in hatcheries not using water from target streams can reduce imprinting and return to the target stream. This is the conundrum faced by many hatchery programs that are attempting to optimize returns of migratory species to specific streams (Schreiner et al. 2006; Negus et al. 2012).

In an early experiment to examine imprinting and homing of Atlantic Salmon in Minnesota, yearlings were produced at the FRCWH for three years, instead of the St. Paul Hatchery, and were stocked in the French River from 1984-1986. The numbers of yearlings stocked were 11,866, 25,154, and 28,634 respectively, and they ranged in size from 6.0-9.0 per pound (Table 1; Appendix 2). If imprinting were a major factor for attracting the spawning adults back to the French River trap, then the total returns of Atlantic Salmon after 1986 should have generally increased. However, there was no significant change in the total number of adult Atlantic Salmon returning to the French River trap from 1986-1988 (Figure 5, Appendix 4). Unfortunately, this was not a paired experiment so year affect could not be separated from the imprinting factor.

In a later experiment, three year classes (1989-1991) of paired stocking between St. Paul and FRCWH compared both size at stocking and potential effects of imprinting. Those imprinted at the FRCWH had higher returns, but were generally larger when stocked, which likely influenced the effects of imprinting. Lack of imprinting to the French River did not appear to adversely affect the return rate of the 1979 year class reared at the St. Paul Hatchery and stocked in the French River as yearlings in 1980. The 1979 year class produced one of the highest return rates to the French River trap (Table 5, Figure 6), but was also the year class comprised of the largest fish stocked during the program at 3.2 fish/lb, again confounding the potential effects of imprinting. Unfortunately no controlled experiment to investigate imprinting as the only variable was conducted during this program, but it is well documented that imprinting to natal streams is a natural occurrence in salmonid fishes and is considered as a factor that has great potential to influence return rates in most systems (Negus 2003).

In Minnesota, the conundrum between rearing fish to a larger size and the need to imprint on specific streams before smolting to facilitate homing has also been identified as an issue affecting the Rainbow Trout program (Negus et al. 2012). Time of stocking is closely related to size at stocking, and it is important that hatchery-reared fish be stocked when a food source is readily available, temperatures are acceptable for survival, and predators are least abundant. For Atlantic Salmon this time period appeared to occur in late June or early July, similar to the preferred stocking time determined for Rainbow Trout (Negus et al. 2012). The relationship between size at stocking, time of stocking, and imprinting of Atlantic Salmon are all interrelated and complex, having a major influence on survival. These factors can vary annually and cannot be easily addressed given the constraints of a hatchery based program.

Strain has been shown to influence survival in a number of introduced species (Close et al. 1981; Siesennop 1992; Johnson 2012; Negus et al. 2012). The Grand Lake strain of Atlantic Salmon used in Minnesota is also the original strain used in the St. Marys River program with positive results. Although no other strains were used for comparison in Minnesota, it appears the Grand Lake strain was a good choice, given the results achieved in the St. Marys River.

Although decisions made on factors such as those described above are critical to any hatchery-based program, the ecological and environmental conditions of the system into which fish are being introduced will determine the ultimate fate of the program. Lake Superior is an extremely oligotrophic system with very cold water temperatures and limited productivity. These unique environmental conditions, along with the composition of the fish community from 1980-1998 likely had the greatest influence on the Atlantic Salmon program in Minnesota. Rainbow Smelt populations, which were a major prey source, decreased sharply during the 1980s, while the native Lake Trout stocks increased to near historical levels and Pacific Salmon became naturalized (Schreiner 1995, Schreiner et al. 2006; Negus et al. 2008; Gorman et al. 2010). This greatly reduced available forage and increased predators far beyond the levels in the 1970s when the Atlantic Salmon program was first being considered for introduction.

Cold water temperatures at critical life stages and over extended periods of time was likely a major factor affecting Atlantic Salmon growth, survival and reproduction in Lake Superior. Despite the relative low temperature tolerance of Atlantic Salmon, and the anticipation that they could tolerate the cold Lake Superior environment, in most years they were well outside of their preferred temperature range for up to 8 months of the year. Elliot and Hurley (1997) defined the lower and upper limits for growth of adult Atlantic Salmon as 42.8^{O}F and 72.5^{O}F respectively, with 60.5^{O}F as the optimal growth temperature. As a result of colder Lake Superior water temperatures and competition for forage, weight at age was much lower in the Minnesota program than for Atlantic Salmon introduced into the lower lakes and that reported from the Atlantic Ocean. Similar to Atlantic Salmon, Pacific Salmon and Rainbow Trout in Lake Superior also exhibit poor growth and survival in years with below average water temperatures (Schreiner et al. 2006; Schreiner et al. 2010; Negus et al. 2012; Negus and Hoffman 2013). Given the water temperatures preferred by Atlantic Salmon, slow growth and poor survival will likely occur if water temperatures do not exceed the minimal level for growth, about 43^{O}F or greater, for at least 4-6 months of the year. Lake Superior is on the thermal margin of the range for consistent growth and survival of adult Atlantic Salmon, as it is for many of the introduced salmonids, especially in years with below average lake temperatures.

