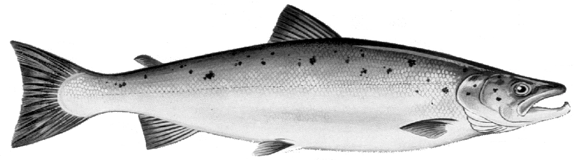
Fisheries and Oceans **Pêches et Océans**

Maritimes Region

DFO Maritimes Regional
Habitat Status Report 2000/2E



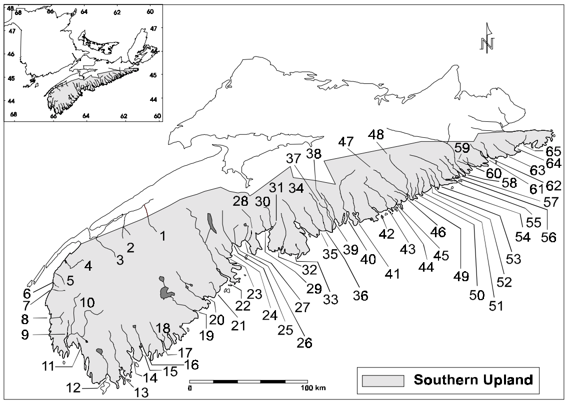
The Effects of Acid Rain on Atlantic Salmon of the Southern Upland of Nova Scotia

Background

The Southern Upland is a coastal plain that extends the full length of the Atlantic coast of mainland Nova Scotia. The majority of the 65 rivers within the Southern Upland typically drain lowland areas of shallow soils and peat bogs underlain by granites and metamorphic rocks lacking in base minerals. Some metamorphic rocks contain metal sulphides (pyrites) that can acidify water. The water of these rivers is generally organic-acid stained, easily acidified, and when combined with acid precipitation can become toxic to Atlantic salmon (Salmo salar L). Interspersed throughout the Southern Upland are pockets of limestone rich soils (drumlins) that provide local areas where river conditions are less acidified.

The salmon returning to Southern Upland rivers are about 80% one-sea-winter (1SW) salmon (also commonly called grilse or small salmon) and about 20% multi-sea-winter (MSW) or "large" salmon including two- and three-sea-winter fish and previous spawners. On average, 1SW fish contribute about 50% of the egg deposition. Virtually all salmon spend 30 or more months in fresh water before emigrating to sea as two- or three-year-old smolts. Salmon within the Southern Upland are important as a recreational species and are fished by Aboriginals for food, social and ceremonial purposes. Fisheries in the area are now limited to minimal or no harvest of grilse or small salmon (salmon ≤ 63 cm in fork length). Fisheries for large salmon have been closed since 1985. The Atlantic salmon is viewed by many as a "barometer" species for environmental health of freshwater rivers and streams.

Acid rain has had a major destructive impact in many of Canada's lakes and rivers. Nova Scotia is the most heavily impacted province in Canada in terms of the proportion of fish habitat that has been damaged by acid rain. The Southern Upland is the main area impacted.



Index of rivers:

1	Nictaux	24	Martins*	47	West (Sh Hbr)*
2	Round Hill	25	Gold*	48	East (Sh Hbr)*
3	Bear	26	Middle*	49	Kirby*
4	Sissibo	27	East (Chester)*	50	Salmon (P.D.)*
5	Belliveau	28	Little East	51	Quoddy*
6	Boudreau	29	Ingram*	52	Moser*
7	Meteghan	30	Indian	53	Smith*
8	Salmon (Digby)*	31	East	54	Ecum Secum*
9	Annis	32	Nine Mile*	55	Liscomb*
10	Tusket*	33	Pennant	56	Gaspereau Bk*
11	Argyle	34	Sackville*	57	Gegogan*
12	Barrington*	35	Salmon (L Major)*	58	St Marys*
13	Clyde*	36	Salmon (L Echo)*	59	Indian Harbour Lakes
14	Roseway*	37	West Bk Porters*	60	Indian*
15	Jordan*	38	East Bk Porters*	61	Country Harbour*
16	East	39	Chezzetcook*	62	Issacs Harbour*
17	Sable*	40	Musquodoboit*	63	New Harbour*
18	Tidney	41	Salmon (Hfx)*	64	Larrys*
19	Mersey	42	Ship Harbour*	65	Cole Harbour*
20	Medway*	43	Tangier*		
21	Petite*	44	E Taylor Bay*		
22	Lahave*	45	W Taylor Bay*		
23	Mushamush*	46	Little West		

* One of the 47 rivers used in the impact analysis

Summary

- Natural reproducing Atlantic salmon are no longer present in many of the 65 rivers which have their source in the Southern Upland of Nova Scotia and are at reduced levels in all other rivers in the area. Except on four rivers which are entirely dependent on hatchery stocking, all salmon fisheries on these rivers (Aboriginal and recreational) have been severely limited in the last three years.

- The principal factors responsible for low salmon abundance are acid toxicity due

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Canada

to acid rain and low marine survival. Because of acid rain, salmon reproduction is no longer possible in several of the rivers and impeded to varying degrees in most others. Low marine survival is compounding the effects of freshwater acidification.

- Significant reductions in acid toxicity for salmon are not anticipated in the near future. Further declines in salmon production and losses of salmon stocks are expected unless marine survival improves significantly.

- Management options to protect remaining salmon stocks include:

– liming to neutralize river acidity and restore some habitat production capacity;
– stocking of hatchery-reared fish to increase salmon returns;
– live gene banking to preserve stocks and support future restoration; and
– restricting exploitation.

- Principal recommendations are to:

– support Canada's position to negotiate a further 75% reduction in SO_2 emission limits in eastern Canada and the United States to facilitate recovery of Southern Upland salmon; and

– develop a recovery plan for Southern Upland salmon to prevent further loss of stocks and hasten their recovery.

Introduction

Historically, the Southern Upland was estimated to have produced about 45,000 adult salmon per year. That number was reduced to 22,700 by 1986. The 50% loss was attributed to acidification of the rivers. In 1996, the total return to the Atlantic coast is estimated to have been 10,500 salmon (8,700 to 13,700, 5th and 95th percentiles). This further decline occurred in spite of closure of essentially all impacting marine salmon fisheries between 1983 and 1992. Since 1996, the numbers of salmon have decreased further and recreational and Aboriginal fisheries have been reduced or closed.

Concern now exists as to the viability of the salmon stocks of the Southern Upland of Nova Scotia. Most of the rivers in this area are sensitive to acidification and acid rain. Highly acidified rivers no longer have natural reproducing populations of salmon. Partially acidified rivers have experienced a loss in salmon production capacity. Coincidentally, most North American salmon, including those of the Southern Upland, are experiencing low marine survival. Collectively these factors have led to concern that many of the remaining runs of salmon to Southern Upland rivers may no longer be self-sustaining. Accordingly, a peer review was held to:

1. Assess the effects of acid rain and reduced marine survival on Atlantic salmon stocks of the Southern Upland of Nova Scotia;
2. Provide a prognosis for the salmon production capacity of individual rivers impacted by acidification; and
3. Recommend measures to save and enhance the recovery of the remaining salmon and their habitat.

