An Identification of Possible Causes for the Downturn of Salmon Stocks of the Inner Bay of Fundy

by

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1. Introduction

The Atlantic salmon (Salmo salar Linnaeus, 1758) is a renowned sport fish as well as being important in commercial fisheries and the aquaculture industry. The value of harvested Atlantic salmon in the aquaculture industry was estimated to reach 16 million dollars by 1987 (Scott and Scott, 1988). In1983 alone the value of the commercial Atlantic salmon catch reached 4.8 million dollars (Scott and Scott, 1988). The salmon of the Atlantic provinces are also caught in the Greenland commercial fishery (Reddin and Burfitt, 1980).

The recent trend of low salmon catches in the inner Bay of Fundy has caused concern, especially among sport fishermen. Several possible causes for the decline in stock levels have been put forward (Scott and Scott, 1988) and include:

- habitat destruction;
- obstructions blocking passage to spawning grounds;
- overfishing (local and high seas);
- poaching;
- pollution;
- adverse environmental conditions.

In light of all the possible causes for declines in salmon abundance, it was relevant to compile and review the available information concerning Atlantic salmon of the inner Bay of Fundy. In compliance with our technical proposal, we conducted the following review and analysis. The biology of Atlantic salmon and a description of the Bay of Fundy river salmon runs are first summarized. Mortality factors such as fishery, predation and disease operating at sea and in rivers are discussed. Important environmental conditions of the inner Bay of Fundy rivers were compared to past fluctuations in salmon abundance. Recent trends in oceanographic and estuarial conditions in the Bay of Fundy were compiled. Information on bird, fish and mammal predation were gathered. Historical and recent local high-seas commercial and sport catch were examined. The significance of by-catch in intertidal weirs, shad drift net fishery and the herring purse seine fishery was considered. Problems concerning Atlantic salmon survival including diseases (both natural and aquaculture-related), pollution sources or stream blockages and the possible effects of introduction of exotic species were researched. Finally, this information was used to prepare a list of recommendations of possible study areas in order to determine possible causes for fluctuations of salmon stocks.

2. Life History

The Atlantic salmon is an anadromous species occurring in the North Atlantic Ocean. Salmon spawn during autumn, usually during October and November (Scott and Crossman, 1973). Actual timing of freshwater entry by adults is a particular characteristic of each river. Elson (1962) suggested that most enter freshwater with falling water temperatures and the onset of autumn rains, but many runs begin in spring and some populations even run upstream a year before they spawn (Huntsman, 1931). In late spring and summer the adults are usually found at the river mouths. In the Cobequid region, spawning migrations occur in late summer. Research has shown that salmon return to their parent stream after spending time at sea. White (1936) showed that salmon in the Apple river, Cumberland Co., N.S., could even distinguish between branches in the river, and may even return to the same pool where they were marked.

Once in freshwater, the mature fish seek gravel beds, in which the female excavates redds. Before the actual spawning redd is built many "trial redds" are excavated (White, 1942). Many of the trial redds are shallow and clearly inappropriate, however some are deep and clean when abandoned. The redds are dug by repeated fanning of the caudal fin in relatively shallow water above regions of current acceleration. Redds are commonly located at the head of rapids or where there is a strong flow of water, but sites where the current is swift are avoided. Redd substrate is characterized by a mixture of sand and fine gravel, with little coarse gravel, however salmon also use stream regions with coarse gravel free of sand. Construction of the redd may take as long as a week to complete if the substrate is compacted. The size of the redd varies according to the size of the fish, ranging from 0.15 to 0.20 m deep and 0.46 m in diameter for small fish (0.45 kg) to 0.3 m or more in depth and over

0.91 m in diameter for a 9 kg fish (Hobbs, 1937). At the bottom of the redd is a region called an "egg-pocket", where several large loose stones lie upon fine sediments. Usually a single egg pocket is present, but up to 4 pockets have been noted in a single redd. Most of the eggs released are found within this pocket. The spawning act takes place after dark and may be completed in a few seconds. The eggs and milt are shed simultaneously by the female and male, and are deposited into the egg pocket. A single spawning occurs at a redd. The eggs are covered by the female immediately after the spawning by moving coarse gravel upstream of the eggs. This gravel falls into the egg pocket over the large stones. The eggs ultimately end up around and under these large stones. The egg-pocket is first covered with clean material, then is leisurely covered with other material from around the redd. The completed redd forms a low mound which is longer than wide. Redds with multiple egg pockets are usually found in areas with large amounts of clean gravel. Location of spawning sites in areas of high water flow increases seepage and oxygen flow into the egg pockets.

The eggs are large (about 5-7 mm) and adhesive for a short time after extrusion (Huntsman, 1931). The number of eggs deposited varies between populations, but on average is usually 1550 eggs/kg of body weight for salmon, while grilse produce 1050 eggs/kg (Amiro and McNeill, 1986). After spawning, most of the adult fish (now called kelts) remain in pools of the river for a few weeks before returning to sea, however some may overwinter in the river.

During winter the eggs incubate in the gravel, the rate of development depending on temperature. In early spring (usually April), the eggs hatch into alevins, which retain the egg sac. The alevins remain in the egg pocket or closely associated with it. By the time the egg yolk is nearly absorbed, the alevins have migrated upward in the redd. It is not known how the fry manage to escape through the compacted layers, however observations indicate that flood-swept streams quite often are prolific in numbers of fry. Although the alevins are not totally inactive they remain mostly on the bottom. When the egg yolk is exhausted, the fry begins active feeding. The young salmon feed on small freshwater insects and their larvae (White, 1936) and zooplankton (Snow, 1985). At this time the fry, which is only 2.5 cm long, establishes a territory. The fish remain in freshwater for 1 or more years. At this stage the young salmon are called parr and the vertical coloured bands which develop are called parr markings. During this life stage intense predation by larger fish and birds. Additionally, anglers often mistake them for trout.