Cold Lake Superior water temperatures may also negatively affect survival of newly stocked Atlantic Salmon yearlings. Laboratory research found that growth, food intake and food conversion efficiency for post-smolts (~ 7.0 in) was very sensitive to water temperature (Handeland et al. 2008). In experiments using water temperatures of 42.8, 50.0, 57.2, 64.4^{O}F they found feeding and growth of post-smolts to be minimal at 42.8^{O}F, and much higher at 50.0-57.2^{O}F, with a slight reduction at 64.4^{O} F. This has implications for Atlantic Salmon programs in Lake Superior, and likely explains why larger yearlings stocked in late June or July survive better than yearlings stocked in April or May when water temperatures are still relatively cold. Besides increased predator avoidance, larger yearlings may have an advantage in colder temperatures since they have a store of energy to sustain them until lake temperatures warm and they can feed more efficiently. The summer of 1990 had particularly high mean water temperatures from June-September, and the 1989 year class, stocked in 1990, had relatively high survival. Low lake temperatures in 1992 and 1993 may have negatively affected the young fish stocked in 1991 and 1992 at 4.4 and 4.6/lb. Lake Superior water temperatures during the summer of stocking or smolting was also found to influence Rainbow Trout survival in Minnesota (Negus et al. 2012).

Part of the goal for the experimental Atlantic Salmon stocking program in Minnesota was to determine if self-sustaining populations could be established. If they were to become naturalized, Atlantic Salmon would have to effectively use streams for spawning and nursery habitat over the first 1.5-2.5 years of their life cycle. In Minnesota, productive stream habitat is extremely limited and where it is available, it is shared by five other migratory Salmonids, four fall spawners (Brook Trout, Chinook, Coho and Pink Salmon) and one spring spawner (Rainbow Trout or Steelhead). The streams appear more suitable for spring spawners since in most cases they have one less winter to endure. In addition, there is likely much competition for limited spawning space among the fall spawners (Schreiner 2003; Scott et al. 2003; Scott et al. 2005; Coghlan and Ringler 2005; Coghlan et al. 2007). Little natural reproduction of any fall spawners occurs in Minnesota streams, except for Pink Salmon, which migrate immediately from the streams to Lake Superior after emergence as fry in the early spring (Schreiner et al. 2006).

Besides having limited habitat available for migratory Salmonids, Minnesota streams experience extreme fluctuations in environmental conditions that are inhospitable for cold water fish. Minnesota tributaries to Lake Superior have very little ground water and rely on run-off to support flow (Ostazeski and Schreiner 2004). Most summers experience reduced flows, and temperatures can warm to intolerable levels. During some winters with little snow and extended cold temperatures (below -20^{O}F), sections of streams routinely freeze to the bottom, further decreasing the limited habitat that is present and reducing carrying capacity for juvenile Salmonids (Negus et al. 2012). Large annual variations in stream temperatures may influence time of smolting and emigration, potentially impacting survival of naturalized Atlantic Salmon (Zydlewski 2005). Spate flows in Minnesota tributaries are frequent during the summer and in the spring, when heavy precipitation coupled with snow-melt can physically destroy redds and negatively affect newly hatched fry (Close et al. 1989; Schreiner 2003; Negus et al. 2012).

In the mid-late 1980s, a study was conducted to examine interspecific competition between Rainbow Trout (Steelhead), Atlantic Salmon and Chinook Salmon for habitat use under low flow conditions in North Shore Streams (Close et al. 1989). The results indicated that because Chinook Salmon inhabited deeper portions of the stream, and emigrated from the streams at age-0 in late June or July, they had minimal interaction with Steelhead and Atlantic Salmon. Most Steelhead and Atlantic Salmon that survived to adults remained in the stream for 2-3 years before smolting, and they tended to inhabit similar habitat types (fast shallow water) as both age-0 and age-1 parr. Unfortunately, annual summer flows during the study period remained relatively constant, precluding comparisons when habitat was limited during extremely low flow conditions (Close et al. 1989). Although summer flow was not limiting during the Close et al. (1989) study, high spate flows during the spring, high water temperatures in the summer, extreme winter conditions, and potentially acid rain (during spring run-off) may have had a greater influence on survival. They did not investigate the competition between Chinook and Atlantic Salmon for spawning habitat, but others have found this to be significant in other systems (Jones and Stanfield 1993; Crawford 2001; Scott et al. 2003; Scott et al. 2005). The major conclusion was that similar habitat is used by both Atlantic Salmon and Steelhead parr in Minnesota tributaries, and when habitat is limited, direct competition for space would likely occur (Close et al. 1989).

A potential reason for low Atlantic Salmon return rates to fall anglers was that adults generally returned to the streams later in the fall with each year of stocking. In the early 1980s, adults started returning to the French River trap in late summer, but by the 1990s, most adults returned in late October to mid-November when weather conditions were not ideal, and fishing pressure was very low (Figure 7; Appendix 5). When the program was initiated the majority of Atlantic Salmon were expected to return in late summer–early fall, creating a popular shore and stream fishery. Likely due to the very cold Lake Superior water temperatures, spawning adults took longer to mature and spawning runs were delayed compared to those in the lower Great Lakes and Atlantic Ocean (Webb and McLay 1996). Delayed spawning and increased age at maturity as a response to cold water temperatures has also been reported for Pacific Salmon and Rainbow Trout in Lake Superior (Negus 1992; Negus 1995; Schreiner et al. 2006).

As discussed in this section, a variety of hatchery influenced factors and environmental variables appear to influence Atlantic Salmon survival in Lake Superior. Rearing yearlings to a relatively large size in the hatchery may increase returns, but is very expensive and requires a trade-off between larger size, fewer fish stocked and a potential decrease in the level of imprinting. A major factor for establishing naturalized populations is the limited amount of spawning and nursery habitat in Minnesota North Shore streams and the annual environmental influences on that limited habitat. Both hatchery-reared and naturalized Atlantic Salmon would have to endure the cold Lake Superior water temperatures, the declining forage base and the increase in predators, especially native Lake Trout, to survive. Some of the hatchery factors could be overcome at increased expense, such as size and time of stocking, but external factors would be more difficult or impossible to address, such as variable stream conditions, environmental conditions in the lake, a reduced forge base, increased predators, and a system that is presently at carrying capacity for major fish species (Schreiner et al. 2006; Negus et al. 2008; Negus et al. 2012; Pratt et al. 2015).