Salmon of the Southern Upland

Habitat

The salmon production area for 47 of the Southern Upland rivers is estimated to be 84.8 million m^2. Twenty-nine percent of the salmon habitat area has stream gradients less than 0.12% which is considered marginal for the production of juvenile Atlantic salmon. Only 16% of the salmon habitat is in the gradient category of 0.5 to 1.49% which is considered to be prime for juvenile Atlantic salmon production. Unsurveyed rivers offer very little additional salmon production capacity because they are either very small or have impassable waterfalls or dams and reservoirs.

Hydroelectric dams and water storage reservoirs on the Tusket, Roseway, Jordan, Mersey, Medway, Indian and East rivers have significantly reduced the salmon-production capacity of the Southern Upland. However, all facilities were in place by the 1950s, i.e., prior to the recent decline in salmon returns.

Stock Abundance

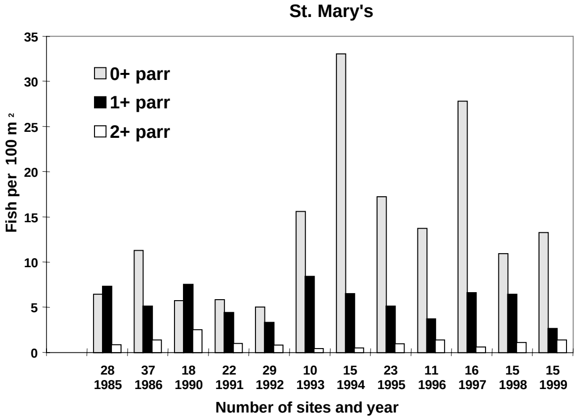
Conservation requirements have been assigned for two important low-acidity rivers, the St. Mary's and the LaHave. These requirements are 7.4 million eggs or the equivalent of 3,155 fish for the entire St. Mary's River and 1.9 million eggs, equivalent to 1,320 fish, for the LaHave River above Morgans Falls.

The estimated escapement to the West River, St. Mary's, in 1999 was 390 fish (256–915). Based on the proportion of habitat sampled, total escapement to the St. Mary's River in 1999 was estimated to be 700 fish or 22% of the fish conservation requirement and 30% of the egg requirement. Egg depositions have been considerably below the river's conservation requirement in each of the last three years.

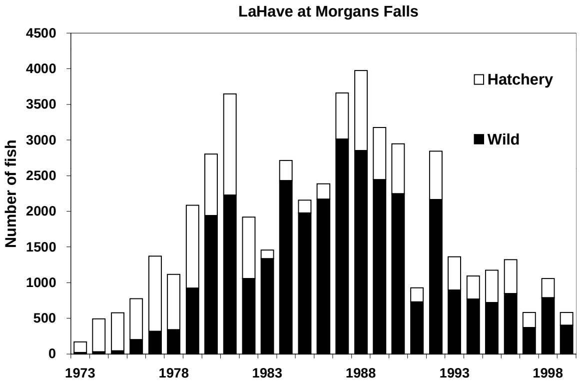
Salmon escapement estimate – St. Mary's River

Year	Small	Large	% egg requirement
1995	2,038	437	92
1996	1,535	590	93
1997	709	110	28
1998	1,926	74	55
1999	559	150	30

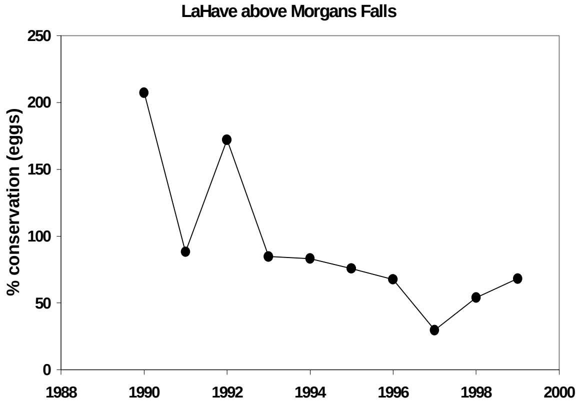
Age-1^+ and age-2^+ parr densities remain low while age-0^+ parr (fry) are higher since 1993.



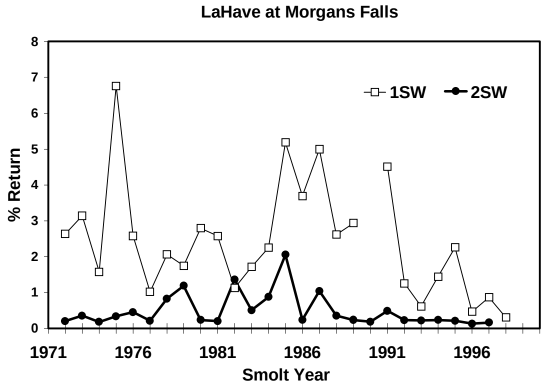
On the LaHave River at the Morgans Falls fishway, counts in 1999 were only 585 fish, which indicated a return of 48% of the fish conservation requirement and 68% of the egg requirement. After broodstock removals, egg deposition was 55% of the requirement. Hatchery fish contributed 33% of the potential egg deposition.



The return of salmon in 1999 was the seventh consecutive year that egg deposition above Morgans Falls has been less than the conservation requirement.

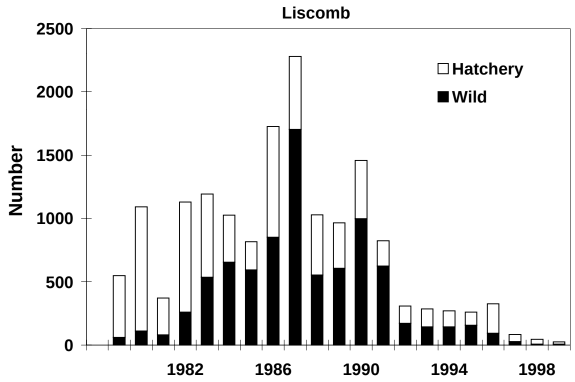


The return rate of hatchery smolts to Morgans Falls, LaHave River has declined since 1984. Return rate of 1998 hatchery smolts as 1SW fish in 1999 decreased to 0.3% from 0.9% the previous year, the lowest in the time series. Returns of 2SW hatchery salmon in 1999 (1997 smolt class) remained below 0.2%.



The status of all low-acidified rivers in the Southern Upland, which are still capable of producing wild Atlantic salmon, is expected to be similar or worse than the St. Mary's and LaHave rivers. Dissimilarities in the status of salmon stocks among rivers may be attributed to the levels of acidification and to supplementation with hatchery-produced smolts.

No conservation requirements have been developed for partially-acidified rivers such as the Liscomb. Returns to the Liscomb River fishway numbered only 25 fish in 1999. Wild salmon have almost disappeared and survival of hatchery-origin salmon has declined severely.



