RESTORATION OF WESTERN FUNDY ATLANTIC SALMON

PROJECT REPORT

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SUMMARY

The wild salmon run in the Magaguadavic River has steadily declined from 293 in 1992 to a low of 6 fish in 2003. The number of escaped aquaculture salmon captured in the river's fish ladder in 2003 was also the lowest on record. However, escapees have dominated the wild run since 1994, ranging from 67 to 90% of the annual salmon returns in this period.

One case each of Infectious Salmon Anemia (ISA) and infectious pancreatic necrosis was recorded in escapee salmon in 2003. This was the first time pathogens have been detected in salmon since 1999.

The five year (1999-2003) average egg deposition was only 3.5% of the conservation threshold set for the river, and 2003's value was a dismal 1.4%.

The relative abundance of juvenile salmon have been low at most sites examined in the Magaguadavic and neighboring outer Bay rivers. Parr have been absent at sample stations in the Digdeguash River and Dennis Stream during the last two years. Higher numbers of parr caught near salmon hatcheries may have been due to juvenile escapees. Escaped juveniles from the hatcheries in the Magaguadavic River have dominated the smolt samples every year except 1999. Escapee smolt represented 98% of the smolt run in the Magaguadavic River in 2003.

About 33,000 juvenile salmon were stocked into the Magaguadavic River drainage in 2003 as part of the salmon recovery program. New fish from the Black River was added to the live gene bank Magaguadavic salmon in 2003 to prevent inbreeding. Those fish were spawned with Magaguadavic broodstock in November 2003.

A total of 13 landlocked salmon were acoustically tagged and tracked leaving the Magaguadavic River in 2003. The tracking study showed that landlocks are capable of surviving in a marine environment and some fish moved into the open ocean.

INTRODUCTION

The Magaguadavic River is situated near the center of North American East Coast Atlantic salmon aquaculture industry (Figure 1), and large numbers of escaped cultured salmon from sea-cages have entered the river in recent years. Three commercial salmon hatcheries that together produce about four million smolt for the sea-cages are located within the drainage, and cultured juvenile salmon are escaping from those sites.

All salmon arriving at the Magaguadavic River from the ocean must pass through a fish ladder that bypasses a head-of-tide dam built in 1903 (Figure 1). Complete counts of the river's salmon run have been made in the fish ladder's trap since 1992. Information on the history and characteristics of the salmon run prior to the 1980s is sketchy (Figure 2).

This review presents the results from our studies in 2003 on the interactions between wild and cultured Atlantic salmon (*Salmo salar)*, in the Magaguadavic River, New Brunswick, and draws on the data from previous years to illustrate trends. Also included in this report is information on the status of Atlantic salmon stocks in the New, Pocologan, Digdeguash, Bocabec, Waweig, and Dennis Rivers. Our objective is to help provide research managers with a factual basis for planning and decision-making.

STUDY SITES

Magaguadavic River

The Magaguadavic River is the sixth largest river in New Brunswick. It originates in Magaguadavic Lake in the southwest part of the province and flows southeasterly 97 km to Passamaquoddy Bay (an offshoot of the Bay of Fundy) near St. George. There are 103 named tributaries and more than 55 lakes within a drainage area of 1812 km^2. A 13.4 m high dam (built in 1903) located at the head of the tide is equipped with Francis runner-type turbines, which generate about 3.7 megawatts of power. A pool and weir fish ladder bypasses the dam for upstream fish passage. A sluiceway intended for downstream fish passage is situated adjacent to the penstock. Water storage reservoirs are located in Digdeguash and Magaguadavic Lakes.

The Magaguadavic system supports a sport fishery for anadromous and landlocked Atlantic salmon, brook trout (*Salvelinus fontinalis*), and introduced smallmouth bass (*Micropterus dolomieui*). Also, non-indigenous rainbow trout (*Oncorhynchus mykiss*) have been recorded in the river but their origin is unknown. A limited sport dip net fishery occurs during the spring in Lake Utopia tributary streams for two populations of landlocked smelt: rainbow smelt (*Osmerus mordax*) and dwarf smelt. A commercial fishery exists in the lower sections of the river for American eels (*Anguilla rostrata*) during their seaward migration in the fall. The spring run of alewives (*Alosa pseudoharengus*) is sometimes fished for lobster bait in the tidal waters.

Wild salmon ascend the river from June until early November. Spawning occurs from late October until mid November. Wild salmon spend two to four years in the river before they migrate to sea as smolt (Carr 1995).

New River

New River originates from a series of lakes and flows about 21 km southeasterly before emptying into Maces Bay at New River Beach (Figure 3). Atlantic salmon habitat is restricted to the lower portions of the river since the river becomes marshland about 7 km above the head of tide. The only industry situated along the river is forestry.

Pocologan River

Pocologan River originates in Pocologan Lake and flows about 26 km southeasterly before emptying into Maces Bay at Pocologan (Figure 3). Salmon utilize the first 9.6 km of river from its mouth (Dalziel 1957). Dalziel (1957) reported that speckled trout utilize the entire stream. The only industry along the system is blueberry harvesting and forestry. The Department of Fisheries and Oceans stocked salmon fingerlings originating from the Saint John River system into the Pocologan River from 1947 to at least 1957 (Dalziel 1957).

Digdeguash River

Digdeguash River originates from a series of springs near McAdam, New Brunswick, and flows southeasterly about 63 km before emptying into Passamaquoddy Bay (Figure 4). One commercial Atlantic salmon hatchery is situated along the river (Figure 4). The Department of Fisheries and Oceans stocked brown trout fingerlings and yearlings into the Digdeguash River from 1947 to at least 1957 (Dalziel 1957).

Bocabec River

Bocabec River originates from Kerrs Lake and flows about 3 km before emptying into Passamaquoddy Bay (Figure 4). A lumber mill is situated at Johnsons Lake. Atlantic salmon parr were reported in the river in the early 1990s (B. Glebe, personnel comm.).

Waweig River

The Waweig River is a sub-watershed of the St. Croix River system. It flows about 3 km south from the confluence of Sawyer and Meadow Brooks to the head of tide (Figure 5). The river then flows 2.5 km before emptying into the St. Croix River estuary (Figure 5). One commercial salmon hatchery is situated along this river (Figure 5).

Dennis Stream

Dennis Stream, a sub-watershed of the St. Croix River system, supports sea-going runs of alewives, brook trout, and Atlantic salmon. The principal land uses are classified as 80% forest, 8% agriculture, and 7% wetland. The N.B Department of Natural Resources and Energy stocked sea-run brook trout in the system in the early 1990s(1992 and 1993). Salmon utilize the stream from its mouth to Moore's Mills Lake, a distance of about 12.5 km (Figure 5).

METHODS

Adult Sampling Regimes

Wild salmon returning from the sea were distinguished from cultured escapees using external morphology and scale characteristics (Carr, 1995). Captured fish were placed in an aquarium and anesthetized with clove oil (see Anderson et al. 1997). Biological sampling included a fork length measurement, external morphology, scale and tissue samples, and external observations for parasites.

Disease screening overtime has been conducted by three agencies: (1) the New Brunswick Department of Agriculture Fisheries and Aquaculture (NBDAFA) in St. George (post-mortem exams for bacterial pathogens), (2) the Department of Fisheries and Oceans in Moncton (bacterial and virology screening in 1995, and from 1997-2003), and (3) the Research and Productivity Council in Fredericton (RT-PCR screening for an array bacterial and viral pathogens).

Most wild fish screened for disease were found dead in the river. Wild broodstock had blood, mucus, and reproductive fluids sampled for disease screening by RT-PCR analysis. In 2000 and 2001, wild fish were non-lethally screened for the Infectious Salmon Anemia virus by conducting RT-PCR analysis of gill mucus swabs. All escapees (1992-2003) were either found dead in the river, or deliberately sacrificed for disease tests.

Magaguadavic River Fish Ladder

Since 1992, June to November salmon counts have been made in the St. George fish ladder trap (except in 1996 when monitoring did not begin until July). In 2003, the fish ladder was operational from late April to early December. The trap was left open from 16 June to July 7 during the peak of the alewife run.

Egg depositions required for conservation purposes in the Magaguadavic River watershed were calculated as follows:
Interim required depositions of 1.35 million eggs is based on an estimated 563,000 m^2 of juvenile rearing substrate and a deposition of 2.4 eggs/m^2 (Anon MS 1978). Spawners required to obtain those eggs were estimated at 140 1SW and 230 MSW salmon. Measurements from orthophotographic maps and air photos (Amiro 1993) estimated 9.33 million m^2 of available habitat (>0.125 gradient).
For wild fish, we used the 1992-1995 average sex ratios of 60% males and 40% females for 1SW fish and applied it to fish of unknown sexes in 1996 - 2003. The 1992-1995 average MSW sex ratios were 18% males and 82% females and the undetermined sexes in 1996 and 2000 were adjusted similarly.

For the escapees, the 1SW sex ratios from 1995-1998 were adjusted after applying the 1992-1994 average of 64% females and 36% males to the undetermined 1SW sexes. The 1992-1994 average MSW sex ratios of 34% males and 66% females were used to calibrate the undetermined MSW sexes.

Once the total female escapement was determined for each of the years, the mean length-fecundity relationship for Saint John River salmon ($Y=430.19e^{0.03605x}$, Marshall and Penney MS 1983) was used to estimate potential egg deposition from the fish passed through the fish ladder.

Adult Salmon Monitoring in Dennis, Waweig, Bocabec, Digdeguash, Pocologan, & New Rivers

Counting Fence

In 1999 and 2000, a counting fence was placed at the head of tide in the Bocabec stream to monitor all upstream salmon passage (Figure 4). In 1999, the trap was operational from 22 May to 10 November. The trap was operational from 17 May to 8 November in 2000.

In 2001, a counting fence was placed 1.8 km above the head of tide in the Dennis Stream to monitor all upstream salmon passage (Figure 5). The trap was operational from 8 June to 13 November. In 2002, the trap was operational from 16 July to 31 October.

River Snorkeling, Seining, and Redd Counts

In 1998 and 2000, we snorkeled and seined for adult salmon in the following rivers: New, Pocologan, Digdeguash, Waweig, Dennis, and Bocabec (1998 only). In 2002, snorkeling and seining was conducted in the Dennis, Waweig, and Digdeguash drainages. In 2003, snorkeling was conducted in the New River between Routes 760 and 1. Searches for salmon redds also took place on the Dennis, Waweig, and Digdeguash Rivers in November 2003.

Fish were captured using a seine net, placed in an aquarium and anesthetized with clove oil ([40 mg/l]). Biological sampling included a fork length measurement, external morphology, scale and tissue samples, and external observations for parasites. Wild salmon were distinguished from cultured escapees using external morphology and scale characteristics (Carr, 1995). Wild fish were released back into the stream. All cultured escapee fish were sent to the Department of Fisheries and Oceans laboratory, Moncton, New Brunswick, for disease screening.

Juvenile Salmon Sampling

Parr and Fry

Accessible juvenile rearing habitat was identified throughout the Magaguadavic watershed and in other southwestern New Brunswick outer Bay of Fundy rivers. Open monitoring stations were established, including sites in the vicinity of commercial salmon hatcheries (see Figures 1-4). Juvenile salmon were captured by electrofishing. Captured salmon were anaesthetized, weighed, and measured, and a sample of scales and tissue was taken before release. Catches per unit effort (relative abundance) were calculated as the number of fry (0+ parr) and parr ($\geq$ 1+ parr) caught per 100 seconds fishing time.

Smolts

Smolts were sampled leaving the Magaguadavic watershed from 1999 to 2003. A fykenet was

placed in a bypass channel below the St. George dam during the spring sampling period from 1999 to 2001 (Figure 1). A counting fence replaced the fykenet in 2002 and 2003. In addition, a fykenet was placed in the outlet of Linton Stream in 1999, and a smolt wheel was placed in the river's mainstem at Lee Settlement from 1999 to 2003 (Figure 1). Captured salmon were anaesthetized, weighed, and measured, and a sample of scales and tissue was taken before release. From 2000 to 2003, smolts captured in the smolt wheel were marked to facilitate identification upon recapture at the lower site so that the smolt output of the river could be determined.

Escaped juvenile salmon captured in the river, and/or moving out to sea as smolts, were identified based on age, and physical characteristics. Wild Magaguadavic salmon become smolt at age $\geq$ 2+ (Carr 1995). By contrast, cultured fish become smolt at age 1+. Fins of cultured fish are also often eroded. A satellite-rearing program released wild origin fish to the river in 1997. These fish were adipose fin clipped for ready identification. Landlocked salmon annually released into lakes in the system by the Provincial government are also fin clipped.

RESULTS

Magaguadavic River Salmon Returns

Wild salmon

Wild salmon numbers in the Magaguadavic River have decreased from 293 fish in 1992 to a low of 6 fish in 2003 (Figure 6). Fifty percent of the 2003 wild salmon returns entered the river in July, with a single fish returning monthly from August to October (Figure 7).

Ratios of 1SW salmon outnumber MSW salmon for the 5 and 10 year averages (Tables 1 and 2). Females dominated the numbers of MSW salmon returns for the 5 and 10-year averages (Table 2). In 2003, the average size of 1SW wild salmon was the lowest on record. The opposite was true for MSW salmon. Overall, the average sizes of both 1SW and MSW wild salmon are trending up as shown for the 5 and 10 year averages (Tables 1 and 2).