Program Discontinuation

In early 1991, the MNDNR critically reviewed the status of the experimental Atlantic Salmon program over its 10 year history in Minnesota's portion of Lake Superior. High cost, low return rate, and limited angler interest all supported phasing out the program (Schreiner 1995). Although a small number of dedicated and vocal anglers continued to support the program, input from public meetings held in Duluth, Grand Marais, and St. Paul in late 1991 to discuss the status of Atlantic Salmon resulted in minimal support to continue the program. In early 1992, the decision was made to eliminate the Atlantic Salmon broodstock, stock the fish remaining in the hatchery, and continue to monitor the program.

A window of opportunity was left open to reestablish the program if returns to the angler and angler interest increased substantially over the next two years. A reestablished program would have originated with gametes collected from feral Atlantic Salmon returning to the French River trap. The fertilized eggs would then have been hatched at the FRCWH and used to rear smolts for stocking. In 1992, anglers harvested a relatively high number of Atlantic Salmon compared to previous years and returns to the French River trap increased to an all-time high (Figure 5, Appendix 4). Almost all of the 1992 returns were from the 1989 year class, the most successful year class on record. This prompted inquiries as to the future of the Atlantic Salmon program, although in general, interest remained low among most anglers.

The MNDNR Section of Fisheries indicated that no final decision to discontinue the Atlantic Salmon program would be made until the 1993 angling season was monitored. The 1993 angling season was monitored through a special Atlantic Salmon creel survey (Jones 1993), charter fishing reports and routine spring and summer creel surveys. All data indicated a large decline in the catch of Atlantic Salmon when compared to 1992, with much of the 1993 catch being composed of the large 1989 year class, and continued low interest among all but a few avid anglers.

In fall 1993, the MNDNR, Section of Fisheries decided to discontinue the Atlantic Salmon program, with no plans to reestablish it. The final decision was based largely on cumulative returns to the angler and low angler interest. Anglers harvested a few Atlantic Salmon through 1997, but harvest never approached the relatively high level reported from the 1989 year class. Many factors influenced the decision to discontinue the program, and much discussion, data analysis and debate occurred before the final decision was made. Appendix 6 includes the position statement developed by the MNDNR, Section of Fisheries that outlines the major reasons and justifications for making the decision to discontinue the program.

After the program was discontinued occasional requests to reinstate the program were received from a small group of avid Atlantic Salmon anglers. Based on the results of the Atlantic Salmon program summarized in this report it is unlikely the program will be reconsidered. The costs of energy intensive hatchery programs are now under review because major reductions in energy use and carbon emissions have been mandated from the Governor's Office. The MNDNR also continues to seek and develop more cost-effective program management, including programs with positive cost:benefit ratios, so limited financial resources are spent wisely.

Most importantly, changes in the Lake Superior fish community over the last 35 years are less favorable for Atlantic Salmon than they were in the 1980s. Lake Trout are now self-sustaining and approaching historical levels of abundance, Pacific Salmon have naturalized and Rainbow Smelt have decreased to less than 5% of their historical abundance. Due to these dramatic changes in the fish community, survival of stocked fish of all species has decreased to the point where most stocking is no longer economically feasible or required. The present composition of the Lake Superior fish community has largely reverted to the native species assemblage which can more effectively utilize the unique environmental conditions in Lake Superior.

Acknowledgements

Thanks to all the staff from the Lake Superior, Duluth, Finland and Grand Marias Areas for their work on the Atlantic Salmon program over many years. Staff from the French River, St. Paul and Peterson Hatcheries were instrumental in initiating the production program. Tom Jones and Ted Halpern made major contributions to monitoring the program; Don Schliep oversaw returns to the French River trap, while Fred Tureson and Darryl Bathel were instrumental in successful production of Atlantic Salmon from the hatchery. Mark Ebbers assisted with statewide costs and evaluation of the Coldwater Program. Tim Goeman, Cory Goldsworthy and Keith Reeves made suggestions on the manuscript, and Colleen Telander prepared the final report format. The MNDNR appreciates the interest of all the anglers that participated in the Atlantic Salmon program and shared their input through public meetings, questionnaires, and various surveys.

References

Behmer, D. J., R. W. Greil, S. J. Scott, and T. Hanna. 1993. Harvest and movement of Atlantic salmon stocked in the St Marys River, Michigan. Journal of Great Lakes Research 19:533-540.

Bring Back the Salmon Lake Ontario. 2013. Bring back the salmon Lake Ontario. Retrieved from http://www.bringbackthesalmon.ca.

Brown, S. B., J. D. Fitzimons, D. C. Honeyfield, and D. E. Tillit. 2005. Implications of thiamine deficiency in Great Lakes salmonines. Journal of Aquatic Animal Health, 17, 113-124.

Close, T., S. Colvin and R. Hassinger. 1981. Evaluation of Madison, Donaldson and Kamloops Strains of Rainbow trout (*Salmo gairdneri*) in Lake Superior. Minnesota Department of Natural Resources Investigational Report 372, St. Paul.

Close, T., D. Belford, S. Colvin and C. Anderson. 1989. The role of low flow habitat and interspecific competition in limiting anadromous parr abundance in north shore streams. Minnesota Department of Natural Resources Investigational Report 398, St. Paul.