Some rivers can no longer support the production of salmon because of inadequate fish passage, flooding of habitat and acidification. Conservation requirements for salmon in these rivers have also not been addressed. The East River Sheet Harbour, Clyde and Jordan rivers (14% of the measured potential salmon production habitat in the Southern Upland) and Mersey River (habitat potential unknown) receive hatchery smolts for harvest fisheries.

Stock Integrity

Recent molecular genetic surveys of stocks in 10 rivers (Medway, Petite, LaHave, Mushamush, Martin's, Gold, East River St. Mary's, West River St. Mary's, Isaac's Hbr, and Country Hbr.) of the Southern Upland indicated that these stocks were significantly different from stocks of the Bay of Fundy and Newfoundland. Survey results also indicated evidence of significant population structure within each of the 10 rivers, although these conclusions may be biased by samples from a single year and an unknown number of age classes.

Possible discreteness among stocks of the Southern Upland exists in spite of the stocking of 24 of the 65 rivers with hatchery-produced smolts and juveniles since 1976. Broodstocks were from Southern Upland rivers but only four of the 24 rivers stocked received hatchery products solely of native origin.

Currently, approximately 300,000 smolts and about an equal number of fall parr are released in Southern Upland rivers. Stocked fish contribute to 25-100% of adult returns, depending upon the level of stocking and the capacity of the river to naturally produce salmon.

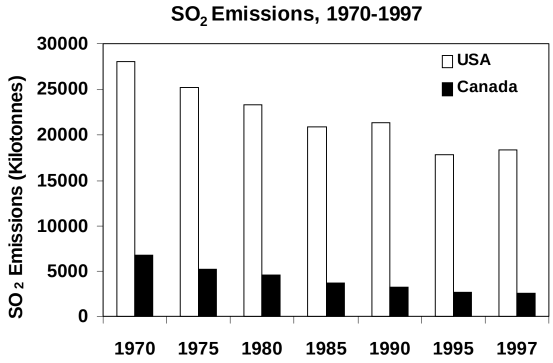
Prior to the early 1970s, hatcheries generally used broodstock from rivers distant to those in which the progeny were stocked and released early life stages in the presence of natural juvenile populations. Assessments in the late 1960s and early 1970s determined both practices to be ineffective in building populations in these rivers. This was evidenced by the low presence or absence of hatchery returns to stocked rivers, and more recently, by the genetic discreteness of remaining stocks.

Acid Rain Effects

Emissions and Deposition

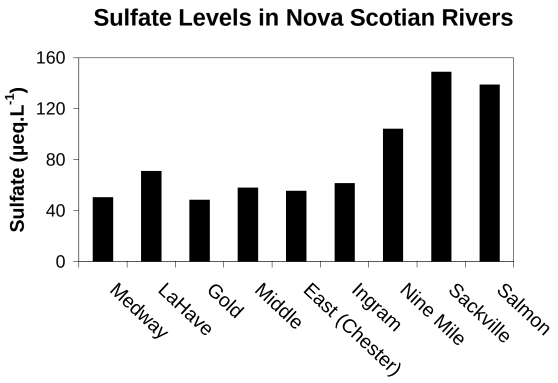
Sulfur-dioxide (SO_2) emissions (from metal smelting, coal-fired electrical utilities) and nitrous oxide (NO_x) emissions (combustion) are the principal acidifying pollutants. They are transported over long distances (hundreds or thousands of kilometers) and fall as acids in the precipitation. In Nova Scotia the principal acidifying agent in the precipitation is sulfate.

North American emissions of SO_2 increased during the industrial revolution. They peaked in the early 1970s. Reductions in emissions were implemented as a result of concerns about effects on human health and the environment.

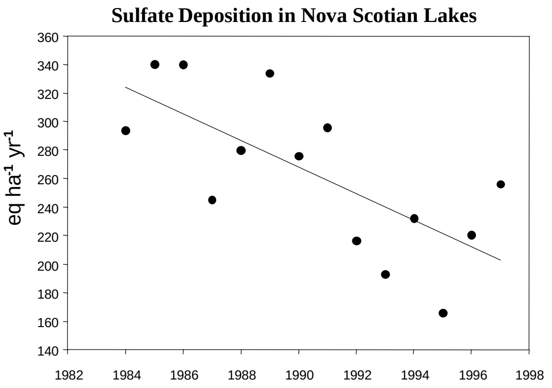


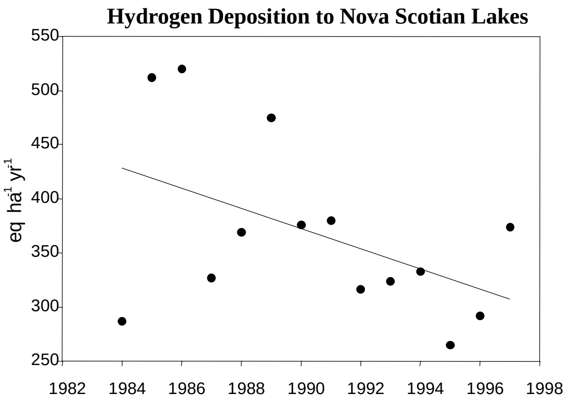
Regular measurements of deposition are made by Environment Canada at the Kejimkujik National Park monitoring station. These measurements are representative of wet sulfate deposition in relatively “clean areas” of southern Nova Scotia, i.e., at least 50 km away from important local sources of SO_2 emissions. Approximately 60% of the wet sulfate deposition at this site is from human activities in North America; the remaining 40% is background concentration. Of the 60% anthropogenic component, roughly 75% is from United States sources; 25% is from Canadian sources.

Measures of sulfate in Nova Scotian rivers show that total deposition (i.e., wet and dry) is enhanced by local sources of SO_2. For instance, the Halifax industrial area is a significant local source. This is depicted by the higher mean sulfate concentrations, 1982-1986, in the Nine Mile, Sackville and Salmon rivers that are adjacent to the Halifax metropolitan area.



The reduction in emissions is correspondingly reflected in both wet sulfate depositions and hydrogen ion concentrations monitored at the Kejimkujik National Park monitoring station. Anthropogenic sulfate deposition has decreased about one third since the mid-1980s. This has caused a large decrease in the deposition of acidifying substances to the Nova Scotia environment.





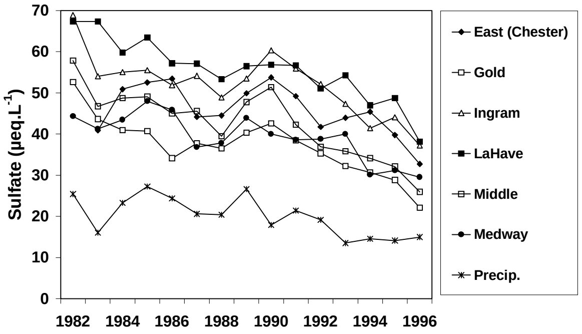
The decrease in sulfate deposition has also caused a clear, measurable decrease in lake sulfate. Of the 64 Nova Scotian lakes distributed throughout the mainland and Cape Breton Island in Environment Canada's monitoring network, 54 show measurable decreases in sulfate over the present decade. Unfortunately the reduction in atmospheric hydrogen (H^+) deposition has not resulted in a substantial decrease in lake acidity, as only two of the lakes have shown reductions in acidity. Furthermore, reduction in acid deposition is not reflected in the acid neutralization capacity (ANC), as six sites show a worsening, and only three sites show improvement. Moreover, 15 lakes show a decrease in acid neutralizing base cation (C_b) concentrations. Calcium, a major component of (C_b), is an important element in salmon survival.