No repeat wild salmon spawners have been recorded in the Magaguadavic River since 1997. Percent return of repeat spawners prior to 1998 are as follows:

Year	Male	Female	Percent return
1992	2	8	3
1993	1	9	4
1994	0	3	2
1995	1	0	1
1996	0	1	1
1997	0	1	2

Cultured Escapees Ascending River

Only 23 escapees were recorded at the fish ladder in 2003. This was the lowest number since the monitoring program began in 1992 (Figure 6). The most escapees on record were 1200 fish in 1994 (Figure 6).

Cultured escapees entered the river later than wild fish in all years and their numbers generally peaked from late August to October (Figure 7).

One-sea-winter fish outnumbered MSW fish for the escaped cultured salmon by margins of 6.8:1 and 7.6: 1 for the 10 and 5 year averages (Tables 4 and 5). Increased numbers of escaped postsmolt were observed in the river from 1994 to 1997 when a brackish water cage site reared fall smolt at the mouth of the Magaguadavic River (Table 3). The size of escaped salmon varied, presumably in part depending on the time of escape from cages (Tables 3 - 5).

Spawning Escapement

Conservation egg requirements for the river were never met in the 1992 - 2003 period, nor were the desired escapements of large and all salmon (Table 6 shows the last 10 years). Both have deteriorated significantly over the study period. The 5 year (1999-2003) average egg depositions are only 3.5% of target level (Table 6). In 2003, an estimated 1.4% of the conservation level was met (Table 6).

In the 1992-1996 periods, cultured escapees contributed an average of 14.8% of the total eggs. The highest contribution of estimated escapee spawners was in 1996 when 32.9% were considered to be sexually mature (Table 6). Only one escapee was released into the river since 1997. This fish was mistakenly released into the river in 2000, and it had the potential to contribute 15.9% of the overall egg contribution in that year.

In 2002, 103 captive reared broodstock of Magaguadavic River genetic strain were released into the river. As many as 63% (35 females) were sexually mature. The release of those fish may have increased the overall egg contribution to an estimated 10.8% of the conservation level for that year.

Disease Screening

In 2003, one case of the Infectious Salmon Anemia (ISA) virus was detected in an escaped cultured salmon. This was the first time the virus was detected in the river since the 1999 outbreak (Table 7). One escapee was infected with infectious pancreatic necrosis (IPN) in 2003. The only other year that IPN was detected was in 1999 (Table 7). No pathogens were detected in the one wild salmon screened in 2003. Five wild salmon released into the river were not screened for disease.

None of the three landlocked salmon screened for disease in 2003 tested positive for pathogens (Table 8). Thirteen alewives were screened for disease in 2003. An aquatic birnavirus was detected in that group of fish (Table 8).

A complete summary of all fish screened for disease (1992 – 2002) is found in Tables 7 and 8, and additional details are in Carr and Whoriskey (2002).

Magaguadavic River Juvenile Salmon Estimates

Smolt estimates

Smolt monitoring in the Magaguadavic River has detected high numbers of escaped hatchery juveniles leaving the river system. The percentage of hatchery escapee smolts (one year-old smolts) ranged from 33% to 98% over the 1998 to 2003 period (Figure 8). Wild smolts outnumbered hatchery smolts only in 1999 (Figure 8). Some of the smolts classified as wild (two- and three year-old smolts) may have been fish that escaped as fry from hatcheries. Most smolt were captured below the dam in all years (Figure 9).

In 2003, a total of 517 smolt were captured leaving the Magaguadavic River (Figure 9). Of these smolt, 98.3% were hatchery escapees, 1.4% were wild, and for 0.3% the smolt origins could not be determined (Figure 8).

A population estimate was derived by incorporating mark-recapture data into a Bayesian estimation procedure (Gazey and Staley 1986) to describe the most probable estimate (mode) among a binomial distribution of less probable solutions. The Bayesian estimator suggests the most probable number of wild smolt migrating from the Magaguadavic River was 1,320, 290, and 460 in 2000, 2001, and 2002 respectively. The Peterson corrected estimate using the same mark-recapture data suggests the smolt estimate to be 1142, 164, and 462 for 2000, 2001, and 2002 respectively. Capture efficiency of the trap below the dam was only 19, 10, and 15% for 2000, 2001, and 2002 respectively. These estimates should be treated with caution due to the low recapture rate and high confidence intervals.

Landlocked salmon captures during the smolt monitoring period ranged from 67(1998) to 21 (2003, see Figure 9). All landlocked salmon were captured below the dam with the exception of one fish captured in the smolt wheel at Lee Settlement in 2003.

Parr Relative Abundance

Juvenile densities have been monitored since 1994 at as many as 8 mainstem and 16 tributary sites in the Magaguadavic watershed. Parr have been rare, with the largest catches in most years being escapees found in the vicinity of the hatcheries (Figure 10). With the exception of 0+ parr in 2002, and 0+and 1+ parr in 2003, the average numbers of all parr at sites away from hatcheries have trended downwards since 1997 (Figure 10). The increase in parr numbers away from hatcheries in 2002 and 2003 result from stocking efforts from the wild salmon restoration program.

Other Outer Bay of Fundy Rivers

Adult Salmon Monitoring

Adult monitoring has been conducted in other outer Bay of Fundy rivers by snorkeling, seining, redd counts, or the use of counting fence traps. A counting fence trap was planned for New River in 2003 but high water and landowner issues prevented trap placement. However, a

snorkeling survey was conducted in New River during October covering a 7 km section between Routes 760 and 1. No salmon (adults nor juveniles) were found during the swim through. Partial redd surveys were conducted in the Dennis, Waweig, and Digdeguash Rivers in 2003. No redds were found. Increased river flows in the fall prevented the completion of redd surveys in the Digdeguash and Pocologan Rivers.
Biological data on adult salmon captured in previous years is presented in Table 9.

Parr Relative Abundance

The relative abundance of parr in the New, Pocologan, Digdeguash, Waweig, and Dennis drainages was low to nil in each of the years examined (Figures 11 and 12). No juvenile salmon (0+ and $\geq$ 1+ parr) were found in Dennis Stream or the Digdeguash River in 2002 or 2003. The last year 0+ parr were found in Dennis Stream was 2000 (Figure 11). Parr numbers have varied in Pocologan River from 1999 to 2003 (Figure 11). In 2001 and 2003, no 0+ parr were found in that river. Both 0+ and $\geq$ 1+ parr were found in all years that the New River sites were monitored (Figure 11).

In the Waweig River, very few parr were found in each of the years (Figure 12). Only one site was sampled away from the commercial salmon hatchery in 1999 (found only $\geq$ 1+ parr) and 2003 (found only 0+ parr). Numbers of 0+ parr escaping from the hatchery trended down since 2000 (Figure 12). Very few 1+ parr were found near the hatchery in all years.

Exotic species

Chain Pickerel is the newest exotic species detected in the Magaguadavic drainage. Personnel from the Department of Natural Resources and Energy captured four pickerel (in trapnets) in Magaguadavic Lake in September/October 2003.

Smallmouth bass have become well established throughout the Magaguadavic watershed since their introduction in the 1920s. They have be found in juvenile salmon riffle habitat in the Magaguadavic River. Bass densities have trended up near hatcheries since 1998 with bass outnumbering parr at these locations. No smallmouth bass were recorded in any of the other sample stations in Southwestern NB outer Bay of Fundy Rivers.

Rainbow trout have on occasion been captured ascending the Magaguadavic fish ladder from 1992 - 2000. All have been removed. Those screened for the presence of viral and bacterial pathogens have tested negative (Table 8). During the smolt-sampling period in 1999, one rainbow trout was captured leaving the Magaguadavic River.

Wild Magaguadavic Salmon Recovery Program

A live gene program was started at the Department of Fisheries and Oceans Mactaquac Biodiversity Center using offspring from seven wild broodstock collected from the head of tide fish ladder in the Magaguadavic River in 1998. The seven fish were originally spawned and the eggs incubated at Heritage Salmon Lake Utopia hatchery. Smolt were reared to broodstock in both sea water (cage site was operated by Cooke Aquaculture Limited, and then in tanks at the Huntsmen Marine Science Center) and in freshwater at the Department of Fisheries and Oceans (DFO)

Mactaquac Biodiversity Center, French Village, New Brunswick. All broodstock from the seawater rearing sites were released into the river in 2002. Some broodstock reared in freshwater (Mactaquac) were retained for a live gene bank program to preserve the original wild Magaguadavic salmon stock. A total of 103 broodstock (30 acoustic tagged and 67 externally floy tagged) were released into the Magaguadavic River in 2002.

Fifty captive first generation Magaguadavic River origin broodstock (live gene bank program) were spawned at Mactaquac in November 2002. Twenty crosses were made from those spawnings resulting in 114,000 green eggs. A summary from the 2002 live gene bank matings is as follows:

- In February 2003, 37,000 eyed eggs moved to Heritage Salmon Lake Utopia Hatchery for rearing to smolt stage (intended to be released as smolt in 2004)
    - Fish became infected with Furunculosis at the hatchery in August 2003
        - Less than 2000 fish survived to November 2003
            - Remaining fish destroyed in December 2003

- 37,000 eyed eggs reared at Mactaquac Biodiversity Facility
    - 20,556 unfed fry released into Magaguadavic River drainage in June 2003
    - 5,000 fingerlings released into Magaguadavic River drainage in July 2003
    - 7,336 fingerlings released into Magaguadavic River drainage in October 2003
    - 2,500 to be reared to smolt stage (spring 2004)
        - 300 smolt will be retained for live gene bank program (rear to adults)
        - 2,200 smolt will be released into Magaguadavic River in spring 2004

In November 2003, captive reared Magaguadavic origin salmon were spawned at Mactaquac. New recruits (Black and Irish River) were added to the Magaguadavic live gene bank program in 2003. Fish were spawned at Mactaquac in November 2003, and crosses were as follows: Magaguadavic female (7) x Magaguadavic male (7), and Magaguadavic female (12) x Black and Irish River males (12). Egg production totaled 156,215 eggs (55,039 from Magaguadavic X Magaguadavic and 101,176 from Magaguadavic X Black and Irish Rivers).

Additional details of the recovery program (1996-2002) are found in Carr and Whoriskey (2002).

Landlocked Salmon Tracking

Details of the landlocked salmon tracking study (2002 and 2003) are found in Appendix 1.

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REFERENCES

Anon. 1978. Biological Conservation Subcommittee Report. Prep. For Atlantic Salmon Review Task Force. 203p.

Amiro, P.G. 1993. Habitat measurement and population estimation of juvenile Atlantic salmon (*Salmo salar*). *In* Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. pp.81-97. Ed. By R.G. Gibson and R.E. Cutting. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

Anderson, W.G., R.S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anaesthetic for rainbow trout and its effects on swimming performance. North American Journal of Fisheries Management 17: 301-307.

Carr, J. 1995. Interactions between wild and aquaculture Atlantic salmon in the Magaguadavic River, New Brunswick. M.Sc. Thesis, University of New Brunswick, Fredericton: 77 pp.

Carr, J. and Whoriskey, F. 2002. Assessment of Atlantic salmon in southwestern New Brunswick Outer Bay of Fundy Rivers, with emphasis on the Magaguadavic River, 1992-2002. Project Report prepared for the NB Environmental Trust Fund. March 2002. 31pp.

Dalziel, J.A. 1957. Pocologan River Salmon Survey. Resource Development Branch. MS Rpt. No. 56-7. Fisheries Service Department of Fisheries and Forestry of Canada, Halifax, NS.

Gazey, W.J., and M.J. Staley. 1986. Population estimation from mark-recapture experiments using a sequential Bayes algorithm. Ecology 67: 941-951.

Marshall, T.L., and G.H. Penney.MS 1983. Spawning and river escapement requirements for Atlantic salmon of the Saint John River, New Brunswick. CAFSAC Res. Doc. 83/66. iii + 17p.

Table 1. Numbers, percentages, and mean lengths (X in cm, with standard deviations = SD) of 1SW wild Atlantic salmon in Magaguadavic River from 1994 to 2003. Sexes were determined from secondary sexual characteristics.

Year	Male			Female			Undetermined		Combined	
	Tot	%	X ± SD	Tot	%	X ± SD	Tot	X ± SD	Tot	X ± SD
1994	48	68	57.5 ± 3.47	23	32	58.6 ± 4.56			71	57.9 ± 3.89
1995	34	69	55.4 ± 2.64	15	31	55.6 ± 2.83			49	55.5 ± 2.70
1996	24	75	56.2 ± 3.15	8	25	56.1 ± 2.21	16	55.7 ± 3.16	48	56.1 ± 2.89
1997	20	63	56.1 ± 3.50	12	37	56.1 ± 1.93	3	57.6 ± 0.46	35	56.2 ± 2.85
1998	15	71	57.1 ± 3.17	5	29	60.3 ± 3.53	8	54.4 ± 2.95	28	56.9 ± 3.73
1999	7	47	57.4 ± 4.42	8	53	61.2 ± 4.30	4	57.9 ± 4.09	19	59.1 ± 4.47
2000	2	67	59.1 ± 1.77	1	33	52.6	10	57.3 ± 2.41	13	57.2 ± 2.64
2001	3	38	58.6 ± 0.67	4	50	59.1 ± 2.1	1	60.5	8	59.1 ± 1.53
2002	2	40	58.3 ± 4.60	3	60	57.6 ± 1.25	2	57.3 ± 1.20	7	57.7 ± 2.11
2003	2	67	47.9 ± 11.46	1	33	56.0	0	0	3	50.6 ± 9.35
10 yr mean	15.7	56	56.6 ± 3.58	8.0	28	57.7 ± 3.89	4.4	56.3 ± 3.10	28.1	56.8 ± 3.63
5 yr mean	3.2	32	56.8 ± 5.53	3.4	34	59.3 ± 3.88	3.4	57.6 ± 2.67	10	57.9 ± 4.21

Table 2. Numbers, percentages, and mean lengths (X in cm, with standard deviations = SD) of MSW wild Atlantic

salmon in Magaguadavic River from 1994 to 2003. **No MSW wild salmon returned to the river in 2002.** Sexes were determined from secondary sexual characteristics.