Close, T. L., and C. S. Anderson. 1997. Factors limiting juvenile steelhead survival in streams tributary to Minnesota waters of Lake Superior. Minnesota Department of Natural Resources Investigational Report 462, St. Paul.

Close, T., S. Colvin and R. Hassinger. 2005. Kamloops, Madison and Donaldson strains of rainbow trout in an oligotrophic lake. Minnesota Department of Natural Resources Investigational Report 385, St. Paul.

Conner, D. J., Bronte, C. R., Selgeby, J. H., and Collins, H. L. 1993. Food of salmonine predators in Lake Superior, 1981-1987. Great Lakes Fishery Commission, Technical Report 59, Ann Arbor.

Coghlan, S. M., Jr., and N. H. Ringler. 2005. Temperature-dependent effects of rainbow trout on growth of Atlantic salmon parr. Journal of Great Lakes Research 31:386-396.

Coghlan, S., G. Cain, and N. H. Ringler. 2007. Prey selection of subyearling Atlantic salmon and rainbow trout coexisting in a natural stream. Journal of Freshwater Ecology, 22(4), 591-607.

COSEWIC. (2010). Wildlife species search: Atlantic salmon. Retrieved from http://www.cosewic.gc.ca/eng/sct1/search result.

Crawford, S. S. 2001. Salmonine introductions to the Laurentian Great Lakes. Canadian Special Publication of Fisheries and Aquatic Science 132: xiv+205.

de Guzman, L., L. Gibson, M. Lavery, C. Ly, and K. MacDougall. 2014. Assessing the challenges of reintroducing Atlantic salmon (*Salmo salar*) to Lake Ontario - compiled for the Lake Ontario Atlantic Salmon Reintroduction Program. Queen's Department of Environmental Studies, ENSC 320

Dexter, D. J. and D. V. Schliep. 2007. Design of a compound inclined screen trap for anadromous salmonid smolts. North American Journal of Fisheries Management 27:885-890.

Dexter, J. L., Jr. 2004. Gull Lake as a broodstock source for landlocked Atlantic salmon, 1991–96. Michigan Department of Natural Resources, Fisheries Technical Report 2004-1, Ann Arbor.

Dietrich, J. P., J. N. Bowlby, B. J. Morrison, and N. E. Jones. 2008. The impacts of Atlantic salmon stocking on rainbow trout in Barnum House Creek, Lake Ontario. Journal of Great Lakes Research 34:495-505.

Fay, C., M. Bartron, S. Craig, A. Hecht, J. Pruden, R. Saunders, T. Sheehan, and J. Trial. 2006. Status Review for Anadromous Atlantic Salmon (*Salmo salar*) in the United States. Report to the National Marine Fisheries Service and U.S. Fish and Wildlife Service. 294 pages.

Fisher, J. P., J. D. Fitzsimons, G. F. Combs, Jr., and J. M. Spitsbergen. 1996. Naturally occurring thiamine deficiency causing reproductive failure in Finger Lakes Atlantic salmon and Great Lakes lake trout. Transactions of the American Fisheries Society 125:167-178.

Galbraith, M. G., and J. C. Schneider. 1983. Atlantic salmon in the Great Lakes (Michigan waters). Michigan Department of Natural Resources, Federal Aid in Sport Fish Restoration, Study Final Report, F-35-R-9, Study 410, Ann Arbor.

Gorman, O. T., M. P. Ebener, and M. R. Vinson, M.R., editors. 2010. The state of Lake Superior in 2005. Great Lakes Fish. Comm. Spec. Pub. 10-01.

Handeland, S. O., K. A. K. Imsland, and S. O. Stefansson. 2008. The effect of temperature and fish size on growth, feed intake, food conversion efficiency and stomach evacuation rate of Atlantic salmon post-smolts. Aquaculture 283:36–42.

Hearn, W. E., and B. E. Kynard. 1986. Habitat utilization and behavioral interaction of juvenile Atlantic salmon (*Salmo salar*) and rainbow trout (*S. gairdneri*) in tributaries of the White River of Vermont. Canadian Journal of Fisheries and Aquatic Science 43:1988–1998.

Horns, W. H., C. R. Bronte, T. R. Busiahn, M. P. Ebener, R. L. Eshenroder, T. Gorenflo, N. Kmiecik, W. Mattes, J. W. Peck, M. Petzold, and D. R. Schreiner. 2003. Fish-community objectives for Lake Superior. Great Lakes Fishery Commission, Special Publication 2003-01, Ann Arbor.

Huntsman A. G. 1944. Why did Lake Ontario salmon disappear? Transactions of the Royal Society of Canada, Sec. 5, Ser. 3 (38): 83-102.

Hutchings J. A. and E. B. Jones. 1998. Life history variation and growth rate thresholds for maturity in Atlantic salmon, (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 55(Suppl. 1):22–47.

Jones, M. L. and L. W. Stanfield. 1993. Effects of exotic juvenile salmonines on growth and survival of juvenile Atlantic salmon (*Salmo salar*) in a Lake Ontario tributary. In Gibson, R.J. & Cutting, R.E., editors: The production of juvenile Atlantic salmon, *Salmo salar*, in natural waters, pages 71–79. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

Johnson, J. E. 2012. Review of Attributes of Landlocked Atlantic Salmon in Relation to their Management in Lake Huron. Michigan Department of Natural Resources, Fisheries Division, Fisheries Brief Report 03.

Jones, T. S. 1993. Special creel: Atlantic salmon May 29-June 30, 1993. Minnesota Department of Natural Resources, Lake Superior Area Completion Report, St. Paul.

Lackey, R.T. 2001. Defending reality. Fisheries 26(6):26-27.

