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An Assessment of the possible impact of salmon aquaculture on Inner Bay of Fundy Atlantic salmon stocks

By

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Abstract

The uniqueness and status of inner Bay of Fundy Atlantic salmon (*Salmo salar*) is reviewed. Possible explanations for historic and recent low recruitment are postulated. Concurrent with the most recent and perhaps most severe decline is the developing salmon farming industry in the southern Bay of Fundy. Past tag recovery of inner Bay of Fundy origin smolts place their marine distribution coincident with the salmon farming industry in the western Bay of Fundy. Mechanisms for possible direct negative impact of salmon aquaculture on wild inner Bay of Fundy salmon are examined and logistically assessed. Three possible mechanisms could not be rejected: 1) predator attraction induced by salmon escapes from aquaculture preying on both wild and escapes; 2) disease; and 3) ecological change, either dependant or independant of aquaculture. Salmon stocks of the inner Bay of Fundy are critically low and opportunities for actions to prevent their extirpation are diminishing.

Résumé

Le caractère unique et l'état du saumon de l'Atlantique (*Salmo salar*) de la baie de Fundy font l'objet d'un examen. Des hypothèses sont présentées relativement au faible recrutement actuel et antérieur. Le déclin le plus récent et peut-être le plus important apparaît en même temps que le développement de l'industrie salmonicole dans le sud de la baie de Fundy. La récupération d'étiquettes de saumoneaux ayant pour origine le fond de la baie de Fundy montre que leur dispersion marine coïncide avec l'arrivée de la salmoniculture dans la partie ouest de la baie. Des mécanismes d'incidences nuisibles directes de la salmoniculture sur le saumon sauvage du fond de la baie de Fundy font l'objet d'un examen et d'une évaluation logistique. Trois mécanismes n'ont pu être réfutés : 1) l'arrivée de prédateurs attirés par les saumons d'élevage échappés et qui se nourrissent de saumons d'élevage et sauvages ; 2) des maladies et 3) un changement écologique dépendant ou non de l'aquaculture. Les stocks de saumon de la baie de Fundy sont extrêmement appauvris et les possibilités d'intervention en vue de prévenir leur déracinement sont de plus en plus faibles.

Introduction

The inner Bay of Fundy wild Atlantic salmon stock occupies about 30 rivers in New Brunswick and Nova Scotia (Figure 1). Two rivers, the Annapolis River and the Gaspereau River, have stocks of salmon that are more typical of Atlantic coast rivers rather than inner Bay of Fundy rivers and not included in this analysis.

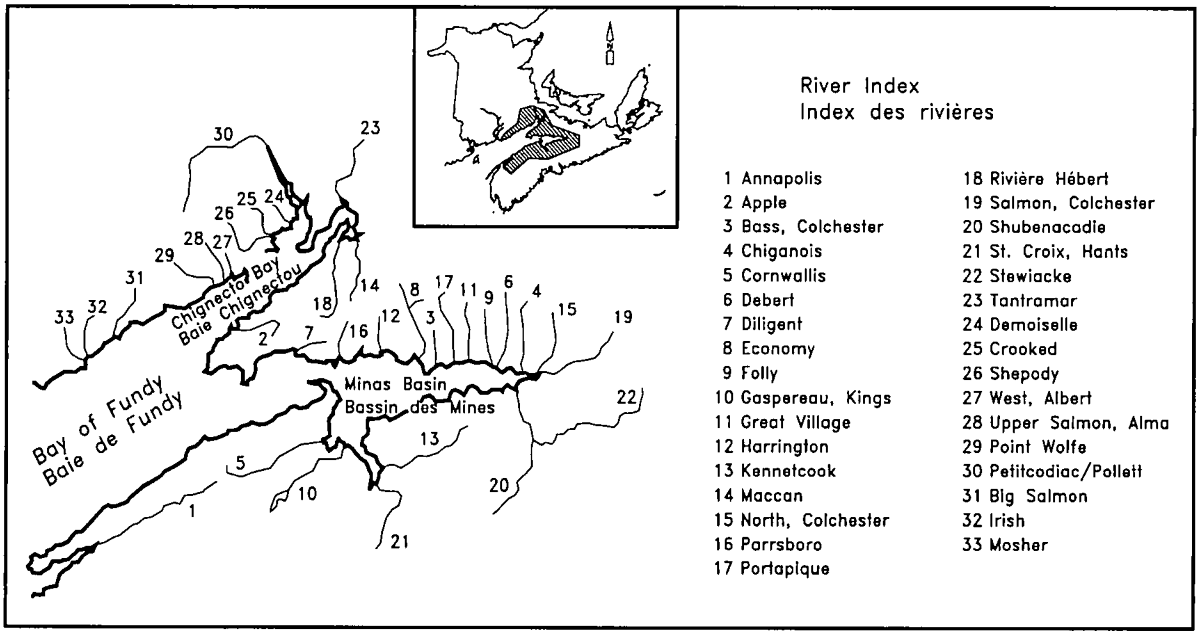

Figure 1 Map of the known salmon rivers of the inner Bay of Fundy, Nova Scotia and New Brunswick.

The Stewiacke River, the principal salmon producing tributary of the Shubenacadie River in Nova Scotia and the Big Salmon River in New Brunswick are the two largest stocks of inner Bay of Fundy salmon (Figure 2).

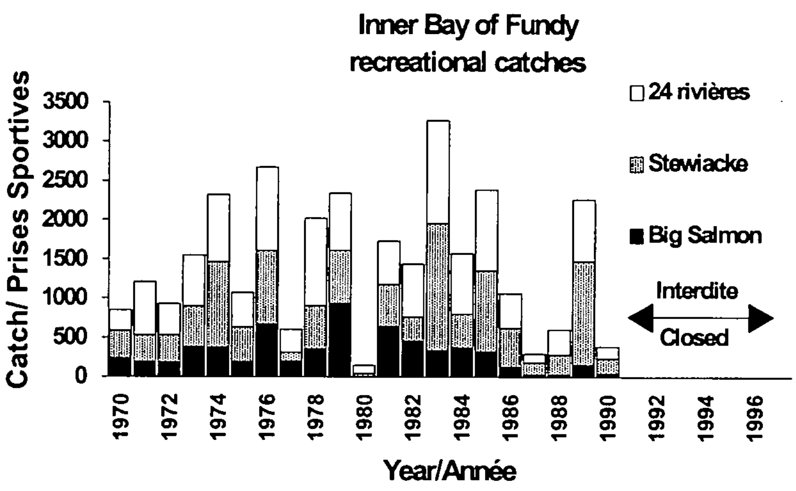

Figure 2. Historic recreational catches from the Stewiacke, Big Salmon and twenty-six other inner Bay of Fundy rivers, 1970 - 1997.

Inner Bay of Fundy salmon stocks are characterized by the high proportion that mature after one winter at sea (grilse), high survival between consecutive years of spawning (most salmon) and the occurrence of post-smolts in the fall of their smolt migration year in the Passamaquoddy Bay - Grand Manan Island areas (Ducharm 1969, Jessop 1976 and 1986, Amiro MS1987 and MS1990). Another important feature of these stocks of salmon is their dependency on the repeat-spawning salmon component for consistent replacement of the population from one generation to the next (Amiro and McNeill MS1986, Amiro MS1987).