Year	Male			Female			Undetermined		Combined	
	Tot	%	X ± SD	Tot	%	X ± SD	Tot	X ± SD	Tot	X ± SD
1994	9	15	76.2 ± 5.13	51	85	76.6 ± 5.07			60	76.6 ± 5.08
1995	15	50	75.8 ± 2.83	15	50	74.8 ± 3.27			30	75.3 ±3.46
1996	2	18	77.8 ± 0.75	9	82	74.9 ± 2.83	10	77.6 ± 4.00	21	76.5 ± 3.60
1997	0	0		24	100	76.6 ± 2.97	0		24	76.6 ± 2.97
1998	0	0		3	100	75.7 ± 0.85	0		3	75.7 ± 0.85
1999	0	0		5	100	80.9 ± 3.35	0		5	80.9 ± 3.35
2000	0	0		0	0		1	77.0	1	77.0
2001	1	11	81.5	8	89	77.8 ± 6.64	0		9	78.2 ± 6.33
2003	0	0	0	3	100	81.9 ± 2.12	0		3	81.9 ± 2.12
10 yr mean	2.7	17	76.3 ± 4.22	11.8	76	76.6 ± 4.52	1.1	77.6 ± 4.00	15.6	76.6 ± 4.42
5 yr mean	0.2	6	81.5	3.2	89	79.6 ± 5.24	0.2	77.0	3.6	79.5 ± 5.00

Table 3. Numbers, percentages, mean lengths (X in cm, with standard deviations = SD) of postsmolt escaped cultured Atlantic salmon in Magaguadavic River from 1994to 2003. Sexes were determined from secondary sexual characteristics.

Year	Male		Female		Undetermined		Combined	
	Tot	X ± SD	Tot	X ± SD	Tot	X ± SD	Tot	X ± SD
1994	1	32.0	0		58	32.5 ± 4.62	59	32.5 ± 4.58
1995	30	24.8 ± 4.60	0		23	30.2 ± 7.08	53	27.2 ± 6.39
1996	13	29.4 ± 7.72	11	36.2 ± 4.13	22	33.9 ± 4.62	46	33.2 ± 5.93
1997	23	25.5 ± 3.23	0		14	33.0 ± 5.62	37	28.3 ± 5.63
1998	0		0		8	35.2 ± 3.81	8	35.2 ± 3.81
1999	7	33.2 ± 8.12	4	29.8 ± 5.68	0		11	32.0 ± 7.23
2000	2	21.8 ± 0.35	0		1	37.0	3	26.8 ± 8.81
2001	3	30.8 ± 13.81	4	33.6 ± 2.72	1	35.7	8	32.8 ± 7.80
2002	5	33.1 ± 3.86	0		1	27.5	6	32.2 ± 4.15
2003	2	42.1 ± 0.21	0		5	42.7 ± 4.42	7	42.5 ± 3.62
10 yr mean	8.6	27.5 ± 6.67	1.9	34.3 ± 4.90	13.3	33.0 ± 5.62	23.8	31.1 ± 6.56
5 yr mean	3.8	32.5 ± 8.39	1.6	31.7 ± 4.60	1.6	40.9 ± 4.77	7.0	34.1 ± 7.72

Table 4. Numbers, percentages and mean lengths (X in cm, with standard deviations = SD) of 1SW escaped cultured salmon in Magaguadavic River from 1994 to 2003. Sexes were determined from secondary sexual characteristics.

Year	Male			Female			Undetermined		Combined	
	Tot	%	Ave ± SD	Tot	%	X ± SD	Tot	X ± SD	Tot	X ± SD
1994	394	37	61.8 ± 4.26	665	63	60.5 ± 4.21			1059	61.0 ± 4.27
1995	184	44	61.5 ± 7.58	242	56	60.4 ± 7.68	65	56.8 ± 3.99	491	60.4 ± 7.40
1996	57	34	59.1 ± 4.31	112	66	59.1 ± 4.43	5	57.8 ± 5.13	174	59.0 ± 4.42
1997	18	34	61.4 ± 5.57	35	66	57.7 ± 5.11	6	56.8 ± 7.14	59	58.7 ± 5.78
1998	38	36	67.4 ± 9.35	72	64	65.5 ± 8.79	101	64.8 ± 7.71	211	65.5 ± 8.49
1999	17	47	59.2 ± 10.03	19	53	62.0 ± 11.87	20	65.9 ± 9.96	56	62.5 ± 10.83
2000	2	29	64.3 ± 1.77	5	71	62.8 ± 3.40	18	60.3 ± 5.69	25	61.1 ± 5.18
2001	70	62	68.2 ± 8.35	43	38	66.7 ± 6.12	7	62.9 ± 7.32	120	64.5 ± 7.70
2002	15	58	61.4 ± 7.44	11	42	65.2 ± 9.71	3	64.5 ± 5.55	29	63.1 ± 8.19
2003	4	29	70.6 ± 17.02	4	29	64.3 ± 2.50	6	74.8 ± 10.01	14	72.0 ± 10.04
10 yr mean	79.9	36	61.9 ± 6.39	120.8	54	60.8 ± 6.02	25.7	62.2 ± 8.38	223.8	61.4 ± 6.46
5 yr mean	21.6	44	62.4 ± 8.70	16.4	33	64.9 ± 8.15	10.8	64.1 ± 10.30	48.8	63.6 ± 8.95

Table 5. Numbers, percentages and mean lengths (X in cm, with standard deviations = SD) of MSW escaped cultured Atlantic salmon in Magaguadavic River from 1994 to 2003. **No MSW escaped cultured salmon were captured at the fish ladder in 2002.** Sexes were determined from secondary sexual characteristics.

Year	Male			Female			Undetermined		Combined	
	Tot	%	X ± SD	Tot	%	X ± SD	Tot	X ± SD	Tot	X ± SD
1994	35	43	75.4 ± 6.09	47	57	73.8 ± 5.82			82	74.5 ± 5.82
1995	113	72	71.3 ± 5.49	43	28	70.3 ± 4.38	12	66.5 ± 2.65	168	70.7 ± 5.22
1996	3	17	74.4 ± 2.55	15	83	71.3 ± 5.18	2	80.2 ± 1.30	20	72.6 ± 5.37
1997	6	33	75.4 ± 4.28	12	67	72.4 ± 3.75	5	68.7 ± 3.51	23	72.4 ± 4.47
1998	1	33	84.5	2	67	71.9 ± 2.90	0		3	76.1 ± 6.39
1999	4	40	82.6 ± 8.67	6	60	72.0 ± 3.34	14	71.6 ± 4.43	24	73.5 ± 6.37
2000	0			0			2	78.7 ± 1.63	2	78.7 ± 1.63
2001	2	50	86.2 ± 5.94	2	50	78.2 ± 0.92	0		4	82.2 ± 5.80
2003	1	50	80.0	0	0		1	77.8	2	78.9 ± 1.56
10 yr mean	16.5	50	73.0 ± 6.39	12.7	39	72.1 ± 5.20	4.0	70.7 ± 5.39	32.8	72.4 ± 5.88
5 yr mean	1.4	22	84.1 ± 6.86	1.6	25	73.6 ± 4.01	3.4	72.8 ± 4.82	6.4	75.5 ± 6.82

Table 6. Escapement of wild and escaped cultured Atlantic salmon in the Magaguadavic River during 1994 - 2003. Numbers of spawners are based on fish classed as sexually mature, and total egg deposition is based on sex ratio, mature female fork length, and fecundity for age classes 1SW and MSW for wild and cultured spawners. Mature postsmolts are all precocious males that escaped from brackish water sites. The mean length-fecundity relationship for St. John River salmon ($Y=430.19e^{0.03605x}$, Marshall and Penney MS 1983) was used to estimate potential egg deposition. The conservation requirement is 1.35 million eggs.

	Wild			Cultured or Stocked					Combined						
Yr	Total spawn	% fem	Tot eggs	Total	Tot mat	% mat	% fem	Post Smolt mat	Tot eggs	Tot escapemt	Tot spawn	% fem	% cult spawn	Tot eggs	% Cons Level
94	130	56.2	425979	695	31	4.5	35.5	0	54125	825	161	52.2	19.3	480104	35.6
95	79	38.0	143575	208	45	21.6	46.7	0	86143	287	124	41.1	36.3	229718	17.0
96	62	45.2	140623	240	79	32.9	55.7	8	178370	302	141	51.1	56.0	318993	23.6
97	48	62.5	157322	0	0	0	0	0	0	48	48	62.5	0	157322	11.7
98	16	43.8	30447	0	0	0	0	0	0	17	16	43.8	0	30447	2.3
99	4	25	3250	0	0	0	0	0	0	4	4	25	0	3250	0.2
00	13	38.5	19845	1	1	100	100	0	3741	14	14	42.9	7.1	23586	1.7
01	17	70.6	71349	0	0	0	0	0	0	0	17	70.5		71349	5.3
02	7	57.1	13688	103	56	63	35	NA	92537	80	53	39.6	86.8	106225	7.9
03	5	60.0	19250	0	0						5	60.0	0	19250	1.4
10 yr mean	38.1	49.7	102533	125	21	21	27.4	0.9	43125	161	59	48.7	23.1	145658	10.8
5 yr mean	9	50.2	25476	21	11	31	27.2	0	22522	26	21	47.3	24.0	47998	3.5

** In 2002, the “cultured or stocked” section represents F1 generation captive reared progeny of 1998 wild adult returns that were released into the Magaguadavic River.

Table 7. Summary of bacteriology and virology disease screening of wild and escaped cultured salmon collected in the Magaguadavic River fish ladder, 1992 - 2003.

Year	Origin	Bacteriology									Virology		
		# sample	No Pathogens	Aeromonas	Pseudeomonas	Vibrio	BKD	IPN	Edwardsella tarda	HKS*	# sample	No Pathogens	ISA
1992	Wild	7	3	2	1	1							
	Cultured	0											
1993	Wild	2	0	1	1								
	Cultured	2	1	1									
1994	Wild	1	0	1									
	Cultured	23	17	4		2							
1995	Wild	0											
	Cultured	99	74	13	11				1		61	61	
1996	Wild	0											
	Cultured	0											
1997	Wild	3	3										
	Cultured	15	4	10		1							
	Cultured	34	29							5			
	Cultured										19	19	
1998	Wild	0											
	Cultured	60	59				1				60	60	
1999	Wild	20	6								20	6	14
	Cultured	58	56				1	1			58	54	4
2000	Wild	1	1								7	7	
	Cultured	28	28								28	28	
2001	Wild												
	Cultured	132	132								132	132	
2002	Wild												
	Cultured	34	34								34	34	
2003	Wild	1	0								1	0	
	Cultured	**12**	**11**					**1**			**12**	**11**	**1**
1992-2001	Wild	35	14	4	2	1					28	14	14
	Cultured	**495**	**443**	**28**	**11**	**3**	**2**	**2**	**1**	**5**	**402**	**398**	**5**

*HKS= Hemorrhagic Kidney Syndrome, later termed Infectious salmon anemia virus (ISA).

Table 8. Summary of virology and bacteriology disease screening for rainbow trout, landlocked salmon, and gaspareau collected in

the Magaguadavic River, and for anadromous salmon collected in the Bocabec and Waweig Rivers. Tests were conducted at the Department of Fisheries and Oceans Lab, Moncton, New Brunswick. Fish were either killed or had died in the St. George fish ladder trap.

Year	site	Species	Sample size	No pathogens	Pathogens detected
1994	Magaguadavic	Rainbow trout	7	7	0
1995	Magaguadavic	Rainbow trout	3	3	0
1997	Magaguadavic	Rainbow trout	2	2	0
1998	Magaguadavic	Rainbow trout	5	5	0
1999	Magaguadavic	Rainbow trout	2	2	0
1999	Magaguadavic	Landlocked salmon	1	1	0
2000	Magaguadavic	Rainbow trout	1	1	0
2000	Magaguadavic	Landlocked salmon	3*	3	0
2003	Magaguadavic	Landlocked salmon	3	3	0
2003	Magaguadavic	Gaspareau	13		Aquatic birnavirus**
1999	Bocabec	Escapee salmon	2	2	
2000	Waweig	Wild salmon	1*	1	

* Those fish non-lethally sampled for the presence of ISA only (mucus swab from the gills).
** One of four tissue pools (from 13 fish) tested positive for aquatic birnavirus. See disease section for additional details.