Lake Superior State University. 2014. Hatchery production of Atlantic Salmon. https://www.lssu.edu/arl/hatchery.php.

Michigan Department of Natural Resources. 2014. Atlantic Salmon. http://www.michigan.gov/dnr/0,4570,7-153-10364_18958-45639--,00.html.

Negus, M. T. 1992. Evaluation of bioenergetics modeling in the study of predator-prey dynamics in Minnesota waters of Lake Superior. Minnesota Department of Natural Resources, Investigational Report 414.

Negus, M. T. 1995. Bioenergetics modeling as a salmonines management tool applied to Minnesota waters of Lake Superior. North American Journal of Fisheries Management 15:60-78.

Negus, M. T. 2003. Determination of smoltification status in juvenile migratory Rainbow Trout and Chinook Salmon in Minnesota. North American Journal of Fisheries Management 23:913-927.

Negus, M. T., D. R. Schreiner, T. N. Halpern, S. T. Schram, M. J. Seider, and D. M. Pratt. 2008. Bioenergetic evaluation of the fish community in the western arm of Lake Superior in 2004. North American Journal of Fisheries Management 28:1649-1667.

Negus, M. T., D. R. Schreiner, M. C. Ward, J. E. Blankenheim, and D. F. Staples 2012. Steelhead return rates and relative costs: A synthesis of three long-term stocking programs in two Minnesota tributaries of Lake Superior. Journal of Great Lakes Research. Volume 38, Issue 4, Pages 653–666.

Negus, M. T., and J. C. Hoffman. 2013. Habitat and diet differentiation by two strains of rainbow trout in Lake Superior based on archival tags, stable isotopes, and bioenergetics. Journal of Great Lakes Research 39:578-590.

Newman, L. E., R. B. Dubois, and T. N. Halpern, editors. 2003. A brook trout rehabilitation plan for Lake Superior. Great Lakes Fishery Commission, Special Publication 2003-03, Ann Arbor.

Ostazeski, J. J. and D. R. Schreiner. 2004. Identification of groundwater intrusion areas on the Lake Superior shoreline and selected tributaries in Lake Superior. Minnesota Department of Natural Resources, Lake Superior Area Completion Report, St. Paul.

Pratt, T. E. et al. 2015. State of Lake Superior 2012. In review. Great Lakes Fisheries Commission, Special Publication 15-XX.

Smith, S. H. 1995. Early changes in the fish community of Lake Ontario. Great Lakes Fish. Comm. Tech. Rep. 60. 38 p.

Scott, R. J., D. L. G. Noaks, F. W. H. Beamish, and L. M. Carl. 2003. Chinook salmon impede Atlantic salmon conservation in Lake Ontario. Ecology of Freshwater Fish, 12:66-73.

Scott, R. J., K. A. Judge, K. Ramster, D. L. G. Noakes, and F. W. H. Beamish. 2005. Interactions between naturalized exotic salmonids and reintroduced Atlantic salmon in a Lake Ontario tributary. Ecology of Freshwater Fish 14:402-405.

Schreiner, D. R., editor. 1995. Fisheries management plan for the Minnesota waters of Lake Superior. Minnesota Department of Natural Resources, Special Publication 149, St. Paul.

Schreiner, D. R., editor. 2003. Rainbow Trout management plan for the Minnesota Waters of Lake Superior. Minnesota Department of Natural Resources, Special Publication 157, St. Paul.

Schreiner, D. R., J. J. Ostazeski, T. N. Halpern, and S. A. Geving. 2006. Fisheries management plan for the Minnesota waters of Lake Superior. Minnesota Department of Natural Resources. Special Publication 163, St. Paul.

Schreiner, D. R., M. J. Seider, S. P. Sitar and S. C. Chong. 2010. Nearshore fish community: Pacific Salmon, rainbow trout and brown trout. *In* The state of Lake Superior in 2005. Edited by O. T. Gorman, M. P. Ebener, and M.R. Vinson. Great Lakes Fisheries Commission, Special Publication 10-01.

Schreiner D. R., C. Goldsworthy, M.T. Negus, and P.J. Schmaltz. 2015. Lake Trout (Salvelinus namaycush) Rehabilitation in the Minnesota Waters of Lake Superior (1962 – 2014). Minnesota Department of Natural Resources, Special Publication 187 St. Paul

Siesennop, G. 1992. Survival, growth, sexual maturation, and angler harvest of three lake trout strains in four northeastern Minnesota lakes. Minnesota Department of Natural Resources Investigational Report 419, St. Paul.

Stewart, T. J., A. Bowlby, C. Wilson, editors. 2014. Proceedings of the Lake Ontario Atlantic Salmon Restoration Science Workshop, February 18-20, 2014. Alliston, Ontario. Ontario Ministry of Natural Resources and Forestry, File Report LOA 14.08.

Thorstad, E. B., F. Whoriskey, A. H. Rikardsen, and K. Aarestrup. 2011. Aquatic nomads: the life and migrations of the Atlantic salmon. Pages 1–32 *in* Atlantic Salmon Ecology. Wiley-Blackwell, Chichester, West Sussex, United Kingdom.

Tucker, S., A. Moerke, G.Steinhart, and R.Greil. 2014. First record of natural reproduction by Atlantic salmon (*Salmo salar*) in the St. Marys River, Michigan. Journal of Great Lakes Research 40:1022–1026

Volpe, J. P., B. R. Anholt, and B. W. Glickman. 2001. Competition among juvenile Atlantic salmon (*Salmo salar*) and steelhead (*Oncorynchus mykiss*): relevance to invasion potential in British Columbia. Canadian Journal of Fisheries and Aquatic Science 58:197–207.