Dr. A. G. Huntsman (1958) wrote of the 1951 apparent demise of the Shubenacadie River Atlantic salmon fishery. However, by the 1970s salmon returns had rebounded. Combining the information of A.G. Huntsman (1931, 1958), P.F. Elson (1957,1962) and R.W. Dunfield (1986) this boom and bust pattern has played out at least four times since 1874 and is shown in the commercial salmon catches from Albert and Westmoreland Counties, New Brunswick from 1875 to 1984 (Fig. 3). The irregularity of catches and returns for this salmon stock has been the centre of much concern dating from as far back as 'a generation' before 1881 when Perley (cited in Elson 1962) wrote of the great numbers of salmon and of their eventual depletion. A decline he attributed to over-fishing. Venning (1870, cited in Huntsman 1958) wrote of new conservation efforts and by 1888 the catches had increased but by 1950 catches had once again declined.

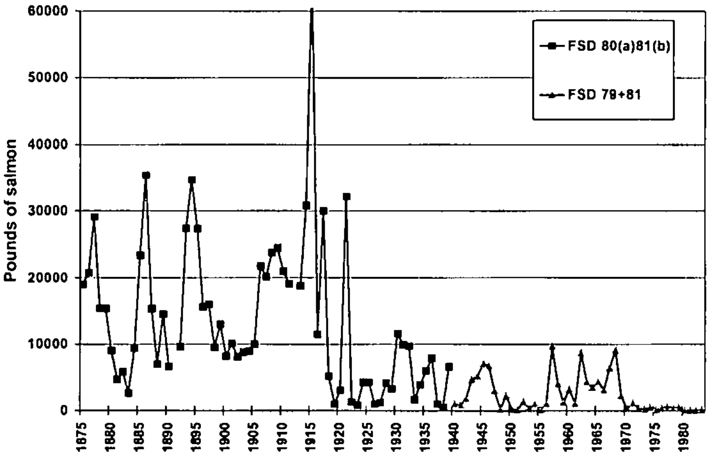

Figure 3. Commercial Atlantic salmon catches (pounds) from Fishery Statistical Districts 80(a) and (b), 1875 to 1940, and FSD 79 and 81, 1941 to 1984, (Albert and Westmorland Counties, New Brunswick. (R.W. Dunfield pers.comm.)

The asynchrony of inner Bay of Fundy salmon catches with Atlantic coast salmon catches was observed and reported by Huntsman (1958). Asynchrony between these two salmon producing areas (Figure 4) continued up to 1989 (Amiro MS1990). Catches or returns, after 1989, of both inner Bay of Fundy and Atlantic coast salmon stocks have declined and both populations are presently at low abundance. The correlation coefficient between the standardized catches for 1875 to 1985 ($r = 0.024$) is not significant ($p = 0.11$).

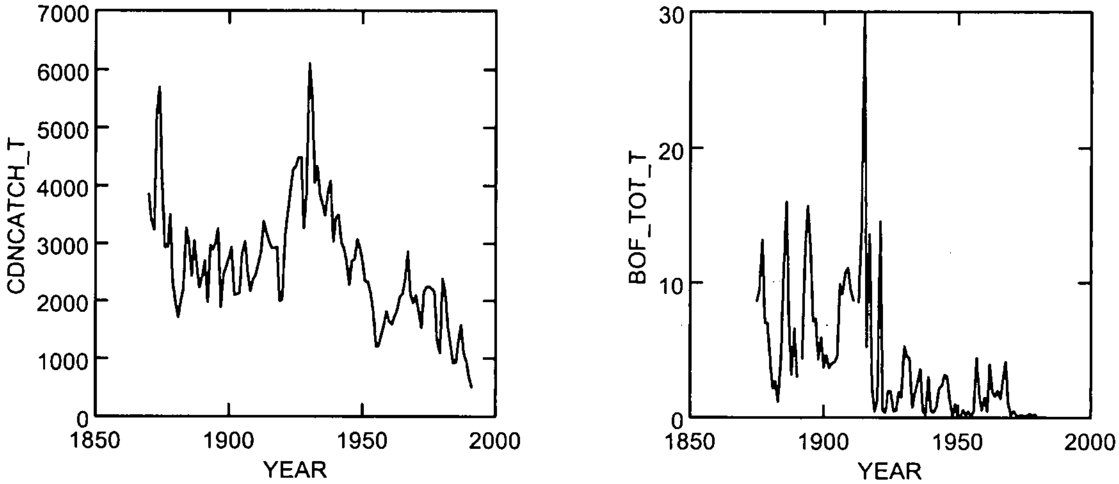

Figure 4. Canadian commercial catch (tonnes) of Atlantic salmon 1870 - 1991 and inner Bay of Fundy commercial catch (tonnes) 1875 - 1984.

Causes for the periodic scarcity of Atlantic salmon of the inner Bay of Fundy have been attributed to many factors. Annual variation and implied periodic low river discharges were thought to affect the distribution of the commercial catch on the north shore of the Bay of Fundy (Huntsman 1958). A reader may assume that over-harvesting resulted and that poor escapements and subsequent low recruitment were implied. Unfavorable water conditions for specific escapement years have also been suggested as a factor in variable recruitment (Huntsman 1958).

Precipitation in the summer previous to smoltification, affecting the survival of smolts and therefore recruits to the Stewiacke River, was shown to account for a significant portion of the variation in survival. This precipitation model was used to forecast returns to the Stewiacke River (Amiro and McNeill MS1986, Amiro MS1987, Marshall *et al.* MS1988, Amiro *et al.* MS1989, O'Neil *et al.* 1989). Forecasts of returns to inner Bay of Fundy salmon rivers stopped in 1990 because returns and catches continued to decline and the forecast models lost statistically significant predictive power (Amiro MS1990).

The 9.6-year cycle of Atlantic salmon abundance postulated by Huntsman (1931) was derived by qualitative interpretation from Atlantic coast and Gulf of St. Lawrence salmon stocks. Asynchrony between Atlantic coast and inner Bay of Fundy infers that a 9.6 year cycle for Atlantic coast and Gulf of St. Lawrence salmon catches would not necessarily apply to inner Bay of Fundy salmon.

Quantitative time-series analysis of the total Canadian catch of salmon from 1870 to 1991 showed no quantitatively significant, nine or ten year cyclic pattern in the catches (Figure 5). Autocorrelation in the differenced time series (catch at year_i - catch at year_{i+1}) was significant and negative for the second order lag only. Therefore, a high catch was most often followed by a low catch two years later. No higher order lags were significant.

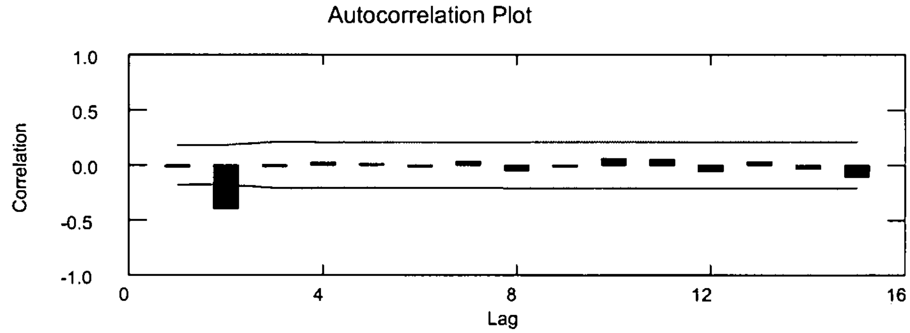

Figure 5. Autocorrelation of lags 1 to 15 of differenced, $year_i$ - $year_{i+1}$, Canadian Atlantic salmon commercial catches, 1870 to 1991.