Table 9. Biological characteristics of each salmon captured in the Dennis (1998), Bocabec (1999), and Waweig (2000) Rivers.

Site	Date	Capture method	Origin	Forklength	Sex	Mature	Smolt age	Sea Age	Tissue sample	Sealice incidence	Pathogen s
Dennis Stream	10/19/98	Seining	Wild	75.3 cm	female	Yes	2	2	Yes	None	N/A
Dennis Stream	10/19/98	Seining	Wild	59.8 cm	female	Yes	2	1	Yes	None	N/A
Dennis Stream	7/21/02	Counting Fence	Wild	54.5 cm	female		2	1	Yes	None	N/A
Bocabec River	09/23/99	Counting fence	Cultured	78.0 cm	male	Yes	1	1	Yes	None	None
Bocabec River	10/05/99	Counting fence	Cultured	51.0 cm	female	No	1	1	Yes	None	None
Waweig River	10/27/00	Seining	wild	52.0 cm	female	Yes (kelt)	3	1	Yes	10 $\leq$ 20 *Lepeophtheirus*	None

Figure 1. Map of Magaguadavic River showing the locations of various sites and facilities.

1. Magaguadavic River (Cook Hatchery, 2 sites)
2. Magaguadavic River (HWY 3 bridge, 2 sites)
3. North East Branch Magaguadavic River
4. Mouth of Davis Brook
5. Davis Brook (2 sites)
6. Lower Trout Brook
7. Deadwater Stream
8. Cox Stream
9. Magaguadavic River (Flume Bridge)
10. Magaguadavic River (Pomeroy Bridge)
11. Kedron Stream (2 sites)
12. Piskahegan Stream
13. Lake Stream
14. Magaguadavic River (Turnover Island)
15. Bonny River
16. Linton Stream (4 sites)
17. Mill Stream

* Commercial salmon hatcheries

** Magaguadavic fish ladder

Figure 1.

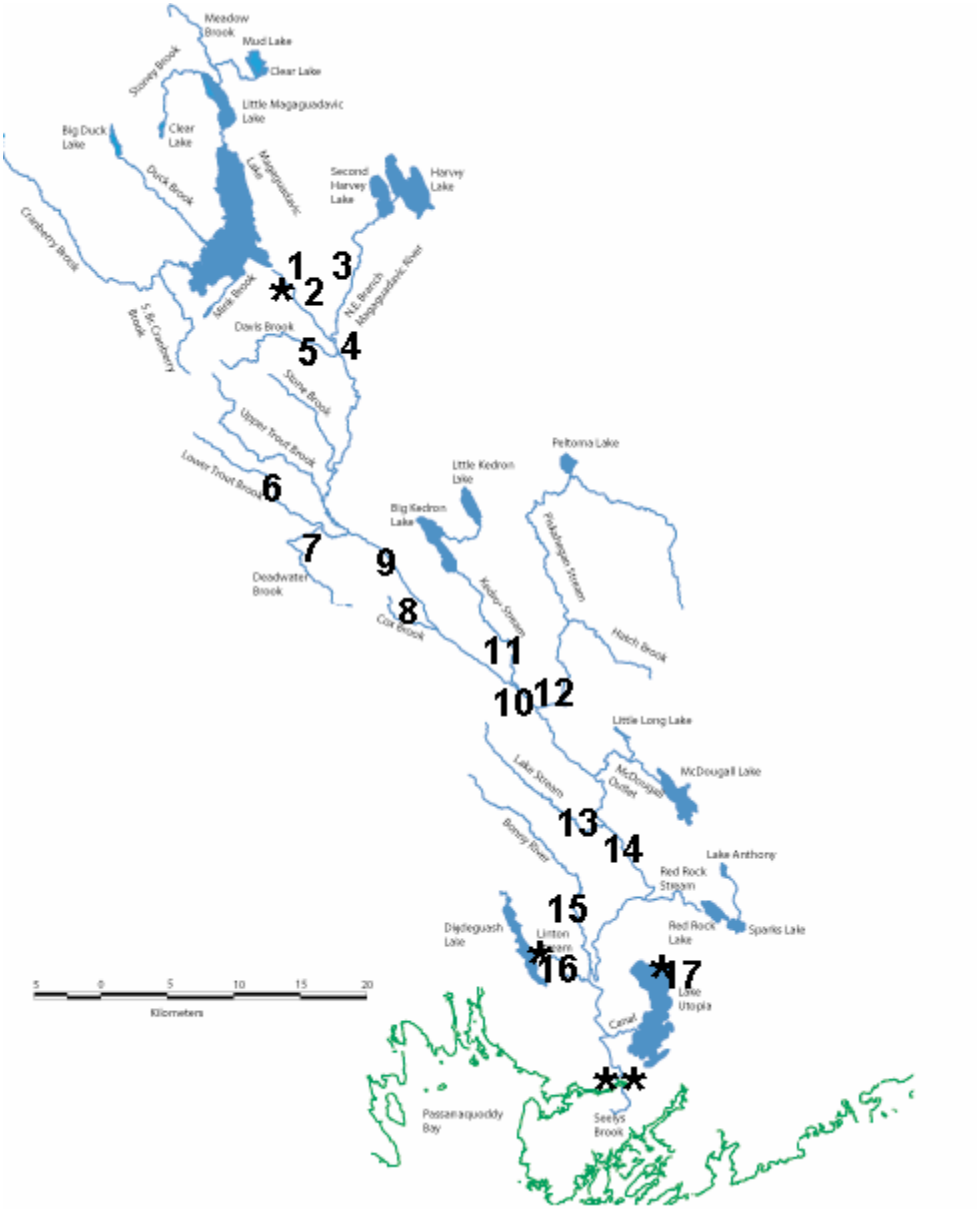


Figure 2. The total numbers of Atlantic salmon recorded annually in the fish ladder

near the mouth of the Magaguadavic River prior to 1992. The 1SW and MSW salmon proportions are given in some years.

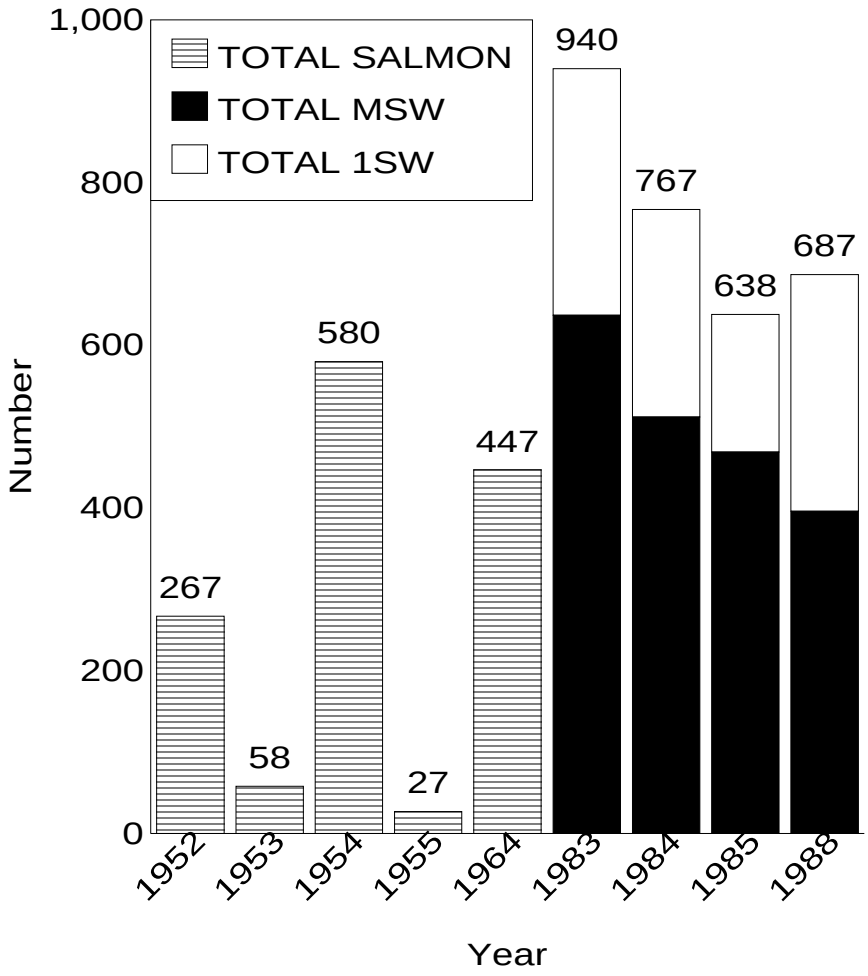


Figure 3. Map of the New and Pocologan Rivers showing the sample stations for Atlantic salmon.

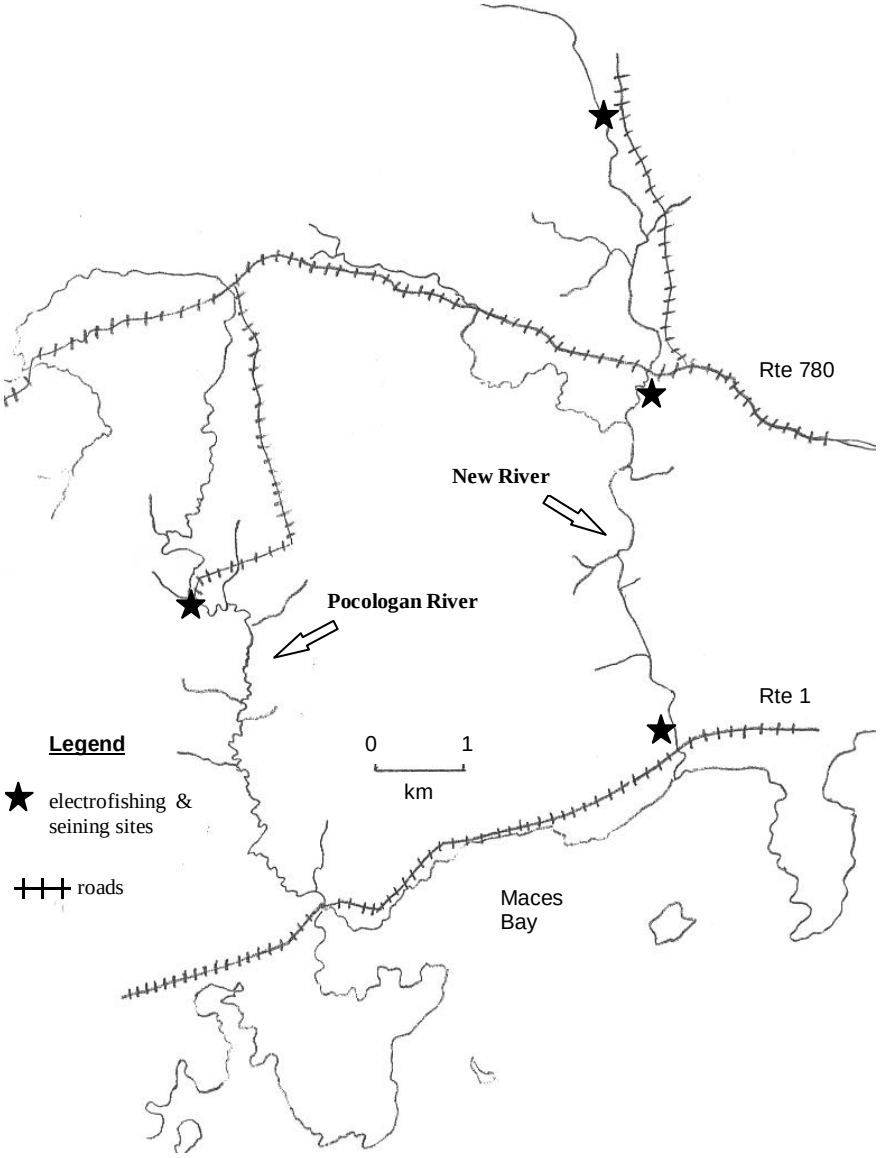


Figure 4. Map of the Digdeguash and Bocabec Rivers showing the sample stations for Atlantic salmon.