Webb, J. H., and H. A. McLay. 1996. Variation in the time of spawning of Atlantic salmon (*Salmo salar*) and its relationship to temperature in the Aberdeenshire Dee, Scotland. Canadian Journal of Fisheries and Aquatic Science 53:2739-2744.

Werner, R. M., B. Rook, and R. Greil. 2006. Egg-thiamine status and occurrence of early mortality syndrome (EMS) in Atlantic salmon from the St. Marys River, Michigan. Journal of Great Lakes Research 32:293-305.

Woods, D. E. 1970. Salmonid fisheries to be considered for management along Lake Superior's North Shore. Minnesota Department of Natural Resources, St. Paul

Zydlewski, G. B. 2005. Evidence for cumulative temperature as an initiating and terminating factor in downstream migratory behavior of Atlantic salmon smolts. Canadian Journal of Fisheries and Aquatic Sciences 62:69-78.

Appendices

Appendix 1. Atlantic Salmon Production at French River Coldwater Hatchery, by Darryl Bathel

We expect 4,000 eggs per female stripped. The green eggs are loaded in heath incubators at 15,000 per tray until eye up. Egg takes for rearing are incubated on unheated lake water which is gradually declining in temperature from about 48°F November 1 until 44°F at the end of November. At this point the water is heated and kept at this temperature (44°F) throughout the remaining incubation period.

The eggs destined for rearing eye up by mid-December at around 92%. The dead eggs are picked out and eyed eggs reloaded into heath trays at 5,000 eggs per tray. A 16 tray incubator has a maximum capacity of 80,000 Atlantic Salmon. The hatch is complete by mid-January. After the egg shells have been removed from the trays a tight fitting piece of plastic “egg crate” material that is used in the lighting industry is placed in each incubator tray as a substrate. It is very important not to let the temperature rise above 45°F from this point until swim up or the yolk sac will pinch off and probably rupture. This same condition occurs regardless of temperature if no substrate is used in the incubator.

Around February 20 the yolk is mostly gone but the fry will never swim up as other salmonids do. Regardless, it is time to get them out of the incubators and on feed in the starting tanks. Weak and defective fry are first removed then the good fry are rated and loaded into the tanks.

Six foot diameter circular tanks are used with a water flow of ten gallons per minute injected so that it produces a moderate current. Any tank with the fry clustered in the center has too high a velocity and needs to be readjusted. Experience has shown the depth of water in the tank should be no higher than twelve inches. This seems to be about the maximum the fry are willing to come off the bottom for feed. About 7,000 fry per tank (250 fry/sq. ft. of tank bottom) seems to be the right number for starting as we expect an 85% survival rate from this. The Atlantic fry are started on bio-diet feed and switched to ASD2 when the fish are ready for #1 granules.

In order to get the fish to feed the water temperature cannot be lower than 50°F. The young fish grow slowly. After they reach about 1.7” (2 months) the fish behavior changes from bottom orientated to more or less pelagic. Tank water levels are raised to three feet. The tanks become overloaded by the time the fish are two inches. The maximum the tanks can hold through the summer is 1 lb/sq ft of tank bottom or approximately 2,400 fish per starting tank. This is only 1/3 the density per tank compared to other species at similar size.

In the fall the Atlantic fingerlings are loaded in the yearling raceways so they reach maximum capacity in the spring. Maximum holding with 35°F to 45°F water is 2 lbs/sq ft of tank bottom. The yearlings must be a minimum of six inches long in the spring in order for them to go into smolt transformation.

Appendix 2. Detailed description of Atlantic Salmon stocked in the French River taken from area stocking slips.

Name	County	Stocking Date	Size	Number	Pounds	Rate	Mortalities	Fin Clip	Location Stocked	Hatchery
French River	St. Louis	5/28/1980	YRL	2,047	569	3.6		Ad/LR	Highway 61	St. Paul
French River	St. Louis	5/30/1980	YRL	990	275	3.6		Ad/LR	Highway 61	St. Paul
French River	St. Louis	6/10/1980	YRL	4,547	1,437	3.2			Highway 61	French River
Lake Superior	St. Louis	12/6/1982	ADL	234	690	3.0	0	LF	Highway 61	Maine
French River	St. Louis	5/12/1982	YRL	8,688	1,174	7.4	0	AO,LR,LR	Highway 61	Maine
French River	St. Louis	5/20/1982	YRL	8,284	872	9.5	0	Ad	Highway 61	St. Paul
Lake Superior	St. Louis	8/4/1982	YRL	980	245	4.0	0	A,LR,LRA	Highway 61	St. Paul
Lake Superior	St. Louis	12/5/1983	ADL	37	222	6.0	0		Highway 61	301
Lake Superior	St. Louis	12/5/1983	ADL	286	286	1.0	0		Highway 61	301
French River	St. Louis	6/2/1983	YRL	11,025	1,125	9.8	0	Ad/RR	Highway 61	St. Paul
French River	St. Louis	6/4/1984	YRL	11,866	1,304	9.1	0		Highway 61	Duluth
French River	St. Louis	7/9/1985	YRL	2,212	316	7.0	0		Palmers landing	Duluth
French River	St. Louis	7/9/1985	YRL	18,142	2,791	6.5	0		Palmers landing	Duluth
French River	St. Louis	9/17/1985	YRL	4,800	320	15.	0		Bluebird landing	Duluth
French River	St. Louis	5/27/1986	YRL	14,030	1,846	7.6			Highway 61	Duluth
French River	St. Louis	5/28/1986	YRL	14,604	1,781	8.2			Highway 61	Duluth
French River	St. Louis	5/26/1987	YRL	7,690	1,602	4.8			"Green Box"	681
French River	St. Louis	5/27/1987	YRL	19,800	3,600	5.5			Highway 61	Peterson
French River	St. Louis	5/27/1987	YRL	8,410	1,752	4.8			"Green Box"	681
French River	St. Louis	5/28/1987	YRL	12,060	1,800	6.7			Highway 61	Peterson
French River	St. Louis	5/28/1987	YRL	2,160	450	4.8			Highway 61	681
French River	St. Louis	9/15/1988	FGL	7,334	191	38.5		Ad/LR	Highway 61	681
French River	St. Louis	11/17/1988	FGL	12,642	196	64.5		Ad/LR	Highway 61	680
French River	St. Louis	6/1/1988	FRY	60,291	21	2871.0			County Rd. 43, 33, 50	Spire Valley