The same analysis performed on inner Bay of Fundy commercial salmon catches shows that a good year was more often followed by a poor year of catches and that no significant long term periodicity to catches is definable (Figure 6).

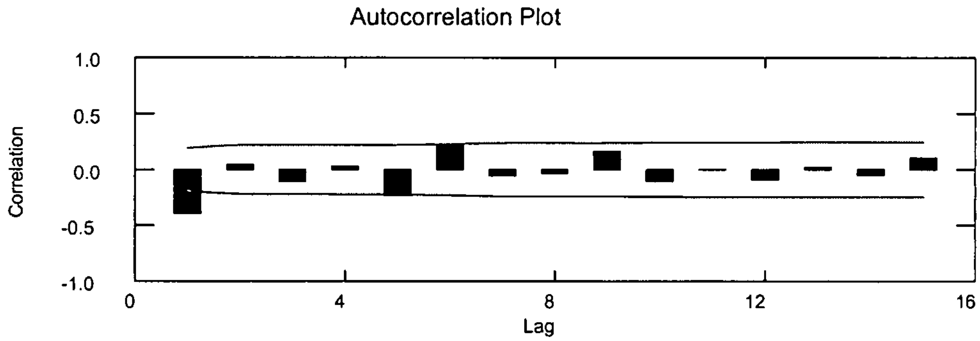

Figure 6. Autocorrelation of lags 1 to 15 of differenced, $year_i$ - $year_{i+1}$, Atlantic salmon catches from inner Bay of Fundy, 1870 to 1991.

These analyses question the conclusion that there is a predictable cycle of abundance for Atlantic salmon. Using these standard time series analysis techniques, a cycle for inner Bay of Fundy was not defined. This result may be due to the fact there is no underlying definable cycle in inner Bay of Fundy salmon abundance or because catch data is not precise enough to detect a cycle. There are no long time series of salmon recruitment rates for inner Bay of Fundy salmon. To date, no statistically significant explanation for the periodic scarcity of inner Bay of Fundy salmon has been shown, although, some hypotheses remain undeniable because of the lack of data to test every hypothesis.

The purpose of this document is to review the status of the inner Bay of Fundy Atlantic salmon, historically and relative to conservation, review the evidence of marine distribution of post-smolts of inner Bay of Fundy stock origin and review some of the remaining viable hypotheses concerning the recent decline of the inner Bay of Fundy salmon stock.

Results

Stock status

Angling catches from inner Bay of Fundy rivers, 1970 to 1990, (Figure 2) have averaged 1,462 salmon (≥63.0 cm) and grilse (<63.0 cm) and ranged from a high of 3,263 fish in 1983 to a low of 144 fish in 1980. The Stewiacke and Big Salmon rivers averaged 58% of the total inner Bay of Fundy recreational catch of salmon. Angling fisheries have been subject to in-season reviews since 1989. In-season reviews were based on estimates of early (before September) returns to the Big Salmon River. No fisheries have opened since 1990 and escapements (fish surviving to spawn) to ten monitored inner Bay of Fundy rivers have been below those required to meet conservation.

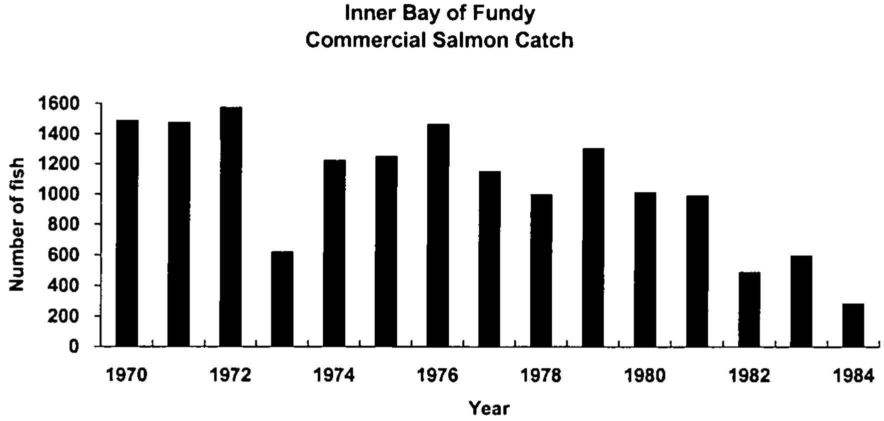

Figure 7. Recorded catch from the inner Bay of Fundy commercial salmon fishery 1970 - 1984.

Commercial fisheries for salmon (Figures 3,4,7) were reduced by the 1983 zero by-catch (fish caught while fishing other species) regulation and by the 1984 Salmon Management Plan of shortened seasons and license buy-backs and by closures of all directed fisheries for salmon in local waters in 1985.

There are no First Nation fishing agreements for harvest of salmon from inner Bay of Fundy rivers and no reported effort or catch by members of the Native Council of Nova Scotia for inner Bay of Fundy rivers.

Similar to other Maritime rivers, conservation of Atlantic salmon stocks for inner Bay of Fundy rivers is assessed by comparing estimates of the escapement of all salmon (or egg deposition) after fisheries to the number of eggs (or salmon) required to produce juvenile and adult salmon at a level expected to maximize gain of the largest fish within the capabilities of the different rivers and stocks (Anon. MS 1986). This number of eggs or fish is known as the conservation requirement. In addition to maximizing gain the conservation requirement also satisfies the World Conservation Strategy, produced by the United Nations Environment Program, to maintain the ecological process, genetic diversity and fullest sustainable advantage (Anon. MS 1991) of the resource. In the absence of river or stock specific data to estimate river specific production parameters, a value of 2.4 eggs m^{-2} (Anon. MS 1991) is used to derive the conservation requirement for most rivers in Eastern Canada. This value was determined to maximize production of smolts and gain of adult salmon in several Maritime salmon streams including the Pollett River, an inner Bay of Fundy river.

Angling catches in inner Bay of Fundy rivers have declined since the recent high catch in 1983 (Figure 2). Low returns and catches in 1987 and 1988 alerted fisheries managers to possible conservation concerns for these rivers. Higher returns, catches and escapements of salmon in 1989 seemed to briefly alleviate those concerns. However, returns of salmon have been insufficient to meet conservation since 1990.

Most inner Bay of Fundy salmon enter rivers in the fall of the year and sometimes after the close of the salmon-angling season. An exception is the Big Salmon River where fish most often began to enter the river in late June or early July. The Big Salmon River was therefore used to conduct the first in-season reviews of the status of the inner Bay of Fundy stock of salmon. An additional indicator of the strength of the late run of salmon to inner Bay of Fundy rivers was derived from a fish counting fence constructed in the lower Stewiacke River in 1992. This was a co-operative project involving the Indian Brook First Nation, the Atlantic Salmon Federation, the Nova Scotia Salmon Association, the Cobequid Salmon Association and the Department of Fisheries and Oceans.

Information collected at the Stewiacke River fence indicated that while the 1992 and 1993 smolt classes may have contributed to increased escapements (Amiro and Jefferson MS1996) these escapements were still insufficient to meet salmon conservation in the Stewiacke. Continued low recruitment (first return of grilse after one winter at sea) eventually results in insufficient escapement for salmon stocks like the inner Bay of Fundy that are dependent on repeat-spawning salmon to achieve population stability. These stocks need at least one good year of recruitment in every four years (a generation). Information collected at the Stewiacke River fence and observations from the Big Salmon River in-season assessments indicate that there has not been a strong year-class of smolt survival since 1993.