Changes in acidification variables, 1989-1997

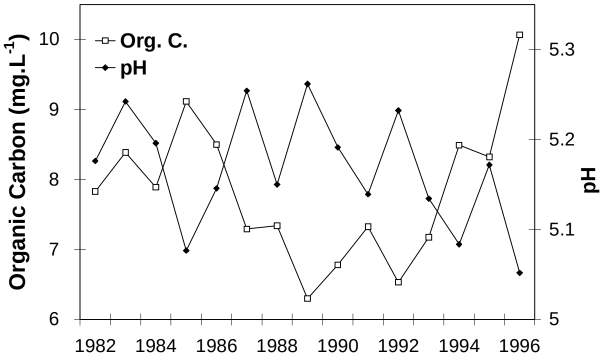
Variables	Up	Down	No change
SO_4^{-2}	0	54	10
H^+	9	2	53
ANC	3	6	55
C_b	1	15	48

Chemistry data from a monitoring program in six Southern Upland rivers from 1982-1996 also show a decline in sulfate. This decline in sulfate did not result in increased pH, but instead pH declined from 1992-1996. A significant negative correlation between pH and dissolved organic carbon is interpreted as being indicative of a causal relationship.

Sulfate Levels



pH and Organic Carbon Levels



There are a number of possible reasons for the lack of consistency between the decline in sulfate and pH in both lake and stream chemistry. The first is the importance of natural organic acids. These are produced by wetlands and can both acidify waters and simultaneously reduce the rates of acidification from man-made acids, i.e., they are natural buffers. Because of this role, organic acids can delay the recovery of pH.

The second reason is that the basins in the Southern Upland have soils and bedrocks which have low amounts of buffering minerals. The soils in these basins have probably been depleted of readily available buffering minerals. This means that reductions in acid deposition cannot be easily reflected in improvements in ANC or in calcium, as there are little of these readily available in the exposed soils.

Toxicity Effects on Atlantic Salmon

Acidic rivers in Nova Scotia have low concentrations of Ca^{++} (≤1 mg. L^{-1}) and high concentrations of dissolved organic carbon (5-30 mg. L^{-1}) and total dissolved aluminum (100-350 µg. L^{-1}). Dissolved organic matter, which is reflected by measurements of total dissolved organic carbon (DOC), is important because of its ability to chelate or bind to ionic forms of aluminum and form organic aluminum complexes. Organic aluminum is the dominant form of aluminum in Nova Scotian rivers (mean 88%) and inorganic aluminum concentrations are usually <50 µg. L^{-1}. It is the inorganic form of aluminum which can be toxic to fish. It has been demonstrated that aluminum is not responsible for the mortality of salmon associated with the acidification of rivers in Nova Scotia. Increased H^{+} ion concentrations coupled with the low concentrations of Ca^{++} are responsible for the mortality of salmon in acidified rivers of Nova Scotia.

The primary site of ionic regulation in fish is the gill epithelium. In fresh water, the osmotic gradient results in the passive diffusion of water into the blood and of ions out of the blood. Passive losses of ions are countered by active uptake of Na^{+} and Cl^{-} from the water to maintain a balanced state. When pH of Nova Scotian rivers is ≤ 5.0, active uptake of Na^{+} and Cl^{-} is reduced and passive efflux is increased resulting in a net loss of both ions. The increased passive efflux of ions results from the displacement of Ca^{++} from binding sites on the gill epithelium by H^{+}. The loss of ions results in a shift of water from the extracellular fluids (e.g., plasma) to the intracellular fluids (e.g., white muscle cells) causing a reduction in blood volume. In addition, red blood cells swell and additional cells are released from the spleen. The reduced blood volume and increased number and size of the red blood cells causes a doubling of blood viscosity and arterial pressure, and death is a result of failure of the circulatory system.

Mortality due to exposure to low pH in fresh water varies with the life stage of salmon. All freshwater stages are unaffected when pH ≥5.4. Significant mortality (19-71%) of fry occurs at a pH of about 5.0. Mortality of smolts also occurs at a pH of 5.0 but the rate is lower (1-5%). Mortality of parr and smolts is relatively great (72-100%) when pH declines to the 4.6-4.7 range. Mortality of eggs and alevins does not begin until pH declines below 4.8. Levels of pH ≤5.0 have also been shown to interfere with the smolting process and seawater adaptation.

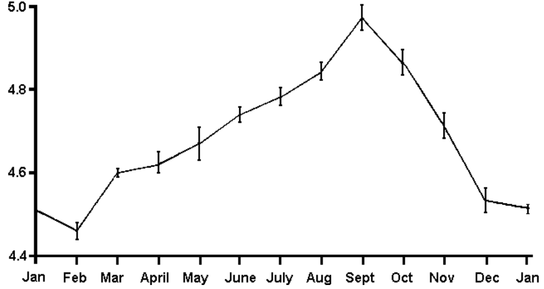
Experimental data indicate that mortality of the various Atlantic salmon life stages increases with increasing acidity of dark-colored low-calcium water found in Nova Scotia.

Stage	**pH**	**Ca^{++} (mg.L^{-1})**	**Mortality (%)**
Egg	4.64	0.67	54.5
Egg	4.92	0.85	22.2
Alevin	4.50	3.0	30.0
Alevin	5.10	3.0	2.0 – 5.0
Alevin	5.00	0.70	5.0 – 8.5
Fry	5.00	0.68	18.9 – 70.8
Fry	5.40	1.00	4.6 – 4.9
Fry	6.11	1.68	4.0
Parr	4.60	1.02	100
Parr	4.70	0.83	100
Parr	5.00	0.79	0
Smolt	4.58	0.58	72.0
Smolt	5.00	0.58	1.3 – 5.3
Smolt	5.46	1.00	0

A general interpretation of these data is that eggs are the least sensitive stage to acidity in low calcium water. Alevin and parr stages are more sensitive and smolt and fry stages are the most sensitive stages.

Regular within-year variation in river water pH exists as illustrated by the means and standard deviations from 10 years of monthly data for the main stem of the Tusket River. The pH is low in cold weather months, rises from spring to autumn, then plunges down again to low winter values. Such variation is largely related to discharge, with pH being high and corresponding acid toxicity being lowest during the summer when flows are generally reduced.