Name	County	Stocking Date	Size	Number	Pounds	Rate	Mortalities	Fin Clip	Location Stocked	Hatchery
French River	St. Louis	4/26/1988	YRL	17,460	1,800	9.7			Palmers landing	681
French River	St. Louis	6/10/1988	YRL	1,777	386	4.6			Highway 61	Spire Valley
French River	St. Louis	6/10/1988	YRL	1,824	397	4.6			Highway 61	601
French River	St. Louis	10/25/1989	FGL	31,208	331	94.2			Highway 61	St. Paul
French River	St. Louis	10/25/1989	FGL	26,520	320	82.9			Highway 61	St. Paul
French River	St. Louis	10/25/1989	FGL	53,888	422	128.0			Highway 61	St. Paul
French River	St. Louis	4/24/1989	YRL	7,866	570	13.8			North. Shore Drive	French River
French River	St. Louis	6/15/1989	YRL	10,666	1,484	7.19			County Rd 61	680
French River	St. Louis	6/15/1989	YRL	2,398	320	7.5			County Rd 61	680
French River	St. Louis	4/23/1990	YRL	9,864	612	16.1	138	Ad/RF		St. Paul
French River	St. Louis	7/16/1990	YRL	2,515	636	3.96	4	Ad/LR	N. Shore Drive	French River
French River	St. Louis	7/18/1990	YRL	10,047	1,563	6.43	0	---	Highway 61	French River
French River	St. Louis	7/19/1990	YRL	7,043	1,847	3.81	0	Ad/LR	Highway 61	French River
French River	St. Louis	5/2/1991	YRL	9,927	886	11.2	98	Ad/RR	Above trap	St. Paul
French River	St. Louis	7/22/1991	YRL	10,355	2,354	4.4	0	Ad/LF	Highway 61	French River
French River	St. Louis	2/4/1992	ADL	369	856	0.4	1	Ad/RR	Highway 61	Peterson
French River	St. Louis	2/6/1992	ADL	354	448	0.8	0	Ad/RR	Highway 61	Peterson
French River	St. Louis	6/9/1992	YRL	7,480	1,081	6.92	0	Ad/RM	Highway 61	St. Paul
French River	St. Louis	6/11/1992	YRL	7,481	1,081	6.92	0	Ad/RM	Highway 61	St. Paul
French River	St. Louis	6/22/1992	YRL	7,947	1,749	4.56	26	Ad/LM	Highway 61	French River
French River	St. Louis	6/25/1992	YRL	7,551	1,656	4.56	0	Ad/LM	Highway 61	French River

Appendix 3. Atlantic Salmon stocked in the Split Rock River. Life stages include: Fgl = fingerlings; Yrl – yearlings, Adl = adults.

Year Stocked	Date Stocked	Life stage	Rate (number/lb)	Number	Pounds
1986	4/29/86	Fgl	40.8	3,876	95
1986	5/7/86	Yrl	21.5	8,074	376
1986	5/16/86	Yrl	4.3	1,447	340
1987	6/8/87	Fgl	48.0	6,048	126
1987	6/2/87	Yrl	7.4	8,229	1,112
1987	6/1/87	Yrl	7.1	10,650	1,500
1987	5/28/87	Yrl	4.8	3,260	680
1988	11/30/88	Fgl	67.2	85,617	1,273
1988	9/20/88	Fgl	38.5	7,334	195
1988	4/27/88	Yrl	7.8	21,439	2,756
1989	6/14/89	Yrl	6.8	10,321	1,511
1990	8/16/90	Fgl	319.0	46,276	145
1990	5/29/90	Yrl	15.5	13,962	901
1990	5/15/90	Yrl	13.9	23,477	1,689
1990	5/18/90	Yrl	12.5	25,539	2,020
1990	5/25/90	Yrl	7.5	6,501	867
1990	6/5/90	Yrl	6.1	6,800	1,114
1991	5/23/91	Yrl	27.0	36,910	1,362
1991	5/28/91	Yrl	9.2	18,390	1,997
1991	6/4/91	Yrl	8.9	9,525	1,066
1991	9/4/91	Yrl	7.4	3,470	472
1992	5/19/92	Yrl	20.8	46,338	2,227
1992	5/21/92	Yrl	9.1	4,991	552
1992	6/1/92	Yrl	6.2	6,495	1,047
1992	6/1/92	Yrl	6.2	9,213	1,476
1992		Adl	0.55	753	1,370

Appendix 4. Estimated catches of Atlantic salmon in seasonal creels, French River trap, and charter fishery. Symbols: * indicates that no creel survey was performed; ^ indicates that too few (<5) Atlantic Salmon were observed to calculate an estimate.