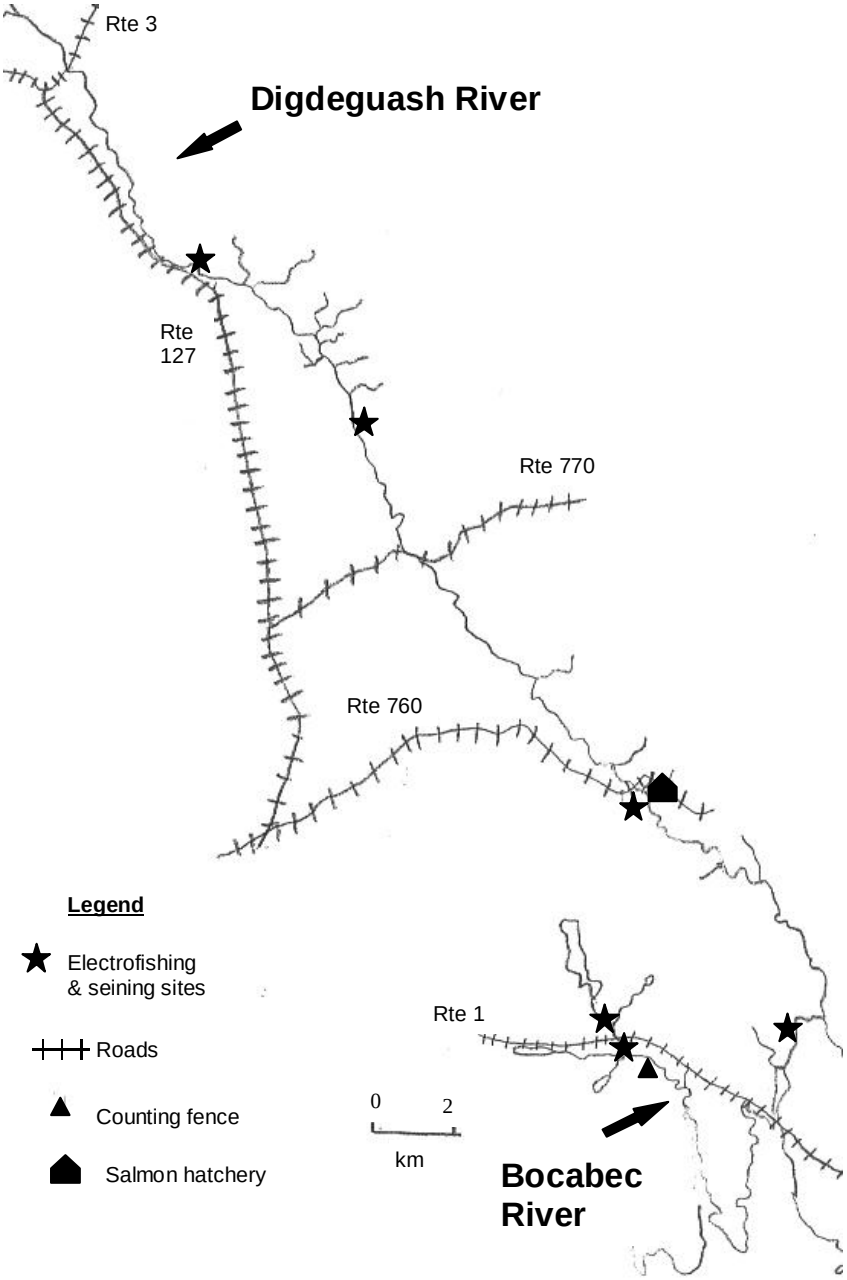


Figure 5. Map of the Waweig River and Dennis Stream showing the sample stations for Atlantic salmon.

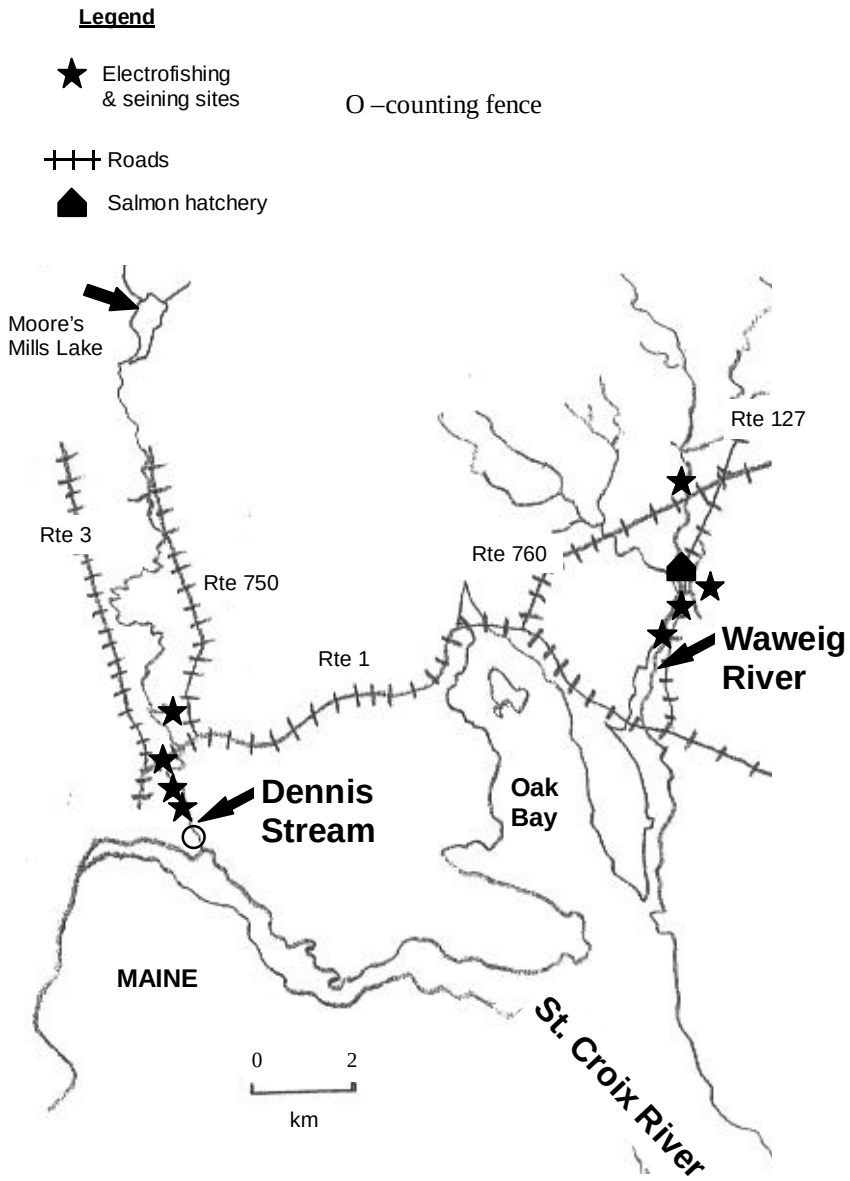


Figure 6. Wild and cultured Atlantic salmon recorded in the fish ladder near the mouth of the Magaguadavic River from 1992 to 2003: (a) total numbers and (b) percentages.

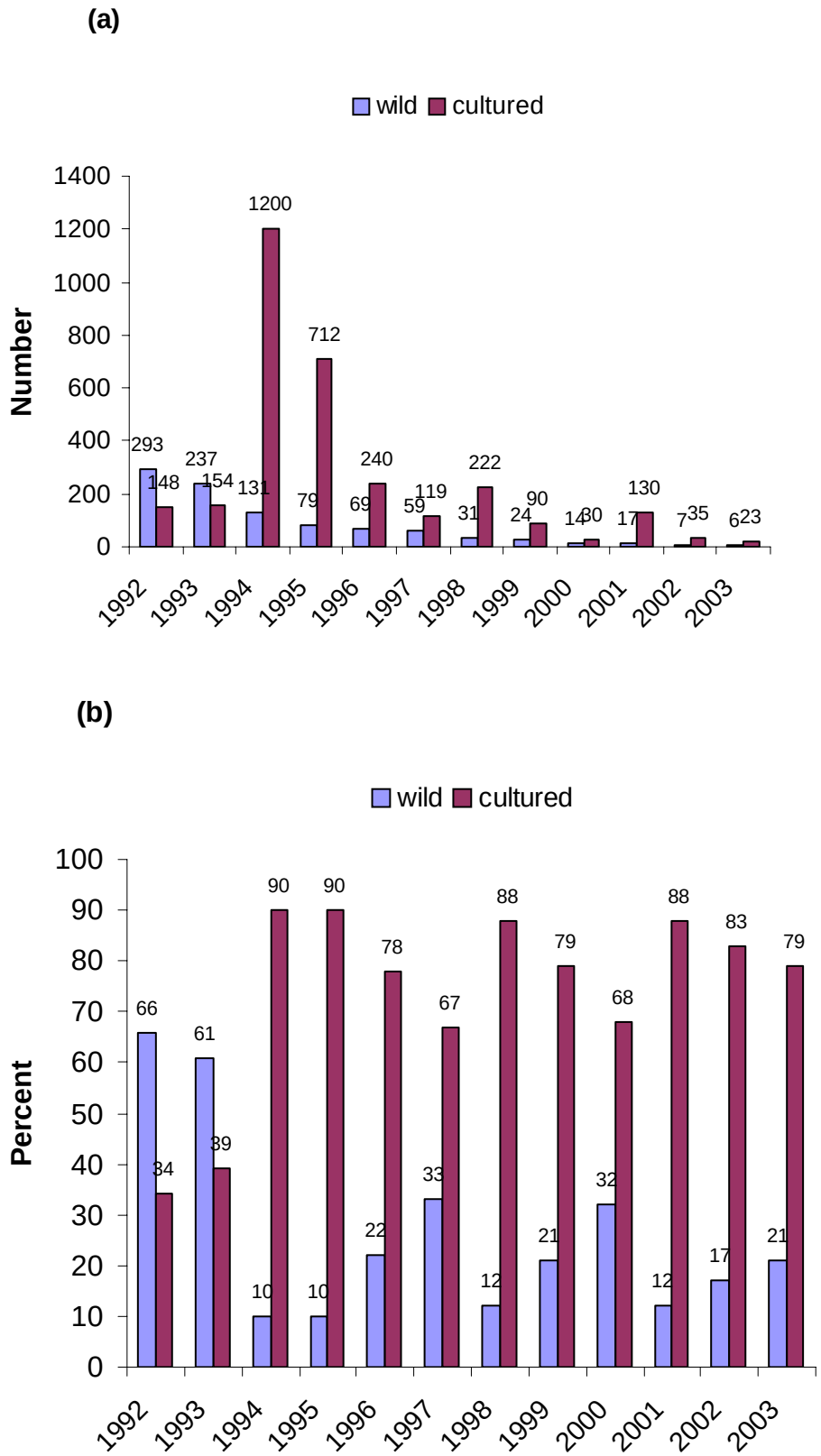


Figure 7. Monthly total numbers of wild and cultured Atlantic salmon recorded at the fish ladder trap at the head of tide in the Magaguadavic River, 1998 – 2003.

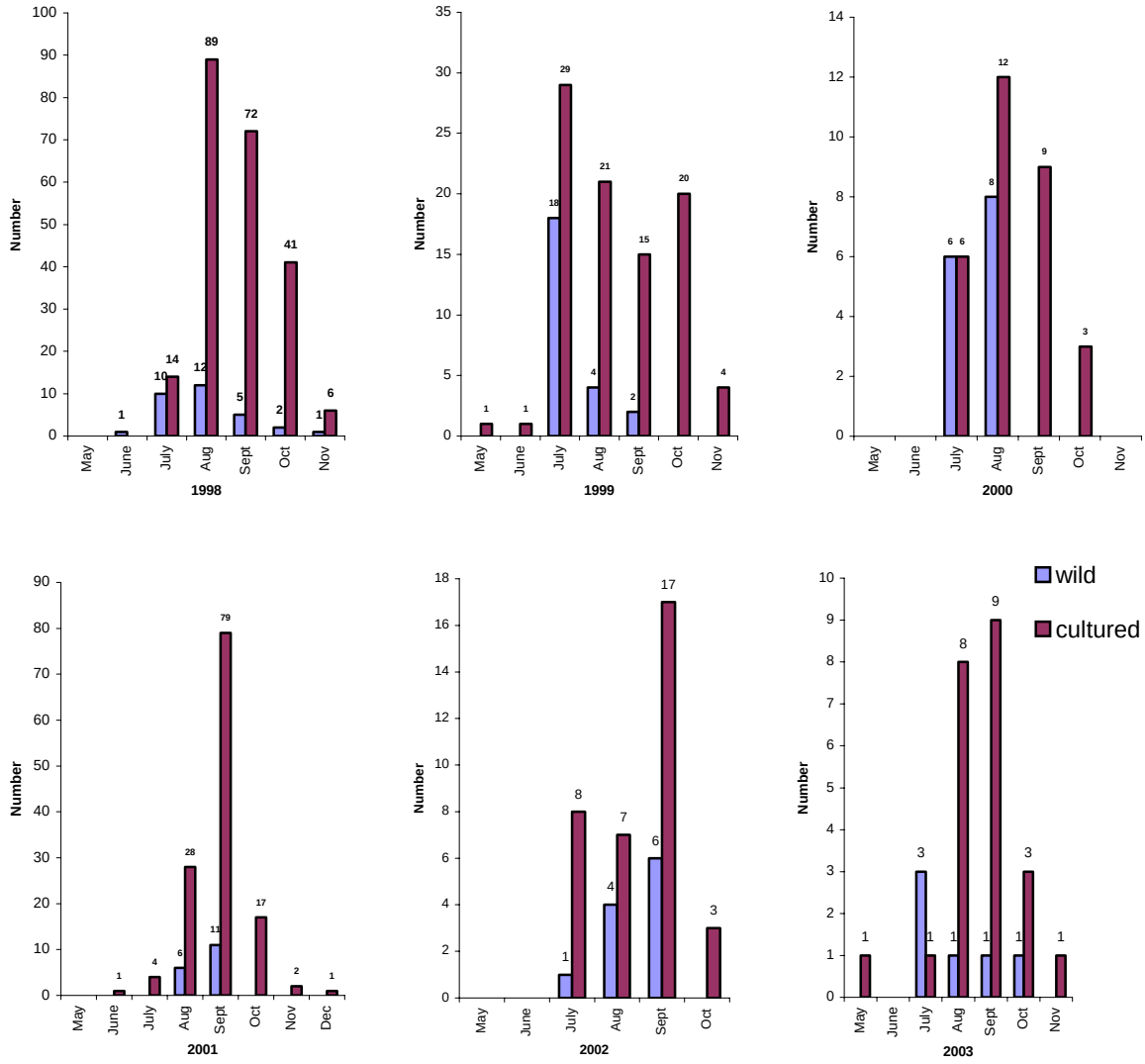


Figure 8. The percent of wild, hatchery, and unknown origin Atlantic salmon smolt captured leaving the Magaguadavic River watershed from 1998 – 2003.