Survival to successive spawning was high in the Big Salmon River, 1965 to 1973, and low for the 1991 and 1992 smolt classes of the Stewiacke River. Using the total age structure data from the Big Salmon River, the first to second spawning survival was about 40%; second to third spawning was about 70% and third to fourth spawning was about 40% (Amiro and McNeill, MS 1986). Data collected at the Stewiacke River fence, 1992 to 1994, indicated that first to second spawning survival was 4.4% for the 1991 and 9.0% for the 1992 smolt classes; 14.9% and 31.5% for second to third spawning for the 1990 and 1991 smolt classes; and survival was 1.9% and 9.0% for third to fourth spawning (Amiro and Jefferson MS 1996). These data are, for the most part, substantially lower than the average values observed from the Big Salmon River, 1964 to 1973 (Jessop 1986, Amiro and McNeil MS1986, Amiro MS1987).

The consequence of low recruitment has been a decline in parr populations in inner Bay of Fundy rivers. Density of salmon parr at 29 to 34 electrofishing sites in the Stewiacke River has declined since 1987 to levels typical of stocks impacted by low escapements or high in-stream mortality of eggs or parr (Figure 8). Relative to many Atlantic salmon stocks the rate of this decline was lessened because of the presence of a high repeat-spawning salmon component. Decline in age-1$^+$ parr is not attributed to deterioration in water quality. Parr densities also declined in six other rivers of the inner Bay of Fundy where historical information is available for comparison (Amiro and Jefferson MS 1998).

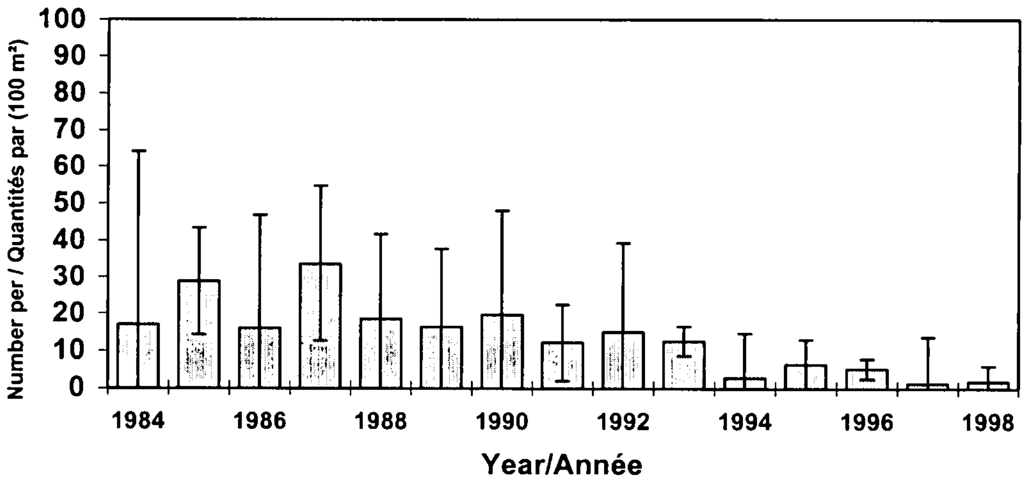

Figure 8. Stewiacke River age-1$^+$ parr average density (bars) and standard deviation (lines).

Mortality of pre-smolts after the parr were monitored did not account for the decline in recruitment of salmon to the Little River, a tributary of the Stewiacke River. Successful production of wild smolts was documented in annual counts of smolts emigrating from the Little River, 1990 to 1996 (Amiro and Jefferson MS1996). Also, a total of 123,714 hatchery-grown smolts of Stewiacke River origin were released between 1985 and 1996. Return rates for these smolts ranged from 0.02% to 0.42%. These return rates are much lower than the average of 4.2% reported for wild smolts of the Big Salmon River (Jessop 1986). Collectively the data and observations indicate that marine survival is implicated in the decline of salmon returns to inner Bay of Fundy rivers.

In comparison to the last drop in salmon recruitment to inner Bay of Fundy rivers, which occurred from 1958 to 1965 (Swetnam and O'Neil 1985; O'Neil and Swetnam 1991), the current reduction is of about the same duration and may be more severe. The severity may be implied from angling and juvenile salmon densities obtained by electrofishing shortly following the last decline compared to data available for the most recent period of low abundance. During the 1958 to 1965 era, angling in the Stewiacke River fell from 128 fish in 1958, to 7 fish in 1959, to none reported until 59 salmon were reported angled in 1962. While the reasons for the nil reports for 1959 to 1961 are unclear, low recruitment is suspected. There was no reported electrofishing in the Stewiacke River during the 1958 to 1965 period of low abundance. However, data collected in 1968 at six locations in the Stewiacke River had an average total parr (not including fry) density of 14.5 per 100 m^2 (Carey MS1968). In 1998, after six or seven years of low returns, based on the fry densities observed in 1998 there is no reasonable expectation that as many as 14.5 parr per 100 m^2 will be counted in 1999. Total parr densities of 14 parr per 100 m^2 have not been observed since 1993. Electrofishing data obtained in 1998, the results of the electrofishing boat counts of adult salmon in the Stewiacke in the fall of 1997 and 1998 (unpublished) and the smolt count at Little River in the spring of 1998 (unpublished) continue the documentation of low population size and indicate that there are few Atlantic salmon, of any age, left in the Stewiacke River

Marine distribution

The most unusual characteristic of inner Bay of Fundy salmon is their post-smolt distribution. Post-smolt is the term given to an immature salmon that has smoltified but has not passed a winter season. Carlin tags have been applied to wild and hatchery raised smolts of the Big Salmon River and hatchery smolts of Stewiacke River origin and release. Post-smolts of Stewiacke River and Big Salmon River origins have been recovered in low-head weirs along the Nova Scotia coast of the Bay of Fundy in July and in the high-head weirs of Passamaquoddy Bay and Grand Manan Island in August to October (Amiro and Jefferson MS1996). This distribution of post-smolts is not typical of outer Bay of Fundy salmon stocks such as the Saint John River. Outer Bay of Fundy salmon smolts were typically recovered in the coastal fisheries of Newfoundland in July and August (Ritter 1989).