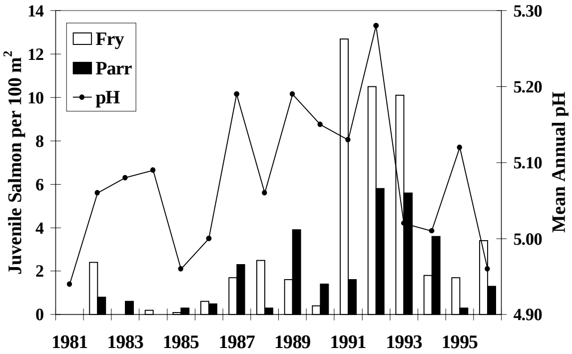
Monthly Mean pH, Tusket River, 1965-1974



Effects on Local Salmon Populations

Changing juvenile densities in five electrofishing sites within the Middle, Ingram and Salmon (L. Echo) rivers with mean pH verging on acute toxicity (pH 5.0-5.4) for Atlantic salmon, confirm a significant relationship between pH and juvenile salmon densities.

pH and Juvenile Densities



Rivers have been categorized according to their pH. At mean annual pH below 5.1 salmon production is considered unstable and only remnant populations may persist. Based on pH measurements taken during the early 1980s, 34 (54%) of the 65 rivers in the Southern Upland fall below 5.1. Fourteen of these have mean annual pH <4.7 (category 1), are considered to be acidified, and are known to have lost their salmon populations. Twenty rivers have mean annual pHs of 4.7-5.0 (category 2), are partially impacted by acidification, and some may yet have remnant populations of salmon.

Rivers with pH 5.1-5.4 (category 3) continue to have conditions in which salmon should be able to reproduce naturally but at reduced levels. These rivers generally have tributaries or sections in which pH is low enough to prevent natural reproduction. Salmon reproduction is not inhibited by acidity in rivers with mean annual pH >5.4 (category 4).

Rivers Categorized by the Mean pH observed in the early 1980s

Category 1 < 4.7	Category 2 4.7 - 5.1	Category 3 5.1 - 5.4	Category 4 > 5.4
Argyle	* Bear	Annis	Belliveau
Barrington	Cole Harbour	Chezzetcook	Boudreau
Broad	East (Chester)	Gaspereau Bk	Gegogan
Clyde	East (Sheet Hbr)	Gold	Country Hbr
Indian, Guys. Co.	East (St. Margarets)	Kirby	Ecum Secum
Jordan	*Indian (Halifax Co)	LaHave	* Meteghan
Larrys	Ingram	Medway	Indian Hbr
Nine Mile	Isaacs Harbour	Moser	Mushamush
Patterson	Liscomb	New Harbour	Musquodoboit
Pennant	Little East	Round Hill	Petite
Roseway	Martins	Sackville	Quoddy
Sable	* Mersey	Salmon (Digby)	Ship Harbour
Tidney	Middle	Salmon (Jeddore)	St. Mary's
East, Shelb. Co.	* Nictaux	Salmon (Dufferin)	
	Salmon (L. Echo)	Taylor Bay Bk	
	Salmon (L. Major)	Necum Teuch	
	* Sissiboo		
	Tangier		
	Tusket		
	West (Sheet Harbour)		
* Salmon habitat is unavailable due to impassable dams or falls.			

Most recent measurements indicate that pH toxicity in Southern Upland rivers has not improved and may even have deteriorated, particularly in certain rivers with mean annual pHs bordering 5.0 (e.g. Middle, Ingram, Salmon (L. Echo), and Liscomb).

Expectations for current population presence for 47 rivers of the Southern Upland were based on modeling of optimum use of parr habitat, pH, and marine survival. Modeling took into consideration elements of gradient-quantified stream habitat, mean annual pH, survival rates between various freshwater life stages, density dependent size, and a critical length at which parr transformed to smolts. Determinations for adult recruitment were based on projections with 5 and 10% marine survival values.

Results of the modeling exercise suggested that 55% of salmon stocks in the Southern Upland rivers are already extirpated, a further 36% are at risk of extirpation (produce less than three recruits per spawning fish), and that only 8% of the rivers are capable of sustaining salmon populations at 10% marine survival (Table 1 at end of document).

Twenty-nine of the 47 rivers had electrofishing information available since 1986. Of these, 17 had juvenile Atlantic salmon present, 12 were void of juvenile salmon. Of the remaining 38 rivers not surveyed, some continue to have self-sustaining populations of wild salmon as indicated by angling catches in the absence of stocking. Based on pH conditions, some others might also have remnant populations.

The Tusket, Middle, Ingram, Sackville, and Salmon (L. Echo) rivers, and West River Sheet Harbour were classified as extirpated by the model but yielded juvenile salmon to electrofishing. Such inconsistencies are likely the result of using main river pH in the model. Main river pH does not detect areas that may be non-toxic for salmon. For example, the Carleton River, a tributary of the Tusket River, is known to have much higher pH than the East Branch of the Tusket. Similarly, it has been documented that both West River Sheet Harbour and Salmon River (L. Echo) have tributaries with higher pH. As well the Sackville River has significant numbers of hatchery returns contributing to the spawning escapement.

Expectations based on 5% marine survival were that 85% of the 47 stocks in surveyed rivers of the Southern Upland either are or will be extirpated (Table 1). Even this expectation may be optimistic considering that wild smolt returns to the LaHave River have been less than 5% for the past three years. This analysis suggests that if low marine survival persists, additional partially-acidified rivers can be expected to lose their salmon populations.

Other Effects

Hydrological Conditions

Based on precipitation records at Halifax Airport, 1961-1998, there was no significant trend in annual rainfall, although the 1990s experienced the lowest decadal precipitation of the time series (8% lower than the long-term average). Similarly, no significant time trends were detected in mean annual discharge for the LaHave or St. Mary’s rivers over the period 1916-1998. Annual discharges in the 1990s for both rivers were however lower than those of the 1970s, but not unlike those of earlier decades. No significant time trends in seasonal means (winter, spring, summer and fall) are evident for either river. Low flow events have been more frequent in the 1990s, but were less severe than in the past, especially for the LaHave River.

Air temperatures at Halifax Airport, 1961-1998, were analysed as a proxy for Southern Upland water temperatures. No trend was detected in the mean annual air temperature. However, on a seasonal basis, significant positive linear trends were detected in the spring ($p<0.005$) and summer ($p<0.04$). Increases in spring mean air temperatures were 0.4°C per decade; summer air temperatures increased 0.2 °C per decade.

Hydrological conditions do not appear to have deteriorated significantly and hence are unlikely to be a major factor in the current decline in salmon returns to Southern Upland rivers. More low flow events and warmer spring and summer temperatures during the 1990s should not, however, be ignored as contributors of added stress to the area’s wild salmon.