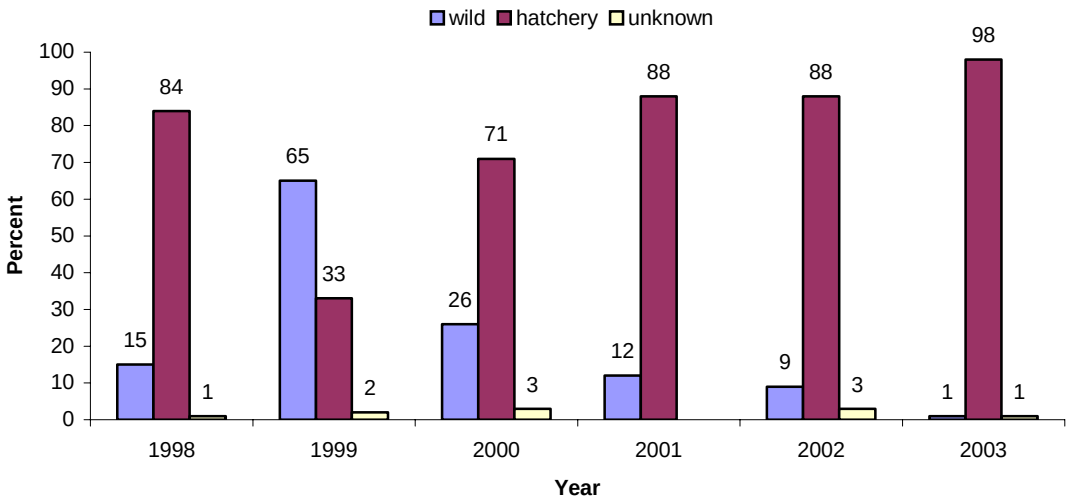
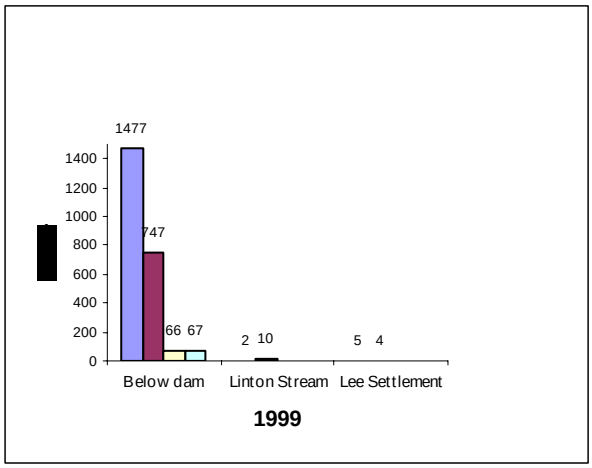
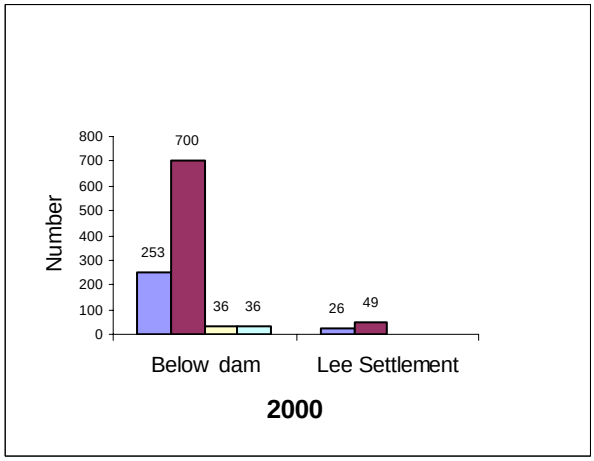
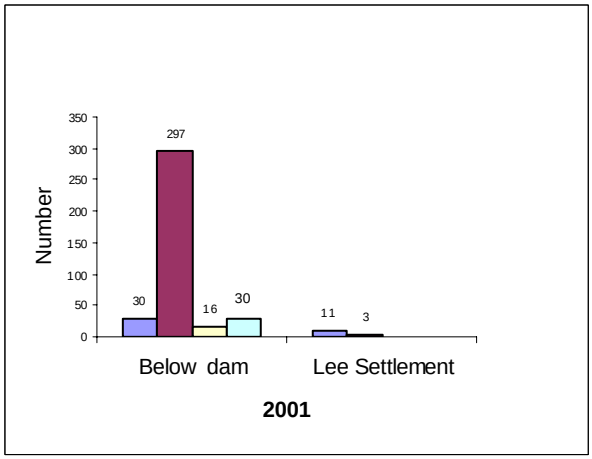
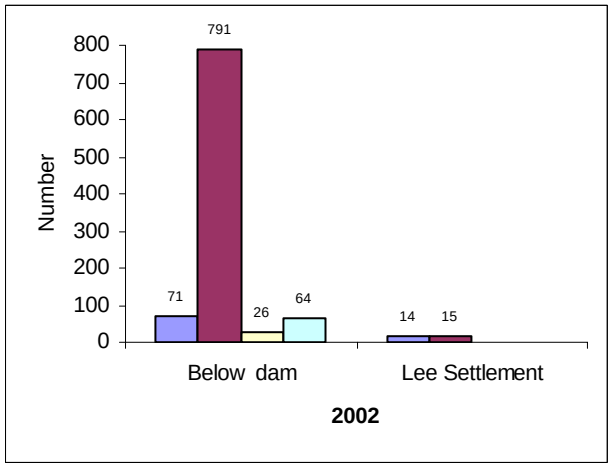


Figure 9. The numbers of wild, hatchery and unknown origin Atlantic salmon smolt captured in the spring at sites in the Magaguadavic River watershed from 1999 – 2003. Numbers of captured landlocked salmon in the smolt output are also included.









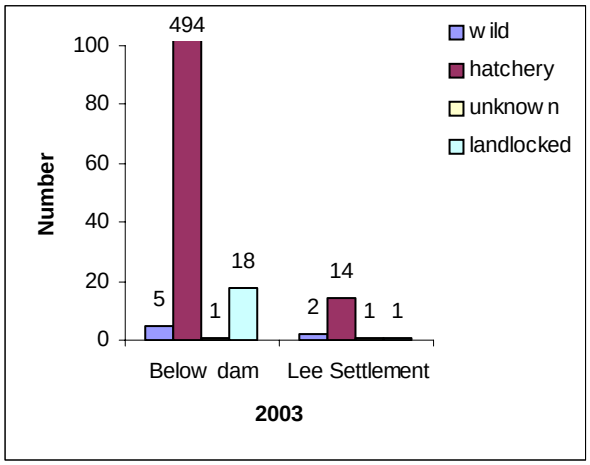


Figure 9. The average number of (a) 0+ parr and (b) ≥ 1+ parr captured per 100 seconds of electroshocking time near and away from hatcheries in the Magaguadavic watershed from 1994 to 2003. The number of electrofishing sites per year is as follows: 1994: 17 away; 1995:10 away; 1996: 23 away and 7 near; 1997: 8 away and 4 near; 1998: 7 away and 4 near; 1999: 4 away and 4 near; 2000: 4 away and 4 near; 2001: 5 away and 4 near; 2002: 11 away and 3 near; 2003: 6 away and 2 near.

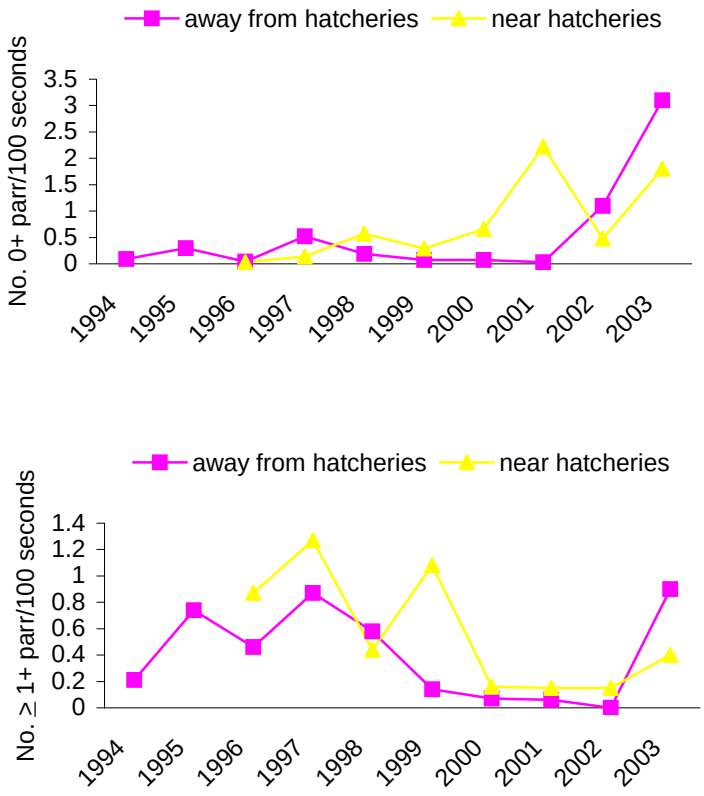


Figure 11. The average number of 0+ parr and ≥ 1+ parr captured per 100 seconds of electroshocking time in the Pocologan, New, Digdeguash, and Dennis drainages from 1998 to 2002. The number of electrofishing sites per year in each drainage is as follows: Pocologan: 1 (2000, 2001); New: 2 (1998,2000,2001); Digdeguash: 1 (1999,2000), 3 (2001); Dennis: 3(2000), 1 (2001), 2 (2002).

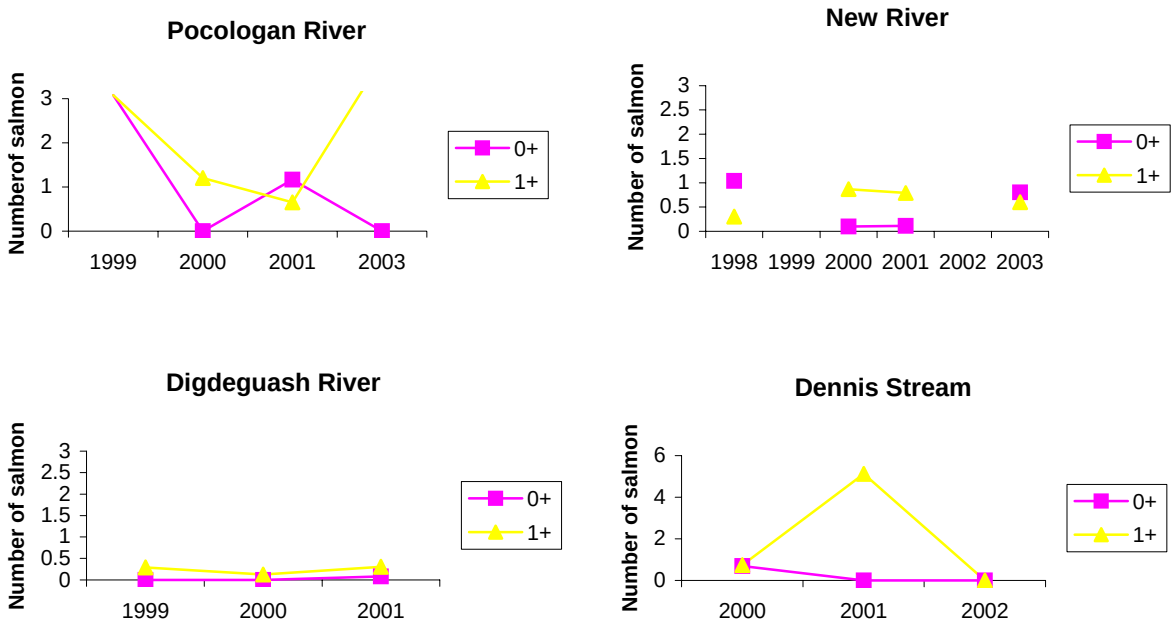
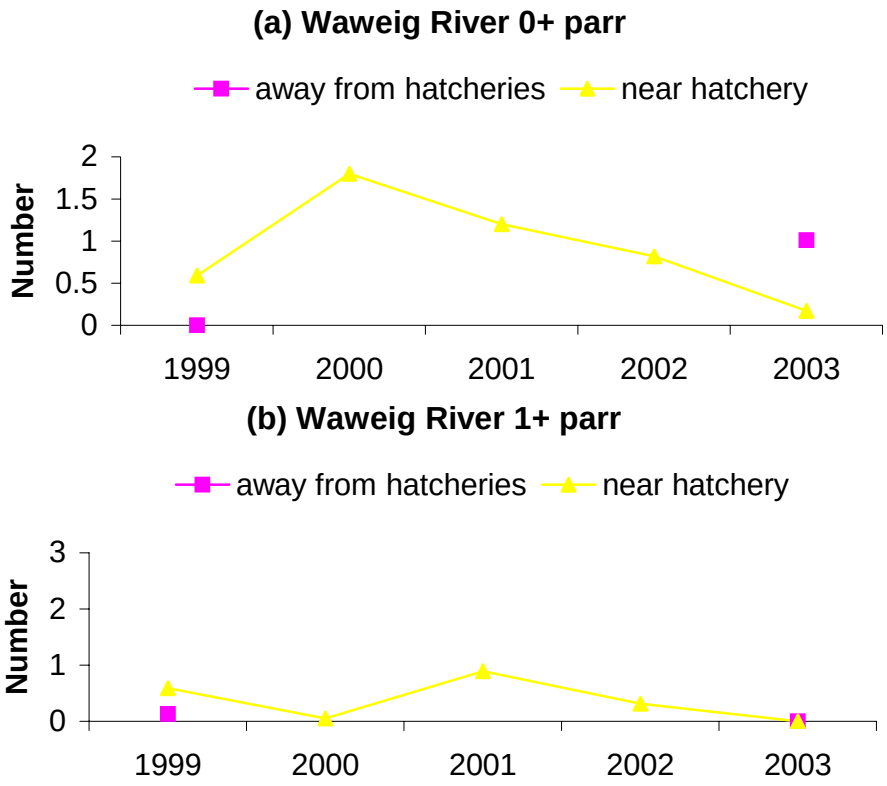


Figure 12. The average number of (a) 0+ parr and (b) ≥ 1+ parr captured per 100 seconds of electroshocking time near (two sites) and away (one site) from hatcheries in the Waweig drainage from 1999 to 2002. The site distant to the hatchery was sampled only in 1999 and 2003.