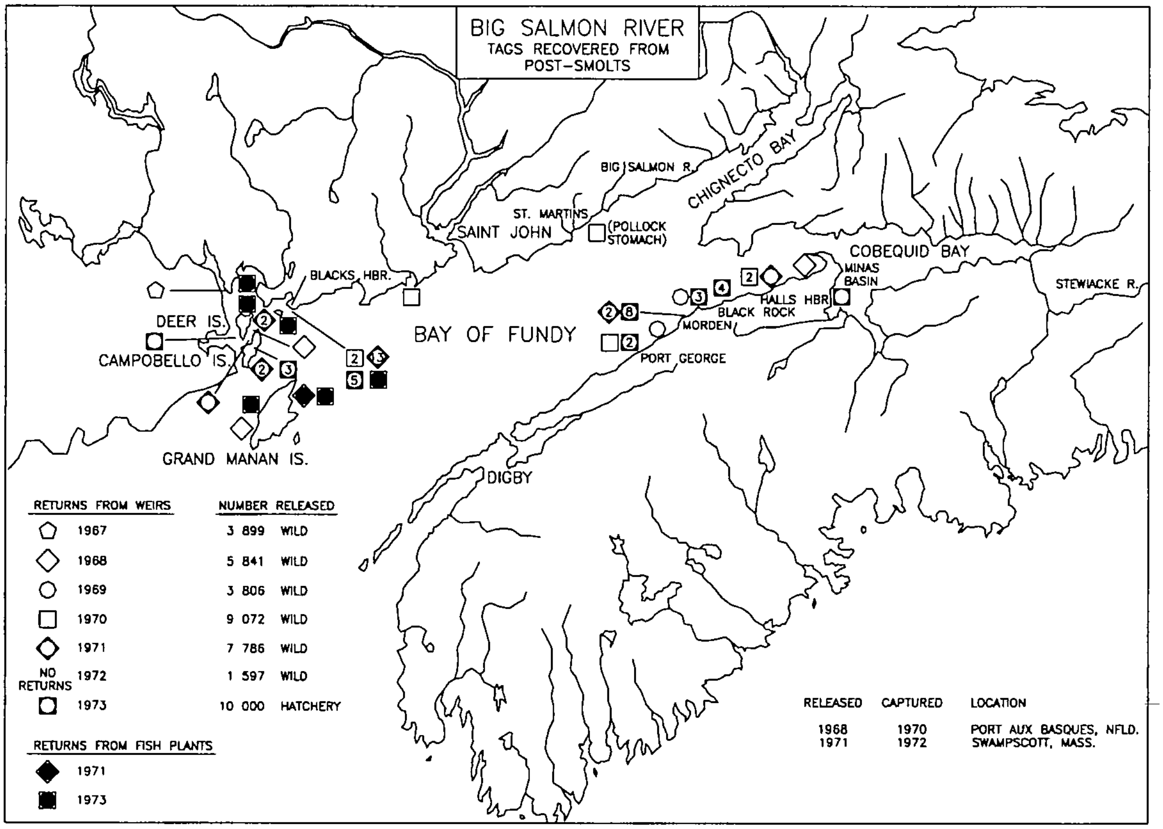

Figure 9. Post-smolt recapture locations of Big Salmon River tagged smolts 1966 to 1973.

Recaptures of inner Bay of Fundy tagged adult salmon were common in the low-head weir fisheries of the Bay of Fundy during June and July of the return year. The most southerly of these recaptures was in Swampscot, Mass., USA. Only three tagged inner Bay of Fundy salmon have been captured in the North Atlantic. Recaptures of tagged Big Salmon River wild smolts occurred in the years following the introduction of Miramichi River origin stock to the Big Salmon River. Also the possibility that an outer Bay of Fundy smolt was inadvertently included in an Inner Bay of Fundy tagging lot, cannot be ruled out.

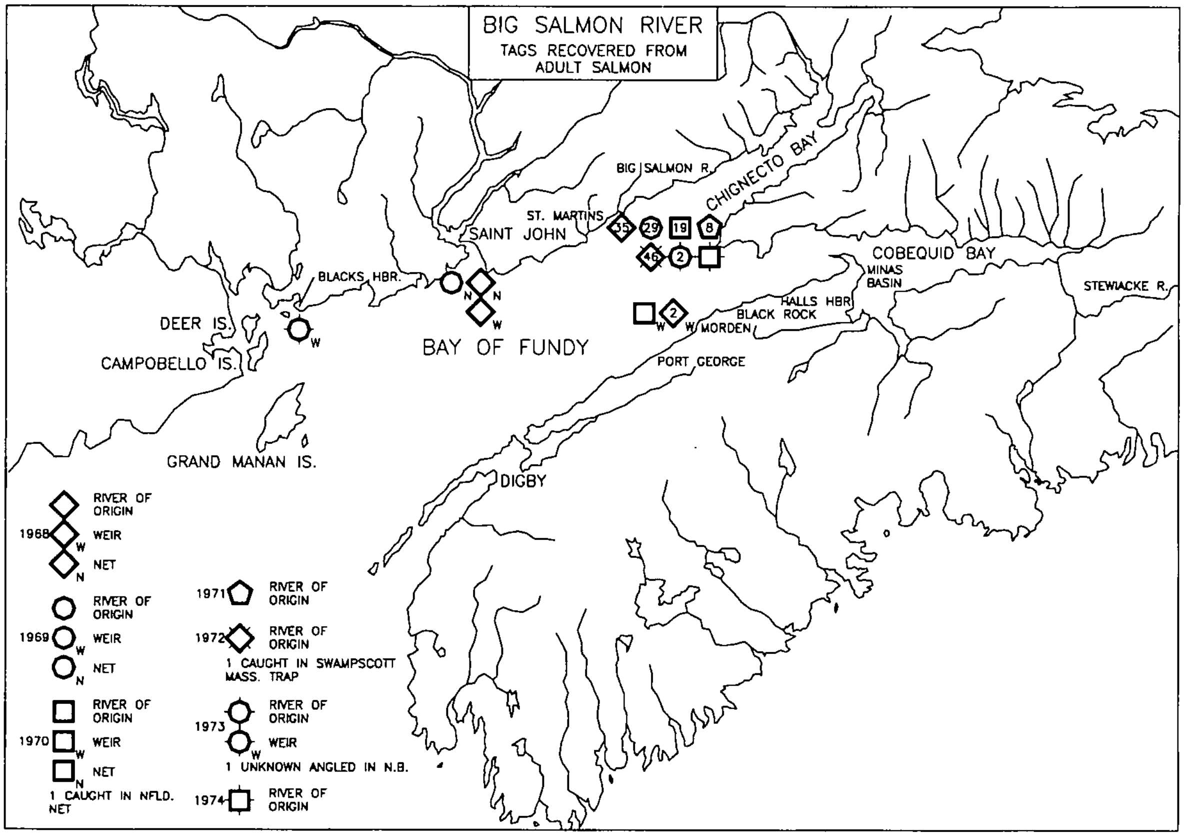

Figure 10. Adult salmon recapture locations of Big Salmon River tagged smolts, 1966 - 1974.

A total of 37,150 tagged Stewiacke River origin hatchery smolts have been released in the Stewiacke River since 1985. Stewiacke River tagged smolts were typically recaptured in the same fisheries as those of the Big Salmon River (Figure 11).

These observations, combined with the established similarities of life history and recruitment pattern of inner Bay of Fundy salmon, suggest that inner Bay of Fundy salmon do not migrate to the North Atlantic and have a more localized marine distribution than salmon of the Atlantic coast or outer Bay of Fundy.

A cross-check to this conclusion is the distribution of recaptures of tagged smolts from outer Bay of Fundy and Atlantic Coast salmon stocks tagged in the same years as inner Bay of Fundy smolts, 1985 to 1990. This comparison clearly showed that while other stocks were recaptured in Newfoundland and Greenland fisheries, inner Bay of Fundy salmon were not (Amiro and Jefferson MS 1996). The distribution of inner Bay of Fundy post-smolts in the southern Bay of Fundy in the fall of the year, together with a lack of tag returns from interceptory fisheries, supports the hypothesis that inner Bay of Fundy salmon do not utilize the North Atlantic for their winter habitat. While there is no direct information on the over-winter location of inner Bay of Fundy salmon, there is ample evidence that inner bay of Fundy post-smolts spend significant time in the Passamaquoddy - Grand Manan Island areas during the summer and fall.