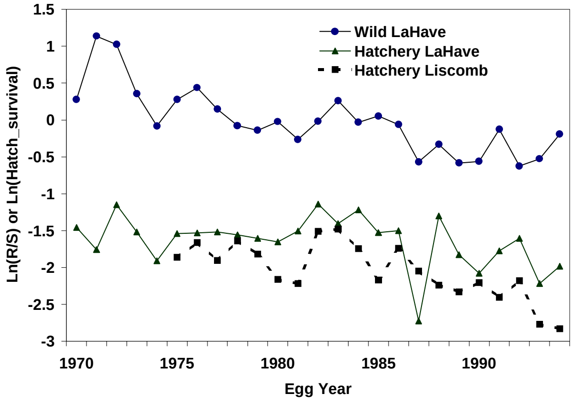
Marine Survival

Declining survival of smolts in the marine environment has been suggested as an explanation for the general decline in recruitment of North American salmon. Wild smolt survival rates in excess of 10% were recorded for the LaHave River during the late 1950s, but are now less than 5%.

Despite almost complete closure of distant interceptory and local marine salmon fisheries, survival of wild smolts throughout North America has declined. Since 1987 survival declined from a range of 6-15% for Newfoundland rivers and an estimated 8-10% for Maritime rivers, to a range of 1-8% for both areas.

The decline in recruitment of wild salmon is paralleled by the decline in marine survival of hatchery smolts. This is evident in plots of natural log (Ln) recruits per spawner (R/S) for wild Atlantic salmon above Morgans Falls, 1970 to 1994. The Ln (proportion survival) of hatchery smolts stocked above Morgans Falls on the LaHave River and Liscomb River, 1975 to 1994, shows a similar trend to the wild salmon recruitment index.

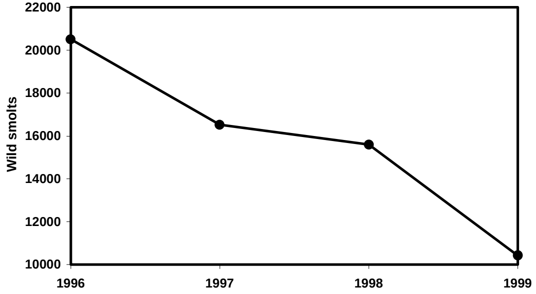
Survival trends – hatchery and wild



Freshwater Survival

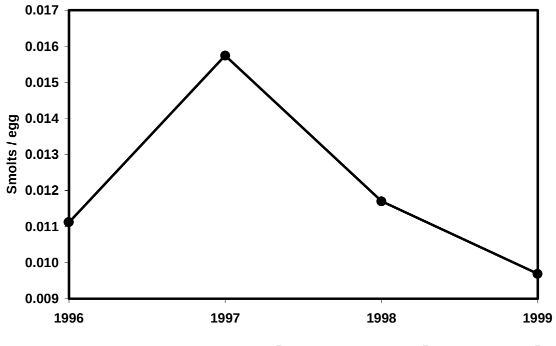
The decline in spawning escapement has been followed by a decline in the production of smolts from above Morgans Falls, LaHave River. A similar decline in smolt production is assumed to be occurring in all rivers that are still producing salmon in the Southern Upland.

Smolts Above Morgans Falls



Egg-to-smolt survival of 1.0-1.6%, above Morgans Falls in the 1990s is within the range of values [albeit lower end] reported between 1962 and 1998 for rivers in Maine, Atlantic Canada and Ireland. This suggests that the decline in smolt production is not the result of a decline in survival of eggs to smolts.

Smolts per Egg Above Morgans Falls



Because egg-to-smolt survival in the LaHave River, a low-acidified river, is consistent with values from outside the Southern Upland, it is unlikely that factors other than acid rain and marine survival have had major effects on recent reductions in Southern Upland salmon production.

Prognosis for Recovery

Habitat

No significant reduction in acidification of rivers in the Southern Upland is anticipated in the near future. Recovery of water acidity, as well as calcium, will be slow as deposition is reduced. In many rivers slow recovery is expected because of the effect that natural organic acids have in buffering changes in acidity and because of the low levels of buffering minerals in the soils and bedrock. Return to pre-acidification pH will be dependent upon further significant reductions in emissions and is expected to take several decades.

Salmon Production

Low- or non-acidified rivers (pH>5.1)

Analysis based on modeling of optimum use of parr habitat, pH and marine survival indicates that persistence of salmon in the Southern Upland rivers will be as dependent on the trend of marine survival as it is on pH. Smolt production above Morgans Falls, 1996-1999, averaged 15.1 smolts per spawner (range: 9.0-17.8). A production of 17.8 smolts per spawner requires a 5.6% smolt-to-adult survival rate for replacement of the population. Higher survival is required for a population increase.

The measured smolt to recruit survival at Morgan Falls was 1.7% for the 1996 smolt class and 4.8% for the 1997 smolt class. Both of these values are below the population replacement point for the LaHave River. Based on this index, low- or non-acidified rivers similar to the LaHave River with productivity less than 20 smolts per spawning salmon are likely to be subject to population declines. Most and possibly all rivers of the Southern Upland are below this productivity level. However, analysis also indicated that such rivers, numbering perhaps seven, are not likely to lose their population of salmon completely.

Partially-acidified rivers (pH 4.7-5.1)

The loss in productivity associated with pH toxicity effects in partially-acidified rivers has increased their vulnerability to population extirpation. Analyses indicate that wild salmon production will be lost from most or all 21 rivers in this category if marine survival remains below 6% and/or pH does not improve. One exception to this may be the Tusket River because of its Carleton River tributary which is generally not acidic.

Acidified rivers (pH<4.7)

Rivers in this category are not expected to support Atlantic salmon production until significant improvements in pH are realized.

Management Options

Reduced Emissions

The "Canada-Wide Acid Rain Strategy for Post-2000" was approved in October 1998, by 26 federal, provincial and territorial ministers of environment and of energy. Commitments in the Strategy will result in reduced sulfate deposition in Nova Scotia. These include aggressive pursuit of SO_2 emissions reductions in key areas of the USA and establishment of targets and schedules for further SO_2 emission reductions in Ontario, Quebec, New Brunswick and Nova Scotia.

Analyses of the effectiveness of Canadian and American SO_2 control programs was reported in the "1990 Canadian Long-Range Transport of Air Pollutants and Acid Deposition Assessment Report". Major improvements were predicted in lake chemistry and biota for Ontario and Quebec; little improvement was predicted in aquatic conditions in the sensitive areas of New Brunswick, Nova Scotia and southern Newfoundland. The 1990 assessment produced the first map of critical load values for wet sulfate deposition, designed to maintain at least 95% of lakes in the region at pH ≥6.0.

An assessment in 1997 concluded that present control programs do not go far enough to protect many sensitive ecosystems, especially in eastern Canada (i.e., Manitoba eastward). Even with full implementation of the USA program by 2010, sensitive ecosystems in almost 800,000 km^2 in southeastern Canada will continue to receive harmful levels of acid deposition, i.e., above the environmental threshold or "critical loads". A further 75% reduction in SO_2 emissions from southeastern Canada and the northeast and mid-west USA will be required to reduce depositions to below critical loads for wet sulfate and to achieve fish habitat recovery.