(a) Waweig River 0+ parr
away from hatcheries
near hatchery
Number
2
1.5
1
0.5
0
1999
2000
2001
2002
2003
(b) Waweig River 1+ parr
away from hatcheries
near hatchery
Number
3
2
1
0
1999
2000
2001
2002
2003

APPENDIX 1.

Feasibility of using landlocked salmon in anadromous salmon recovery program

Objectives

(1) Tag and track movements of landlocked salmon exiting the Magaguadavic River to determine their behaviour, movements, survival, and at sea residency time. Completed. See report below.
(2) Run DNA pedigree analysis on known landlocked salmon collected in the Magaguadavic River and compare to DNA of known anadromous salmon to assess the feasibility of including landlocked salmon in anadromous salmon recovery program. Analysis ongoing. To be completed by February 2004.
(3) Run DNA pedigree analysis on Saint John River salmon and compare to DNA of Magaguadavic River salmon to determine feasibility of using Saint John River salmon in anadromous salmon recovery program for Magaguadavic River. Analysis ongoing. To be completed by February 2004.

Background

The wild anadromous Atlantic salmon population in the Magaguadavic River is teetering on the brink of biological extinction. Salmon returns dropped to an all time low of six fish in 2003. The river has benefited in the short-term from a recovery program in which more than 100 adult salmon (first generation descendants from wild parents collected from the river in 1998) were released in the river in 2002. As well, nearly 33,000 juvenile salmon were stocked into the river in 2003. For the recovery program to continue, however, new recruits are needed to maintain the genetic diversity (to prevent inbreeding and out breeding depression) of salmon in the river. In the short term, it is improbable that there will be sufficient wild salmon returns to sustain the genetic diversity of the recovery program.

The Magaguadavic River Recovery Group is considering two options for the breeding program to continue: (1) to use wild salmon from nearby rivers (with similar genetic makeup, i.e. Saint John River); (2) to use landlocked salmon from the Magaguadavic River. The first option was tested in 2003. Male salmon from the Hammond and Black Rivers were included with Magaguadavic Salmon in the breeding program.

The landlocked form of the Atlantic salmon was not indigenous to the Magaguadavic River drainage. They have been in the drainage since at least the 1960s when a stocking program was initiated for lakes to supplement the NB recreational lake fishery. Similar to smallmouth bass (also non indigenous to Magaguadavic), landlocked salmon are now well established in the drainage (lakes, tributaries, main stem river).

An anadromous salmon monitoring program detected landlocked salmon moving downstream towards the ocean, and subsequently back upstream in the river. It was not known if the fish took up residency in seawater, and if so, how far out to sea they ventured. We also did not know if these were passive movements, driven by spring freshets, or if the fish were showing active migratory tendencies.

Methods

Classification of landlocked salmon

Salmon were classified as anadromous or landlocked on the basis of fin clips and scale analysis. Stocked landlocked salmon often have fin clips corresponding to release years and locations. Fork length was recorded to the nearest mm, and a sample of scales was taken. Circuli patterns on the scales were also used to discriminate between anadromous and landlocked salmon, and to distinguish between wild and stocked hatchery salmon.

Tagging Program

Downstream moving landlocked salmon were captured in a smolt counting fence trap (operational from 18 April to 14 June 2002, and from 30 April to 17 June 2003) situated in a bypass stream below the downstream fish passage facility. The trap was monitored daily and fish were classified as landlocked salmon based on size, fin clips, and scale analysis. All fish captured were measured, and a sample of scales and fin tissue was taken. Salmon were kept for tagging if they exhibited no external deformities or injuries. All other fish were released downstream of the collection device.

Tagging Procedures

V16-4H-R04K coded ultrasonic pingers (65 mm length X 15 mm diameter; weight 10 g in water, produced by Vemco Limited, Shad Bay, Nova Scotia) were used to tag landlocked salmon. Pingers had a frequency of 69 kHz, minimum and maximum off delays of 10 – 35 seconds, and an expected life of 366 days.

Pingers were surgically implanted in the peritoneal cavity of the fish. The anaesthetized salmon (using clove oil [40mg/L]) were placed ventral side up in a V-shaped trough with moist paper toweling for support. Germex was used to sterilize all surgical tools, sutures, and pingers. Furacin was used to clean the ventral surface of the fish prior to making a 2 cm mid-ventral incision beginning 1 cm anterior to the pelvic fins. The pinger was inserted into the peritoneal cavity under the incision. Three to four sutures (4-0 Ethilon black monofilament nylon with FS-2 circular cutting needle) were applied to close the incision and a tissue cement (Vetbond) was used to seal the incision and stitches. Furacin was sprayed on the closed incision. Fish recovered in less than 10 minutes from the anesthesia. The salmon were monitored in an oxygenated tank for 24 hours before being released.

Releases

In 2002, a total of 23 landlocked salmon were tagged and released from 9 May to 14 June. In 2003, a total of 13 landlocked salmon were tagged and released from 29 May to 17 June. Also in 2003, two anadromous salmon broodstock that were captured in the counting fence trap (leaving the river) below the bypass facility were acoustically

tagged. Both fish were first generation progeny from wild anadromous salmon parents. The fish had been reared from egg to adult in captivity, and released into the Magaguadavic River in September 2002. Both fish had external FLOY tags (inserted in 2002) for identification purposes. One fish (79.7 cm female) was originally released 35 km above the head of tide dam in September 2003. The other broodstock (82.5 cm female) had been released 67 km above the head of tide dam in September 2003.

All fish were released in the Magaguadavic River estuary, situated 500 m below head of tide. Tagged salmon were released between 06.00 and 20.00 hours. No significant differences were observed among length or weight of tagged fish among the release dates and times ($P>0.05$).

Tracking

Movements of tagged fish were monitored by positioning submersible receivers (VEMCO VR2-Monitor), each having a built-in omni directional hydrophone with data logging components programmed to decode and identify individual tagged fish at various points (Figure 1). Active searches for tagged fish were performed using a boat equipped with a land-based receiver (VEMCO VR60) having either directional (VEMCO V10) or omni directional (VEMCO VH65) hydrophones. The marine arrays placed in the Bay of Fundy were part of SalarMap, a joint tracking program between the Department of Fisheries and Oceans and the Atlantic Salmon Federation.This array was in place only during 2002.

Due to the small sample sizes, statistical comparisons were made by non parametric tests. The SAS generalized linear model (GLM) was used for comparison of samples of unequal size. The Pearson correlation coefficient was used to test the strength of association of environmental parameters between fish captures.

DNA analysis

Scale and tissue samples from landlocked (203 samples) and anadromous salmon (65 samples) were sent to the Department of Fisheries and Oceans Marine Gene Probe Laboratory for DNA analysis. Landlocked and anadromous salmon samples were collected from traps in the Magaguadavic River (smolt traps and fish ladder trap) from 1998 to 2003. Tissue samples from the Saint John, Nashwaak, and Black River salmon were also included in the DNA analysis (collected from DFO personnel).

Results

2002 tagging and tracking summary

A total of 62 landlocked salmon were captured during the anadromous smolt run in 2002, and their mean fork length was 35.7 $\pm$ 5.2 cm. Most of the landlocked (75%) and anadromous smolt (89%) were captured over a 29-day period when water temperatures and water discharges averaged 13.9 $\pm$ 2.2 ^{0}C and 19.7 $\pm$ 10.3 m^3/s, respectively (Figure

2). There was no significant correlation between numbers of salmon captured and any of the environmental parameters measured (P>0.05).

The mean fork length and weight of acoustically tagged salmon was 40.7 $\pm$ 4.5 cm and 597.1 $\pm$ 297.3 grams, respectively in 2002 (Table 1). The ages of the tagged salmon ranged from two to five years in 2002 (Table 1). No significant differences were observed among fork lengths, weights, or ages between wild and hatchery landlocked salmon for both years (P>0.05).

In 2002, only three (13%) tagged salmon remained in the seawater section of the Magaguadavic River (zone 1, see Figure 1). Those fish moved 8 km from the release site to the mouth of the river where they resided (within a 1 km section inside river mouth) throughout the study. A total of 14 (61%) tagged fish moved into Passamaquoddy Bay (zone 2, Figure 1), five of which were detected on receivers in the Bay of Fundy (zone 3, Figure 1). Six (26%) fish were suspected to have died within 3 km downstream of the release site, since their signals were either lost or tag positions remained stationary within two days after release. All active tagged fish (17) moved to the mouth of the river (8 km) in 1 to 22 days after release (Table 2). No significant difference was observed among the number of days to reach the river's mouth by the tagged fish among the three zones they ultimately travelled to (P>0.05, see Table 2).

The final positions after the first year of tracking for the 14 tagged fish that left the river is as follows: six signals were last recorded in Passamaquoddy Bay, four signals were last detected in the anadromous salmon smolt migration route between Grand Manan and Nova Scotia, and four returned to the river. The latter group spent from 1 to 31 days in the bay(s) before returning to the river. Of the fish returning to the river, two were recaptured in the fishway trap at head of tide 45 and 55 days respectively after initial release. One of the recaptured fish had travelled to the inner Bay of Fundy, more than 150 km from the initial point of release (see inner bay arrays, Figure 1). Both recaptures had sea lice infestations and had external damage along the head, typical of sea lice attachment. The fish had increased in fork length by 1.4 and 1.7 cm respectively during their residence at sea.

2003 tagging and tracking summary

A total of 21 landlocked salmon were captured during the anadromous smolt run in 2003, and their mean fork length was 42.2 $\pm$ 5.67 cm. Most of the landlocked (76%) and anadromous smolt (68%) were captured over a 7-day period when water temperatures and water discharges averaged 13.7 $\pm$ 0.69 ^{0}C and 30.9 $\pm$ 6.50 m^3/s, respectively (Figure 2).

The mean fork length and weight of acoustically tagged salmon was 43.8 $\pm$ 5.4 cm and 752 $\pm$ 495.9 grams, respectively in 2003 (Table 1). The ages of the tagged salmon ranged from three to seven years in 2003 (Table 1).

In 2003, ten (77%) tagged salmon moved through the 8 km seawater section of the Magaguadavic River in one to three days (Table 1 & Figure 1). Four of those fish were later detected on receivers in western Passamaquoddy Bay (Figure 1). Five other signals were never detected after the fish left the Magaguadavic River. The signal from one fish remained at the mouth of the Magaguadavic River throughout the tracking period. It is unknown whether any of the 10 tagged fish left Passamaquoddy Bay since no receivers were positioned in the Bay of Fundy during 2003. Results from active tracking in Passamaquoddy Bay yielded no signals from tagged fish. None of the nine fish that left the seawater zone of the river returned to the river during the 2003 tracking period.

Three (23%) tagged fish were suspected to have died near the release site, since their signals were either lost or tag positions remained stationary within one day after release.

The two acoustic tagged anadromous salmon broodstock both moved through the 8 km seawater zone of the Magaguadavic River. It took one fish (79.7 cm female) seven days to reach the mouth of the estuary. This fish is though to have died a short time later (tag detected in same position throughout remainder of tracking study). The other tagged broodstock (82.5 cm female) moved through the seawater zone of the Magaguadavic River in less than one day and was detected (L'Ete receiver) leaving Passamaquoddy Bay towards the open ocean two days after release.

DNA Results

See attached reports titled *" Analysis of genetic diversity and genetic distance among wild anadromous Magaguadavic and nearby landlocked Atlantic salmon"*
and
"A*nalyses of Genetic distance between wild anadromous Magaguadavic River salmon and neighboring populations from the Bay of Fundy".*

Discussion

This study has shown that landlocked salmon move to and survive in a marine environment for extended periods of time. Migration patterns were highly variable among the tagged fish in 2002. Some fish remained in the Magaguadavic estuary, others moved into Passamaquoddy Bay and Bay of Fundy, and some returned to freshwater after up to 55 days at sea. In 2003, all actively tracked fish (69%) left the Magaguadavic estuary and moved to sea.