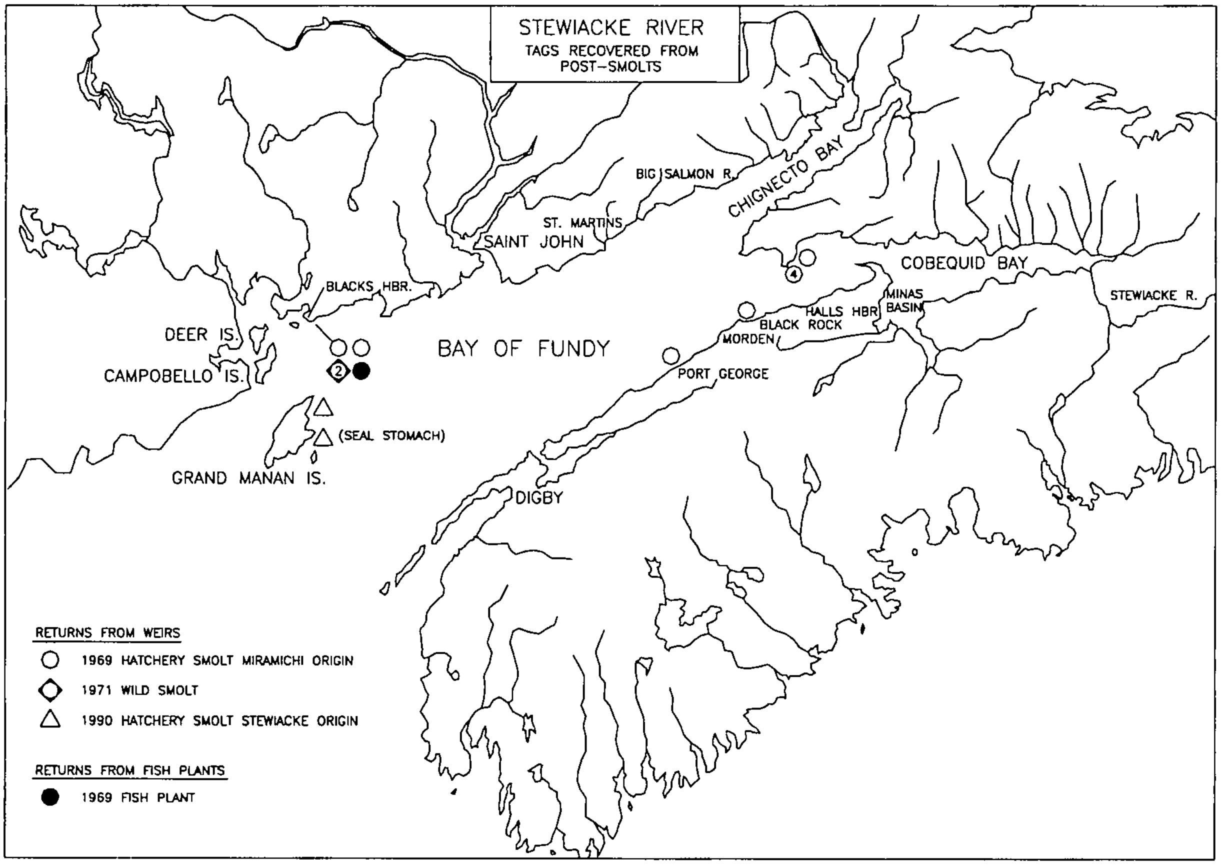

Figure 11. Post-smolt recapture locations from Stewiacke River tagged smolts 1970 to 1990.

Possible causes of low recruitment

Possible causes of low recruitment have been reviewed by Amiro (MS1990) and Amiro and Jefferson (MS1996) and are further developed here.

One hypothesis for the decline in recruitment of Atlantic salmon to rivers of the inner Bay of Fundy is ecosystem change. According to this hypothesis the ecosystem has either undergone a chronic (constant) change resulting in a loss of productive capacity or has become increasingly unstable. The problem with attributing the loss in salmon recruitment with ecosystem change is that there is little evidence of a chronic single direction decline in recruitment of many marine species over the past 123 years and if salmon are the measure, then the system has been variable for some time. There is no doubt that some decline in production was associated with the installation of hundreds of water control structures in the lowlands of the Bay of Fundy. Most of this development has occurred since European settlement. However, the high catches of the 1970's indicate that this loss of production is not of the magnitude necessary to explain the recent paucity of salmon. However, the possibility that some critical ecological point has been exceeded and populations are no longer viable cannot be rejected because there is no metric measure to test.

Variation in an ecosystem is the norm, not the exception. In order to define a pattern to this variation one needs a long time series of data. There are some physical data that approach the duration necessary to define cyclical trends but none over the 123 years we know the salmon have varied. In addition there are no firm time series of recruitment for the inner Bay of Fundy salmon. Therefore, the power to resolve hypothesis concerning trends and interactions is low.

The success of the Aquaculture industry in the Passamaquoddy Bay - Grand Manan areas, over the duration of the most recent decline (1990's), in itself, cannot rule out the possibility of periodic lethal parasite, infection or gill congestion associated with variation in ecosystem parameters. However, vaccination for the first most common salmon disease which plagued the salmon farming industry, Vibriosis, did not affect the return rate of hatchery-reared smolts released into the Stewiacke River (Amiro and Jefferson MS1996).

Bacterial Kidney Disease is ubiquitous in inner Bay of Fundy Rivers and has not been found in higher than background levels for any inner Bay of Fundy salmon submitted in any routine sampling to the Fish Health Laboratory of the Department of Fisheries and Oceans during the last twenty years. The incidence of ecto-parisites, chiefly salmon lice, has periodically increased in the past 15 years. However, there is no consistent quantitative record of incidence and only one year of abnormally high incidence was noted in the operation of the Stewiacke River fish counting fence.

Size and condition of recruit salmon returning to inner Bay of Fundy rivers are not easily determined while stocks are low. However, no anecdotal evidence or limited numbers of observations of salmon captured during assessments suggest acute loss in condition of the fish. No significant correlation between an index of salmon survival and possible salmon prey abundance was noted in developing the forecast models of Amiro (MS1989). At least three known prey populations, herring (*Clupea harengus*), euphausids (*Meanyctiphanes norvegica*) and sand lance (*Ammodytes sp.*) have declined and some populations have recovered to harvestable levels at least once during the most recent salmon decline (Stephenson and Kornfield 1990; Nelson and Ross 1991). While some subtle but periodically drastic effect associated with variations in the ecosystem cannot be completely ruled out, to date, there are no viable explanations linking ecosystem variation and salmon recruitment.

Another hypothesis for the decline in recruitment to inner Bay of Fundy rivers is the possible negative interaction with the aquaculture industry. Aquaculture production of Atlantic salmon on the east coast of North America (much of it in the Passamaquoddy Bay - Grand Manan Island areas) has risen from low numbers in 1980 to over 30,000 tonnes in 1997. The coincidence of the rise in production of farmed salmon with the most recent decline in recruitment to inner Bay of Fundy rivers has not gone unnoticed. However, any correlation drawn cannot be scientifically supported without an identified cause and effect. There is a need to identify and investigate any possible interaction(s) between farmed and wild salmon.

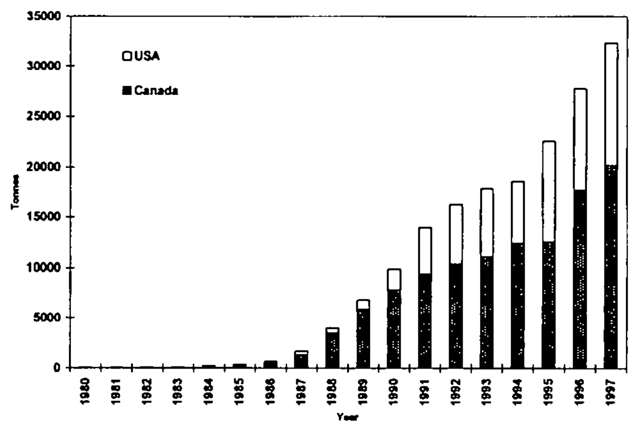

Figure 12. Production (tonnes) of farmed Atlantic salmon on the East Coast of Canada and the United States, 1980 to 1997.