Eastern Canadian Provinces and New England Governors adopted a workplan in June 1998 that called for further national emissions reductions of 50% of sulfur dioxide and 20-30% of nitrogen oxides beyond current commitments. Québec has already committed, as a first step, to reducing its emissions to 40% below its current SO_2 cap by the year 2002.

<u>Liming Acidified Waters</u>

Freshwater habitat can be protected from acidification by adding alkaline substances to the water. The usual neutralising substance is limestone, which consists mostly of calcium carbonate (calcite), and magnesium carbonate (dolomite) with some impurities. Other compounds are available but are less economical and, sometimes, dangerous to health. Effective treatment requires a release of lime proportional to the discharge and acidity of the water that is to be neutralised. Usually, lime has been spread onto the surface of a lake or introduced into a stream from stationary "lime dosers" of various patterns.

Many neutralising substances are compounds of calcium and so liming of waters will also increase their calcium concentrations. Calcium increases the acid tolerance of fish and so liming of acid waters with calcium compounds may confer an additional benefit apart from any effects liming may have on the water's pH. Concentrations of dissolved metals usually fall after the pH has been adjusted by liming. Potential liming compounds differ in theoretical neutralising capacities, solubility in water, ease and safety of handling and cost.

All liming projects in Nova Scotia require a Stream Alteration Permit from the Nova Scotia Department of the Environment. Liming projects that are carried out or funded by the Federal Government are also subject to the Canadian Environmental Assessment Act.

Lake liming

Lakes can be limed to protect salmon habitat in the rivers downstream. Methods of application must be adapted to site and specific conditions. A portion (40-70%) of the limestone settles on the bottom and takes little part in the neutralisation of the lake. Particle size controls the dissolution efficiency and the lime used for lake liming should be the most finely ground available to maximize dissolution. Slurrying the lime before spreading also reduces losses to the sediments.

Winter temperature stratification in lakes can reduce the effectiveness of lake liming. Acid surface runoff enters the lake at 0°C in the winter and forms a shallow layer of highly acidic water at the lake surface. The limed water underlying this surface layer contributes little to the lake's discharge and the water that leaves the lake's outlet may be almost unaltered acid rain. Liming the ice in the winter can overcome this problem. Although winter liming is less efficient in the use of limestone, it is relatively cheap in other respects and treats the lake surface just before the spring runoff and fry swim up. Liming must be repeated at least annually in most Nova Scotia lakes owing to their short water retention times.

Limestone gravel bars

Limestone gravel in streams is effective at low flows but the effect falls markedly at higher flows. The mean pH of interstitial water in the limestone bars is higher than in the water column. This can reduce acidity-related mortalities during incubation and early fry stages but not after the fry swim up from the gravel. Limestone gravel loses effectiveness as the gravel is coated with hydroxide compounds. As well there may be erosion of the gravel from the bar over time. Large quantities of limestone gravel are required to prevent severe acidic episodes during periods of high flow and low temperature.

Revolving drums

Tumbling the limestone gravel in rotating cylinders abrades the gravel, and prevents coating and inactivation. A system has been tested that uses water power to rotate a metal drum that contains limestone gravel. Limestone aggregate is placed into a perforated metal cylinder that turns about the hub. This system does not need an external source of electrical power but there must be a hydraulic head equal to at least the diameter of the drum. Variations in flow can be compensated for by installing multiple drums that begin turning in succession as the flow increases.

Lime dosers (silos)

Lime dosers dispense powdered lime into running water from a vertical silo or other container. An automatic mechanism feeds the powder into the river at a controlled rate proportional to the flow.

Diversion wells

The diversion well is a simple liming device in which limestone chips are kept in motion in a cylinder by upwelling water. The agitation abrades the particles and prevents their surfaces from becoming coated with metal hydroxides. Multiple wells that operate at successively higher flows can compensate for variations in flow.

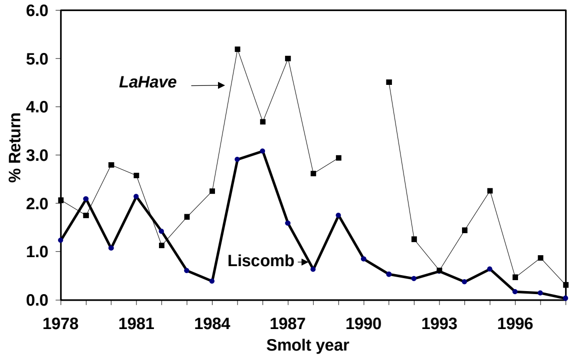
Hatchery Support

Hatchery-reared salmon can be used effectively to supplement or replace natural production. Options range from colonization of vacant habitat, mitigation for loss in habitat production at a specific stage to smolt stocking for support of fisheries.

Like natural production, the application of hatchery stocking is limited by acidification. The smolt stage is potentially the most effective stage because of the short time spent in fresh water after stocking. The stocking of pre-smolts in waters with pH <5.0 is generally not effective.

Of recent concern is the exceptionally low return rate experienced by smolts released into partially-acidified rivers, e.g., Liscomb, East River Sheet Harbour. Return rates for smolts released in these rivers also appear to have declined more so than for smolts stocked in low acid-impacted rivers like the LaHave. Determination of the cause for the recent poor performance of hatchery smolts in partially acidified rivers is imperative if hatchery stocking is to be effective in these types of rivers in the future.

Hatchery 1SW Return Rates



Stocking headwater sections of rivers that have good pH conditions may not be effective if the resulting smolts are required to exit the river through a long mainstem corridor that is acidified. Alternatively, stocking low down in the system or in the estuary would reduce these effects, but the extent that returns penetrate the river may be reduced and the chance of returns straying to nearby rivers increased.

Where the stocking option is chosen, careful planning of the program is required to minimize the risks of harmful genetic effects on the wild stocks and to ensure effectiveness. The use of native stock is advocated.

Gene Banks

Gene banks offer supportive rearing and breeding to maintain increased genetic diversity of a species through periods of critically low population abundance, i.e., they offer the potential to preserve stocks which are at risk of being lost. There are at least three options for live gene banking, all of which could have application to Southern Upland salmon:

- Designate parts of rivers or entire rivers that still have natural reproducing populations as special refuges;
- Lime sections of acidified rivers to establish areas within rivers where remnant stocks could sustain themselves; and
- Establish captive broodstocks derived from the stock designated for protection.

Designation of existing habitat areas is the preferred option but will not always be feasible because residual salmon runs are too small and/or the freshwater habitat is limiting, possibly because of acidification. The use of wild parr to establish a captive broodstock is a proven method and probably offers greater potential for ensuring wide genetic diversity than eggs collected from adult salmon returns.

Harvest Controls

Fishery restrictions continue to be an effective means to limiting losses to exploitation.