Captures of the downstream migrating landlocked salmon occurred at water temperatures > 10^0 C, and as water discharge declined. Anadromous salmon smolt runs typically peak at a water temperature of 10^0 C or higher, and the migration period generally lasts for about 30 days (Elson, 1962; Jessop, 1975; Solomon, 1978; Ruggles, 1980; Moore *et al*., 1998). Montgomery *et al.* (1983) reported that the onset of the downstream runs for anadromous brook charr (*Salvelinus fontinalis*) and Atlantic

salmon smolt coincided with declining water levels and discharge. Thus, the out-migrant landlocked salmon seem to be exhibiting a pattern typical of many salmonids.

Landlocked salmon individuals exhibited very different movement patterns, all typical of salmonids but some atypical of the species. The course tracks suggested a tendency for some tagged landlocked salmon to behave similar to sea run charr and trout. Brook trout (*Salvelinus fontinalis*), Arctic charr (*Salvelinus alpinus*), brown trout (Salmo trutta), and cutthroat trout (*Oncorhynchus clarki*) have been reported to move from freshwater in the spring of the year to marine environments (near their home river), and return to freshwater in the autumn or winter to spawn or overwinter (Dutil and Power, 1980; McCart, 1980; Castonguay *et al.*, 1982; Jonsson, 1985; Trotter, 1989; Finstad and Heggberget, 1993; Gulseth, 2000; Curry *et al.,* 2002). Arctic charr have been documented to spend as few as 10 days at sea, whereas cutthroat trout have spent more than a year at sea (Trotter, 1989; Begout Anras and Gyselman*,* 1999).

In 2002, four tagged landlocked salmon moved into the open ocean and were last detected near Grand Manan. Anadromous Atlantic salmon postsmolt have been detected in the vicinity of Grand Manan Island on their way to ocean feeding grounds (Lacroix, 1996). The only anadromous salmon postsmolt captures from a trawling survey in the Bay of Fundy were reported along the outer Bay receiver array, the same area where some tagged landlocked salmon were detected (F. Whoriskey, personal communication, 2003). Unfortunately, there were no receivers stationed in the Bay of Fundy in 2003, therefore, it is unknown whether any of the nine fish leaving the river during that time moved into the open ocean.

It is probable that the signals lost (or detected in the same position) from nine fish (6 in 2002 and 3 in 2003), seven of which were hatchery, shortly after initial release was a result of predation. Those fish were released during two peaks of the anadromous smolt run, a run composed mostly of hatchery escapes from commercial salmon industries along the river. Avian and seal predators were frequently observed during that period just below head of tide.

Two landlocked salmon were recaptured in the head of tide fishway after spending 45 and 55 days in the marine environment in 2002. One fish moved back and forth between the river and Passamaquoddy Bay. The other salmon spent most time in the inner Bay of Fundy logging a cumulative distance of more than 400 km. Both recaptured fish also had sea lice (*Lepeophtheirus salmonis*.) infestations and external damage, typical of sea lice attachment. Some tagged landlocked salmon (including one of the recaptures) were detected near sea cages in Passamaquoddy Bay. Sea lice infestations have been a major cause of fish mortality and economic loss in the Bay of Fundy Salmon Aquaculture Industry (MacKinnon, 1997).

These preliminary results may have major management implications. Some landlocked Atlantic salmon utilize the marine environment. Given that landlocked fish do maintain the capacity to adapt to seawater, and to undertake ocean movements, it may be possible for rivers that have endangered wild anadromous runs, to utilize landlocked salmon in the system as part of the broodstock in live gene banks for restoring sea-run populations.

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References

Begout Anras, M. & Gyselman, E.C. 1999. Habitat preferences and residence time for freshwater to ocean transition stage in Arctic charr. *J. Mar. Biol. Assoc. U.K.,* 79: 153-160.

Castonguay, M., Fitzgerald, G.J., & Cote, Y. 1982. Life history and movements of anadromous brook charr (*Salvelinus fontinalis*) in the St-Jean River, Gaspé, Quebec. *Can. J. Zool.,* 60: 3084-3091.

Curry, R.A., Sparks, D. & VandeSande, J. 2002. Movement patterns of a riverine population of brook trout. *Trans. Am. Fish. Soc.,* 131: 551-560.

Dutil, J.D. & Power, G. 1980. Coastal populations of brook trout (*Salvelinus fontinalis*) in Lac Guillaume-Delise (Richmond Gulf) Quebec. *Can. J. Zool.,* 58: 1828-1835.

Elson, P.F. 1962. Predator-prey relationships between fish-eating birds and Atlantic salmon. *Fish. Res. Bd. Can. Bull.,* 133. 74pp.

Finstad, B. & Heggberget, T.G. 1993. Migration, growth and survival of wild and hatchery reared anadromous Arctic charr (*Salvelinus alpinus*) in Finnmark, northern Norway. *J. Fish. Biol.,* 43: 303-312.

Gulseth, O. 2000. The brief period of spring migration, short marine residence, and high return rate of a Northern Svalbard population of Arctic charr. *Trans. Am. Fish. Soc.,* 129: 782-796.

Jessop, B.M. 1975. Investigation of the salmon (*Salmo salar*) smolt migration of the Big Salmon River, New Brunswick, 1966-72. Resource Development Branch, Fisheries and Marine Service, Department of the Environment, Halifax, N.S. Tech. Rep. Ser. MAR.T-75-1. 57pp.

Jonsson, B. 1985. Life history patterns of freshwater resident and sea-run migrant brown trout in Norway. *Trans. Am. Fish. Soc.,* 114: 182-194.

Lacroix, G.L. 1996. Successful movement of post-smolt Atlantic salmon from river estuaries to the Bay of Fundy. *Gulf of Maine News,* Summer. Pp 1-3.

MacKinnon, B.M. 1997. Sea Lice: a review. *World Aquaculture*, 28: 5-10.

Montgomery, W.L., McCormick, S., Naiman, R., Whoriskey, F.G & Black, G. 1983. Spring migratory synchrony of salmonid, catastomid and cyprinid fishes in Rivière à la truite, Quebec. *Can. J. Zool.,* 61: 2495-2502.

Moore, A., Ives, S., Meade, T.A & Talks, L. 1998. The migratory behaviour of wild Atlantic salmon (*Salmo salar* L.) smolt in the River Test and Southampton Water, southern England. *Hydrobiol*., 371/372: 347-353.

Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon*. Can. Tech. Rep. Fish. Aquat. Sci.,* 952. 39 pp.

Solomon, D.J. 1978. Some observations on salmon smolt migration in a chalkstream. *J. Fish. Biol.*, 12: 571-574.

Trotter, P.C. 1989. Coastal cutthroat trout: A life history Compendium. *Trans. Am. Fish. Soc.,* 118: 463-473.

Table 1. Total numbers, origins, fork lengths, weights, and ages of acoustically tagged landlocked salmon in the Magaguadavic River during 2002 and 2003.

Year	Origin	No.	Fork length cm		Weight gm		River Age	
			Mean ± SD	Range	Mean ± SD	Range	Mean± SD	Range
2002	Wild	3	44.2 + 11.7	36.7– 57.7	888 ± 810.9	399 - 1824	4 ± 1	3 – 5
	Hatchery	20	40.1 ± 2.6	37.3–41.8	554 ± 66.9	390 - 663	3.2 ± 0.5	2 – 4
	Combined	23	40.7 ± 4.5	36.7– 57.7	597 ± 297.3	390 - 1824	3.3 ± 0.6	2 – 5
2003	Wild	4	42.0 + 3.00	39.3– 45.5	675 ± 127.9	540 - 840	3.8 ± 0.96	3 – 5
	Hatchery	9	44.7 ± 6.14	39.5–59.6	786 ± 598.7	440 - 2350	4.1 ± 1.17	3 – 7
	Combined	13	43.8 ± 5.38	39.3– 59.6	752 ± 495.9	440 -2350	4.0 ± 1.08	3 – 7

Table 2. Total numbers, fork lengths, and number of days to reach river's mouth of tagged fish in the tracking zones for 2002 and 2003. The zones are as follows: Zone 1: seawater section Magaguadavic River; Zone 2: Passamaquoddy Bay; Zone 3: Bay of Fundy. There were no receivers in Zone 3 during 2003.

Year	Zone	No. Fish	Fork length (cm)	No. days to river mouth (range)
2002	1	3	39.7 $\pm$ 1.2 cm	2.1 $\pm$ 1.9 (1 – 5)
	2	9	38.3 $\pm$ 0.9 cm	9.6 $\pm$ 9.3 (1.5 – 22)
	3	5	40.9 $\pm$ 2.9 cm	10.1 $\pm$ 8.6 (1.5 – 21)
2003	1	6	46.1 $\pm$ 7.1 cm	1.3 $\pm$ 0.8 (1 – 3)
	2	4	42.3 $\pm$ 2.5 cm	1.8 $\pm$ 0.5 (1 – 2)

Figure 1. Map of study area showing the release site for tagged salmon the Magaguadavic River, and the tracking array (dotted lines) in Passamaquoddy Bay, and the Bay of Fundy. The international border is shown by a dashed line.

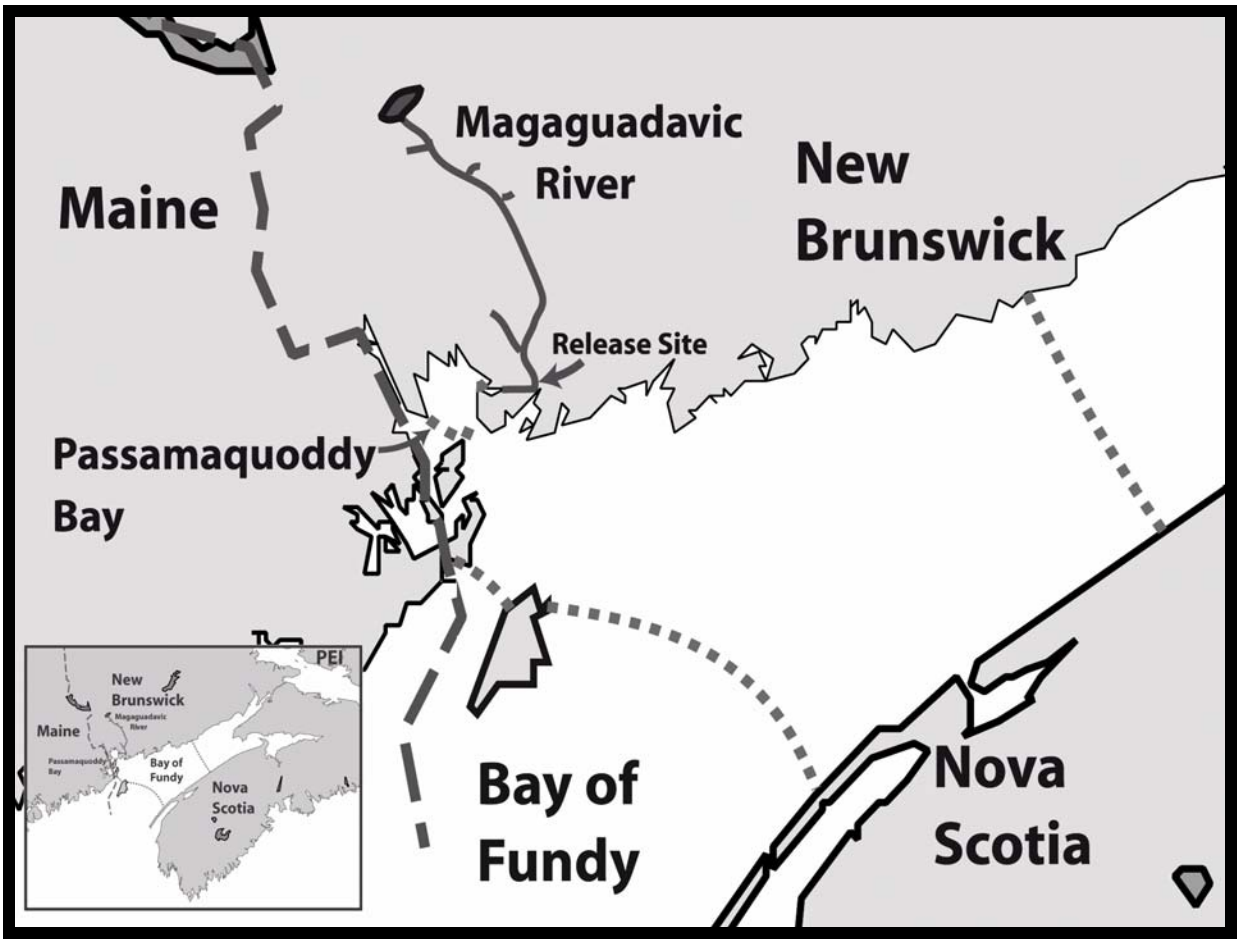

Figure 2. The daily numbers of landlocked salmon and anadromous smolt captured in a counting fence trap below the outlet of a downstream fish passage facility in the

Magaguadavic River in (a) 2002 and (b) 2003. The water temperatures and discharges are also presented.