Year captured	Spring creel survey	Summer creel survey	Fall creel survey	French River trap	Charter fishery
1980	0	0	*	0	*
1981	0	0	*	8	*
1982	0	132	*	235	*
1983	0	106	*	70	*
1984	0	12	*	94	*
1985	0	47	0	95	16
1986	0	56	0	103	37
1987	0	114	23	100	16
1988	0	32	*	100	8
1989	^	255	53	39	46
1990	62	16	*	71	16
1991	*	225	14	15	71
1992	141	790	173	624	200
1993	^	292	28	178	14
1994	^	140	26	69	12
1995	0	0	*	71	4
1996	0	58	*	1	1
1997	0	6	*	0	9
1998	0	0	0	0	0

Appendix 5. Numbers of Atlantic Salmon that returned as adults to the French River trap by date in 1992 and 1993, and percent of the total returns that occurred within each date interval.

	1992		1993		
Dates	**Number**	**Percent**	**Number**	**Percent**	**Overall percent**
8/15-8/31	3	1.7%	1	0.2%	0.5%
9/1-9/15	30	16.9%	19	3.0%	6.1%
9/16-9/30	2	1.1%	87	13.9%	11.1%
10/1-10/15	13	7.3%	186	29.8%	24.8%
10/16-10/31	109	61.2%	252	40.4%	45.0%
11/1-11/15	21	11.8%	72	11.5%	11.6%
11/16-11/30	0	0.0%	7	1.1%	0.9%
Total	178	100.0%	624	100.0%	100.0%

Appendix 6. Atlantic Salmon Position Statement

The Minnesota Department of Natural Resources, Section of Fisheries has reaffirmed its decision to discontinue the Atlantic Salmon program in the state.

The experimental program began in 1980 with the stocking of Atlantic Salmon in Lake Superior and the creation of an Atlantic Salmon brood stock. From 1982-1991, returns to the angler and angling interest for the species remained very low. A series of public input meetings were held in the winter of 1991-1992 which confirmed there was little angler support for the Atlantic Salmon program. The decision was made to eliminate the Atlantic Salmon broodstock, stock the remaining hatchery fish, and continue to monitor the program.

A window of opportunity was left open to re-establish the program if returns to the angler and angling interest increased substantially over the next few years. This would involve collecting eggs from Atlantic Salmon returning to the French River trap, as opposed to using a captive brood stock. The eggs could then be used to rear smolts for stocking. Although the sport catch of Atlantic Salmon in 1992 was relatively high compared to previous years, interest remained low except for a few avid anglers.

Returns to the French River trap in 1992 increased to an all-time high, prompting inquires as to the future of the Atlantic Salmon program. The department indicated that a decision on whether to continue the program would be made after the 1993 angling season. The final decision would be based on returns to the angler and angler interest through the 1993 season. In addition to routine creel monitoring of pressure and harvest, special attempts were made to intensively sample the Atlantic Salmon fishery. The 1993 angling season was monitored through a shore-wide summer creel survey, charter fishing reports, a high intensity spring creel, and a special Atlantic Salmon creel survey from late May through June. All monitoring indicated a major decline in catch of Atlantic Salmon through September when compared to 1992. Continued low interest from most anglers was reflected in very low fishing pressure targeting Atlantic Salmon.

The Section of Fisheries reaffirmed the decision not to continue the Atlantic Salmon program. The decision was not made easily and discussions took place to explore all aspects of the program. Besides low angler interest and low catch, the following interrelated factors also influenced the decision:

1. The department is concerned over the growing number of exotic predators in the Lake Superior fish community and their potential negative impact on forage base stability. The forage base in Lake Superior has changed dramatically over the last 10 years with a major decline in smelt. This change is important because when the Atlantic Salmon program was started, smelt were expected to be their major forage species. Concern over forage stability has also led to considering reductions in the number of Chinook Salmon that are presently being stocked.

2. The department is concerned over potential naturalization of Atlantic Salmon in Lake Superior. Atlantic Salmon have not yet demonstrated high natural reproductive potential, although a few naturally reproduced Atlantic Salmon smolts have been found in stream surveys. If Atlantic Salmon become naturalized, as the pacific salmon have, there would be no practical methods available to control their numbers, and they could have a stabilizing effect on the forage base and the entire Lake Superior ecosystem. Based on angler reports, Atlantic Salmon stocked in Minnesota have been captured in the waters of other agencies on Lake Superior. The chance of naturalization occurring in another agency's streams is far greater than in Minnesota, since the quantity and quality of their stream habitats are more suited for natural reproduction. This has been demonstrated for other anadromous species in Lake Superior and there is presently no interest in establishing another self-reproducing exotic.

3. Atlantic Salmon need to be stocked at a large size before good survival can be expected. Rearing fish to this size is very expensive. It has been our experience in Minnesota that Atlantic Salmon stocked at sizes less than 5/lb provide poor returns to the angler. It is our opinion that the high returns experienced in 1992 were primarily the result of stocking relatively large numbers of large sized yearlings.

4. Reallocation of hatchery space and reprioritization of hatchery effort would be required to rear large numbers of yearlings at approximately 5/lb. The hatchery space once used for Atlantic Salmon has been converted to enhance the quality of Minnesota's Lake Trout stocking programs and increase the number and quality of brook, brown and rainbow trout produced for inland stocking. These strategies are of higher priority than re-establishing the Atlantic Salmon program, when considering statewide fishery goals.

We expect that over the next 3 years anglers will harvest Atlantic Salmon, and there may be periods of relatively good angling success. Even though the Atlantic Salmon in its native range is considered a premier sport fish, we feel for the above reasons, it is not a species we should continue to propagate.