At least four possibilities for negative interaction between farmed and wild salmon have been suggested. These interactions include (in no particular order): i) genetic introgression (the result of inter breeding of escaped farmed salmon with wild salmon); ii) introduction or spread of ubiquitous diseases as a result of crowding; iii) displacement of wild smolts from their usual migration route and resulting higher marine mortality; and iv) attraction of predators to the area and conditioning of predators to prey on salmon as a result of escapees from the sea cages.

i) The possibility for genetic loss of fitness as a result of escapement and mixed spawning with wild salmon is a concern for the long-term stability of any affected stock. Substantial escapements of farmed salmon into rivers with limited wild salmon have been documented, e.g., Magaguadavic River (tributary to Passamaquoddy Bay) in southern New Brunswick, an outer Bay of Fundy type salmon stock. Uncertainties in previous escapements, hydroelectric impacts and the recent downturn in recruitment of North American salmon complicate observations of the decline in recruitment to the Magaguadavic River. Quantitative genetic information concerning the introgression of wild and hatchery salmon in the inner Bay of Fundy is scarce and inconclusive. Theoretic analysis suggests that moderate numbers of escaped farm fish and low numbers of wild fish can result in substantial introgression of the stock (LaCroix *et al.* in prep.). Introgression, however, can neither be the cause of historic downturns in stocks of the inner Bay of Fundy nor can it be the cause of the present low abundance. This conclusion is based on the short duration (about two life cycles) of interaction of farmed escaped salmon and inner Bay of Fundy salmon and the low incidence of farmed escaped salmon observed in rivers of the inner Bay of Fundy. Only one year, 1995, was the number of escaped farmed salmon in the Stewiacke River (7 of 21 fish) remarkable. These farmed escapes were estimated to have potentially contributed to 49.1% of the egg deposition in the Stewiacke River in 1995 (Amiro and Jefferson 1996). These escaped salmon were of unknown origin but were coincidental with the reported loss of aquaculture salmon in the Annapolis Basin in 1995. Increased farmed escaped salmon were also observed in the Annapolis River and in the Gaspereau River in 1995. In subsequent years few, one to two, escapes each year are noted and removed from the Gaspereau River fishway trap. These farmed escaped salmon represent less than three percent of the counts at this facility.

ii) The increased incidence of ubiquitous or the introduction of exotic diseases could be enhanced in or be spread to wild salmon coincident with the sea cages in the southern Bay of Fundy. The documented presence of inner Bay of Fundy salmon in the same bays and estuaries as the sea-cage operations suggests a high probability of cross-contamination. A suggested mechanism for cross-contamination is the common sea louse (*Lepeoptherius salmonis*). Major infestations of sea lice have been documented in both sea-farmed salmon and on returning wild salmon to inner Bay of Fundy rivers. Some of the types of diseases presently found in the farmed salmon were known to exist in wild populations; others are speculated to have been present in the wild salmon found in these areas. The probability that disease has played a substantial role in the downturn in recruitment to inner Bay of Fundy rivers cannot be eliminated without extensive testing of the wild stocks of salmon. The methodologies for the detection of specific anti-gens are just becoming available and plans to test some wild stocks of salmon in the inner Bay of Fundy are being considered.

iii) The displacement hypothesis is difficult to assess and perhaps as difficult to accept. If salmon are displaced from their normal migration routes and if the production of smolts was maintained then there would have to be a coincidental increase in marine mortality in order for the returns to have declined. Smolt production was maintained in the early years of low recruitment and in a sense was controlled in the release of hatchery grown smolts. Any increase in marine mortality could be either from fisheries or from natural causes. The incidence of tag returns from fisheries in the inner Bay of Fundy are low and come from the few remaining herring weirs operating in the southern Bay of Fundy. Reports and samples of untagged smolts from these weirs indicate that while post smolts are observed, few post-smolt salmon are harvested in these fisheries. The weir fisheries provide a valuable indication that the few remaining post-smolts continue to be found in the traditional nursery areas. In recent years there are no reports of large catches or landings of wild salmon in the fisheries of the Bay of Fundy or the Gulf of Maine. Salmon are neither observed in the catches of commercial vessels fishing the southern Scotia Shelf, nor are they observed in the catches of research vessels fishing these areas. If the salmon are displaced then they are displaced afar. There is little commercial fishing of Atlantic salmon in the North Atlantic. However, marine survival of distant migrating Atlantic coastal stocks was at an historic low in 1997. The return rate for wild smolts migrating from above Morgan Falls on the LaHave River, an Atlantic coast stock, was low but still in excess of 2% in 1997. There is no indication that the return rate to any inner Bay of Fundy river approximated 2% in 1997.

iv) Predators of salmon, currently listed as but not limited to seals, piscivorous sea-birds and fish, may have increased in the southern Bay of Fundy area and some predators are a persistent problem in the farming of Atlantic salmon.

While there may be some disagreement concerning the species composition and population abundance of seals in the southern Bay of Fundy, there is little disagreement concerning their impact on the aquaculture industry. The aquaculture industry has invested time and resources to repel seals from the sea-cage sites. Scavenging by seals on salmon moralities or preying upon confined fish is well documented. However, there is less evidence of predation by seals upon wild free-swimming Atlantic salmon. Nonetheless, the only tag return from the 1990 tagging of Stewiacke River smolts was from the stomach of a harbour seal sampled on Grand Manan Island.

The mechanism for increased natural mortality of inner Bay of Fundy salmon could be the interaction of wild and farmed salmon escapees attracting and conditioning of predators to prey on salmon. Without the presence of aquaculture salmon escapees, predators would regulate their consumption of salmon based on the abundance of wild salmon alone. A balance, albeit variable, between the predator and the prey would naturally evolve. This is a type III predator-prey relationship where there is no dependence of the predator on the prey and the rate of predation is density dependent. The constant addition of farmed escaped salmon may de-stabilize this relationship.

Evidence for the possible interaction between predators and free-swimming salmon may be seen in the low numbers of farmed salmon counted in the rivers of Passamaquoddy Bay. Generally less than a total of 500 salmon of aquaculture origin enter the St. Croix, Saint John (above Mactaquac Dam) and Magagudavic rivers. Also, generally more than two million smolts annually are placed in sea-cages in the Passamaquoddy Bay area. The number of escapees in the southern Bay of Fundy salmon farming industry is unreported.

On the West Coast of Canada, 9.5% of known escaped-farmed Atlantic salmon are recovered in fisheries or observed in rivers. Atlantic salmon escaping sea-cages on the West Coast of Canada contributed a total of at least 9,284 Atlantic salmon to fisheries and escapements from 1988 to 1995 (McKinnell *et al.* 1997). If this were the recovery rate for Atlantic salmon in the Passamaquoddy Bay area and river entries of farmed salmon are as low as records indicate, then only five thousand farmed salmon annually escape from the sea cages. However, during the 1988 to 1995 study period, there was 37% greater production of salmon on the east coast of North America than on the west coast of North America. Either the industry is far better at containing salmon in cages on the east coast or there are a lot of unaccounted salmon in the southern Bay of Fundy. The latter case is more likely. The wild inner Bay of Fundy salmon, because of their coincidental marine distribution, may be included in this unaccounted loss and predation may be the mechanism for the loss in recruitment.