Currently there are few or no opportunities to fish Atlantic salmon in the Southern Upland. Commercial salmon fisheries have been closed since 1984. Retention of incidental catches of salmon in other local marine fisheries has not been permitted since 1983. The recreational fishery has required mandatory release of salmon greater than 63 cm since 1985 and is restricted by season, daily and annual limits. Retention of grilse (≤63 cm) has been further restricted to specific enhancement rivers receiving hatchery stocking and to rivers where returns were expected to meet or exceed conservation requirements. Recreational hook-and-release fisheries have been closed when in-season assessments indicated that conservation requirements were unlikely to be achieved.

Aboriginal fisheries are negotiated with First Nations for specific rivers and through general harvest management agreements with the Netukulimkewe'l Commission of the Native Council of Nova Scotia. In rivers with defined conservation requirements, Aboriginal fisheries have been subject to in-season assessments and management. Harvests have always been less than allocations.

Recommendations

Priority should be given to support Canada's position to negotiate a further 75% reduction in sulfate emission limits in eastern Canada and the United States to facilitate recovery of Southern Upland salmon.

Locally urgent is the requirement to develop a recovery plan for Southern Upland salmon both to prevent further loss of stocks and to hasten their recovery. Some of the main elements to be considered in that plan are:

- a survey to genetically characterize stocks and to confirm stock status.
- a water chemistry survey to confirm habitat production capacity;
- further research on the application of liming techniques and stocking practices as mitigative measures, and of pH mortality thresholds for salmon life stages; and
- management actions that prevent further extirpation of stocks and effect stock restoration.

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This report is available from the:

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Table 1. Salmon rearing area, pH category, stocking history since 1986, recorded salmon catch in 1996, detected presence or absence of salmon since 1986, and prognosis of the status at 10% and 5% marine survival for rivers that drain the Southern Upland of Nova Scotia. pH categories are: 1 – pH < 4.7; 2 - pH 4.7-5.1; 3 - pH 5.1-5.4; and 4 - pH >5.4.

River number	River name	Salmon rearing area 100 m^2 units	pH category	Stocking history	Recreational catch, 1996		Presence of salmon since 1986	Prognosis	
					Small	Large		at 10% marine survival	at 5% marine survival
1	Nictaux		2	Native					
2	Round Hill		3	None					
3	Bear		2	Local					
4	Sissibo		2	None					
5	Beliveau		4	None					
6	Boudreau		4	None					
7	Meteghan		4	Local	12	5			
8	Salmon (Digby)	9,797	3	Local	94	44	Present	At risk	Extirpated
9	Annis		3	None					
10	Tusket	150,780	2	Local	133	55	Present	Extirpated	Extirpated
11	Argyle		1	None					
12	Barrington	8,877	1	None			Absent	Extirpated	Extirpated
13	Clyde	55,348	1	Local	46	14		Extirpated	Extirpated
14	Roseway	33,012	1	None			Absent	Extirpated	Extirpated
15	Jordan	29,206	1	Local	0	0	Absent	Extirpated	Extirpated
16	East		1	None					
17	Sable	9,198	1	None				Extirpated	Extirpated
18	Tidney		1	None					
19	Mersey		2	Local	5	0			
20	Medway	99,174	3	Local	490	88	Present	At risk	Extirpated
21	Petite	7,174	4	Local	126	16	Present	At risk	Extirpated
22	Lahave	75,046	3	Local	1,514	327	Present	At risk	At risk
23	Mushamush	2,743	4	Local	20	2		Sustained	At risk
24	Martins	8,334	2	Local				Extirpated	Extirpated
25	Gold	21,962	3	Native	188	71	Present	At risk	Extirpated
26	Middle	12,290	2	Local	14	0	Present	Extirpated	Extirpated
27	East (Chester)	4,598	2	None	1	2	Absent	Extirpated	Extirpated
28	Little East		2	None					
29	Ingram	5,701	2	Local	7	0	Present	Extirpated	Extirpated
30	Indian		2	None					
31	East		2	None					
32	Nine Mile	5,569	1	None				Extirpated	Extirpated
33	Pennent		1	None					
34	Sackville	6,772	3	Local	140	14	Present	Extirpated	Extirpated
35	Salmon (L Major)	750	2	None				Extirpated	Extirpated
36	Salmon (L. Echo)	7,493	2	None			Present	Extirpated	Extirpated
37	West Bk Porters	1,185		None				Extirpated	Extirpated
38	East Bk Porters	2,394		None				Extirpated	Extirpated
39	Chezzetcook	1,757	3	None				At risk	Extirpated
40	Musquodoboit	23,125	4	Native	209	116	Present	Sustained	At risk
41	Salmon (Hfx)	2,834	2	None				At risk	Extirpated
42	Ship Harbour	20,518	4	None	1	0		At risk	At risk
43	Tangier	22,717	2	Local			Absent	Extirpated	Extirpated
44	E Taylor Bay	260	3	None				Extirpated	Extirpated
45	W Taylor Bay	1,300	3	None			Absent	Extirpated	Extirpated
46	Little West	4,087		None					
47	West (Sh Hbr)	20,079	2	Local	20	1	Present	Extirpated	Extirpated
48	East (Sh Hbr)	30,501	2	Local	34	0	Present	At risk	Extirpated
49	Kirby	1,604	3	None				At risk	Extirpated
50	Salmon (P.D.)	7,954	3	None			Present	At risk	Extirpated

Table 1 (continued). Salmon rearing area, pH category, stocking history since 1986, recorded salmon catch in 1996, detected presence or absence of salmon since 1986, and prognosis of the status at 10% and 5% marine survival for rivers that drain the Southern Upland of Nova Scotia. pH categories are: 1 – pH < 4.7; 2 - pH 4.7-5.1; 3 - pH 5.1-5.4; and 4 - pH >5.4.

River number	River name	Salmon rearing area 100 m^2 units	pH category	Stocking history	Recreational catch, 1996		Presence of salmon since 1986	Prognosis	
					Small	Large		at 10% marine survival	at 5% marine survival
51	Quoddy	6,849	4	None				At risk	Extirpated
52	Moser	15,270	3	Local	35	0	Absent	At risk	Extirpated
53	Smith	1,055		None				At risk	At risk
54	Ecum Secum	9,894	4	None	27	5	Present	At risk	Extirpated
55	Liscomb	34,960	2	Local	1	0	Absent	Extirpated	Extirpated
56	Gaspereau Bk	2,826	3	None			Absent	At risk	Extirpated
57	Gegogan	382	4	None			Absent	At risk	Extirpated
58	St Marys	58,717	4	Native	596	177	Present	Sustained	At risk
59	Indian Harbour Lakes		4	None					
60	Indian	9,743	1	None	4	4		Extirpated	Extirpated
61	Country Harbour	3,457	4	None	4	5	Present	Sustained	At risk
62	Issacs Harbour	2,469	2	None	0	0	Absent	Extirpated	Extirpated
63	New Harbour	3,148	3	None	1	0	Absent	Extirpated	Extirpated
64	Larrys	2,632	1	None			Absent	Extirpated	Extirpated
65	Cole Harbour	2,730	2	None	0	0		Extirpated	Extirpated