Summary

Historic declines of salmon to inner Bay of Fundy rivers complicate the conclusion that the inner Bay of Fundy salmon stock is on the brink of extirpation (loss of a species to an area). Inner Bay of Fundy salmon have previously been at very low levels and have subsequently returned to substantial population abundance. The frequency of these low abundance periods seems to be in the three to twenty year range and is unpredictable. Based on juvenile salmon populations the level of the last low population event was not as low as the current observation. The mechanism of this variation remains as much a mystery today as when Venning first wrote about the decline of inner Bay of Fundy salmon. In any event, the high frequency of low abundance of inner Bay of Fundy salmon makes them more susceptible to any new additional population stressor.

At least three mechanisms could not be rejected as contributory to the recent low recruitment of inner Bay of Fundy salmon. These mechanisms are: 1) disease, 2) predator attraction and 3) ecological change. In any case the Aquaculture industry may have exacerbated factors negatively effecting recruitment of inner Bay of Fundy salmon. Inner Bay of Fundy salmon stocks have historically persisted through low abundance periods. However, despite the history of successful persistence, the presence of a new factor, albeit unknown in its effect on inner Bay of Fundy salmon stocks, requires close attention. If, based on the historic record, a similar probability of persistence of inner Bay of Fundy salmon in the future is expected then the addition of a new factor may be negate that expectation. If all options for the future are to be maintained then the minimum allowable population number needs to be established and a recovery or replacement plan enacted before that number is reached.

If persistence of the wild inner Bay of Fundy salmon is to be assured, then, based on the uncertainty in these hypotheses and the status of the inner Bay of Fundy salmon stock, containment of both fish and disease in the salmon farming area of the Fundy Isles is a precautionary and reasonable priority action.

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Literature Cited

Amiro, P.G. MS1987. Similarities in annual recruitment of Atlantic salmon to sport fisheries of inner Bay of Fundy rivers and stock forecasts for 1987. CAFSAC Res. Doc. 87/58, 17 p.

Amiro, P.G. MS1990. Status of Atlantic salmon of the Stewiacke River, 1989. CAFSAC Res. Doc. 90/6, 22 p.

Amiro, P.G. 1990. Recruitment variation in Atlantic salmon stocks of the inner Bay of Fundy. CAFSAC Res. Doc. 90/41. 26 p.

Amiro, P.G. and A.J. McNeill. MS 1986. Status of juvenile Atlantic salmon stocks of the Stewiacke River in 1984 and 1985 and forecasts of recruits to fisheries in 1986 and 1987. CAFSAC Res. Doc. 86/32, 39 p + 1 App.

Amiro, P.G., S.F. O'Neil, R.E. Cutting and T.L. Marshall. 1989. Status of Atlantic salmon stocks of the Scotia-Fundy Region, 1988. CAFSAC Res. Doc. 89/68. 12 p.

Amiro, P.G. and E. M. Jefferson. MS 1996. Status of Atlantic salmon in Salmon Fishing Area 22 and 23 for 1995, with emphasis on inner Bay of Fundy stocks. DFO Atl. Fish. Res. Doc. 96/134, 16 p. + iii

Amiro, P.G. and E. M. Jefferson. MS 1998. Status of Atlantic salmon in Salmon Fishing Area 22 and 23 for 1997, with emphasis on inner Bay of Fundy stocks. DFO Atl. Fish. Res. Doc. 98/040, *in prep.*

Anon. MS 1986. Strategies for the long-term management of Atlantic salmon. Report of the special Federal/Provincial Atlantic Salmon Working Group, December 1986. 35 p.

Anon. MS 1991. Definition of conservation for Atlantic salmon. Canadian Atlantic Fisheries Scientific Advisory Committee, Advisory Document, 15, 4 p.

Carey T.G. 1968. Unpublished manuscript. Diad. Fish Div., DFO, Halifax N.S.

Ducharme, L.J.A. 1969. Atlantic salmon returning for their fifth and sixth consecutive spawning trips. J.Fish. Res. Bd. Canada 26:1661-1664.

Dunfield, R. W. 1986. Le saumon de l'Atlantic dans l'histoire de l'Amerique du Nord. Publ. spec.can.sci.halieut. aquat. 80. 199 p.

Elson, P.F. 1957 b. Number of salmon needed to maintain stocks. Canadian Fish Culturist, pp 19 - 23.

Elson, P.F. 1962. Predator-prey relationships between fish-eating birds and Atlantic salmon. Bull. 133., Fish. Res. Bd. Can. 87 p.

Huntsman, A.G. 1931. Periodical scarcity of salmon. Fish. Res. Bd. Canada, Atl. Prog. Rept. 2:16-17.

Huntsman, A.G. 1958. Shubenacadie salmon. J. Fish. Res. Board Can. 15(6). pp 1213 - 1218.

Jessop B. M. 1976. Distribution and timing of tag recoveries from native and nonnative Atlantic salmon (*Salmo salar*) released into the Big Salmon River, New Brunswick. J. Fish. Res. Board Can. 33:829-833.

Jessop, B.M. 1986. Atlantic salmon (*Salmo salar*) of the Big Salmon River, New Brunswick. Freshwater and Anadromous Division, Fisheries Research Branch, Dept. of Fisheries and Oceans, Halifax, Nova Scotia, B3J 2S7. Can. Tech. Rep. Fish. Aquat. Sci. No. 1415, 50p.

Lacroix, G.L.,J. Korman and D.D. Heath. 1998. Genetic introgression of the domestic Atlantic salmon genome into wild populations: a simulation of requirements for conservation. DFO Atl. Fish. Res. Doc. 98/158, *in prep.*

Marshall, T.L., S.F. O'Neil, R.E. Cutting and P.G. Amiro. 1988. Status of Atlantic salmon stocks of the Scotia-Fundy Region, 1987. CAFSAC Res. Doc. 88/59, 14 p.

McKinnell S., A. J. Thompson, E.L. Black, B.L. Wing, C.M.Guthrie, J.F. Koerner, J.E. Helle. 1997. Atlantic salmon in the North Pacific. Aquaculture Research 28 (2). 145 - 157.

Nelson, G.A. and M. R. Ross. 1991. Biology and population changes of Northern sand lance (*Ammodytes dubious*) from the Gulf of Maine to the Middle Atlantic Bight. J. Northw. Atl.Fish Sci., Vol. 11: 11 - 27.

O'Neil, S.F. and D.A.B. Swetnam. 1991. Collation of Atlantic salmon sport catch statistics, Maritimes Provinces, 1951 - 1959. Can. Data Rep. Fish. Aquat. Sci. No. 860: ix + 259 p.

O'Neil S.F., T.L. Marshall, P.G. Amiro and R.E. Cutting. 1989. Status of Atlantic salmon stocks of the Scotia-Fundy Region, 1989. CAFSAC Res. Doc. 89/80, 13 p.

Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic salmon (Salmo salar L.). Can. Man. Fish. Aquat. Sci. No. 2041. 136 p.

Stephenson, R.L. and I. Kornfield. 1990. Reappearance of spawning Atlantic herring (Clupea harengus harengus) on Georges Bank: population resurgence not recolonizatoin. Can. L. Fish. Aquat. Sci. 47 : 1060 - 1064.

Swetnam, D.A.B., and S.F. O'Neil. 1985. Collation of Atlantic salmon sport catch statistics, Maritimes Provinces, 1960 - 1969. Can. Data Rep. Fish. Aquat. Sci. No. 533: ix + 289 p.