After a freshwater development period of 2-3 years in the Maritime provinces the parr become competent to migrate to sea. In early spring the parr marks are lost and the young fish assumes a silvery appearance due to a coat of guanin on their scales (Elson, 1962). At this stage the young salmon is known as a smolt. Two growing seasons are needed for parr to reach smolt size in the Shubenacadie and Stewiacke river systems (Morantz, 1978). The young salmon are now between 13 - 15 cm long and weigh about 45 g (Elson, 1962). Smolts run down to sea in the spring and early summer usually when water temperatures reach 10°C. Serviceberry blooming time is the usual period of seaward migration.

Rapid growth occurs in the sea. Some salmon return to spawn after 1 year at sea (1SW or grilse). These fish weigh approximately 2 kg and are generally less than 65 cm long. Other salmon may remain at sea for 2 - 3 years and return weighing between 5 and 20 kg (MSW or multiple sea winter salmon). The reproductive potential of grilse is considerably less than that of MSW salmon (Randall, 1984). Randall (1985) noted from estimates of spawning potential that as many as eight grilse were required to produce as many eggs as a single MSW salmon in the Miramichi River and fecundity was directly related to length (Randall, 1984). Paloheimo and Elson (1974) found that there was a significant relation between the number of MSW salmon and subsequent parr densities.

Immature postsmolts migrate northward during summer to feed, passing along the coasts of Greenland and Labrador (Scott and Crossman, 1973). They eventually reach the Davis Strait, off Greenland (Reddin and Shearer, 1987). Water temperatures and abundant food resources make this a good growth area. Most of the time in the Davis Strait and the Labrador Sea is spent feeding. Various invertebrates and fishes are ingested, however feeding ceases when they return to freshwater to spawn. Salmon overwinter at sea then return to their natal rivers to spawn. Life history during the sea phase of the salmon is not well known.

3. Inner Bay of Fundy Salmon Stock Dynamics

There are many rivers of the inner Bay of Fundy which support Atlantic salmon fisheries (Table 1). Most are very similar in physical character. The rivers of the south coast of New Brunswick and the north shore of Cobequid Bay are characterized by having a very steep gradient with fast flow, little silt, and few pools (Jessop, 1986; Hall, 1987; Granger and Priest, 1988). In contrast, the Salmon and Shubenacadie Rivers of Cobequid Bay have steep gradients and extensive regions of stillwater with a smaller proportion of riffle and run (Morantz, 1978; Hall, 1987). The Stewiacke system is intermediate between the two groups and has a moderate gradient with extensive riffles and runs (Morantz, 1978; Amiro, 1986).

The majority of rivers in the inner Bay of Fundy region have Atlantic salmon populations which are predominantly late run grilse stocks (Table 1). Of the stocks which have been characterized, only the Gaspereau River population of the inner Bay is predominantly 2 sea-winter (2SW) at first spawning (Table 1). Huntsman (1931) described the stocks of Minas Basin and Cobequid Bay as remaining in freshwater for 2 years (79%) before running to sea and returning to spawn for the first time as grilse (89%). This would indicate that the majority of salmon from the Minas Basin - Cobequid Bay region require a period of 4 years from egg to spawning. In contrast, the majority of St. John River stocks require 5 years from egg to spawning (2 winters in freshwater and 2 winters at sea before first spawning) (Huntsman, 1931).

Sport catches of most rivers of the upper Bay of Fundy have gradually increased over the past 3 decades (Appendix 1). This trend is especially noticeable for the rivers in the region of Cobequid Bay (Figure 1 a-j). Catches in most of these rivers peaked in 1983 and have since declined. In order to determine trends in catch, it may be more appropriate to look at the catch per unit effort (CPUE= number of fish caught per rod-day). There has been little change in the CPUE since 1975, except for the Shubenacadie and Salmon Rivers (Figure 1). Since 1984 there has been a gradual decrease in the number of salmon caught by anglers per day. The decrease in catch is only reflected as a decrease in CPUE in half of the rivers - the Folly, Economy, Bass, Debert and North rivers. All of these rivers are in close proximity to one another suggesting that there may be a localized phenomenon affecting them.

Other rivers of the Bay of Fundy, those from a line roughly between Annapolis and St. John to Minas Basin show catch patterns similar to those of the Cobequid Bay region (Figure 2 a-g). Catches however, show much more variability than those of the Cobequid rivers. The Annapolis, Kennebecasis and St. John Rivers have experienced a recent increase in CPUE while the remaining rivers further up the Bay of Fundy experienced a decrease in CPUE.

The Margaree, Wallace and Phillip rivers all show similar trends (Figure 3 a-c). These rivers exhibited a decline in CPUE during the 1970's but have been increasing since. All rivers except the Margaree exhibited sudden increases of CPUE in 1987. The Margaree CPUE was probably depressed by an extended increase in effort, from $\approx$ 4000 rod days in 1980 to $\approx$ 13000 rod days in 1987 (Figure 3a).

The commercial Atlantic salmon fishery was closed in 1984 in response to declining stocks. Salmon landings have been recorded since 1890. Early records were kept on a county basis (1890-1969) but later records (since 1947) are gathered by statistical district (Appendix 2). Commercial catches for Cumberland and Colchester Counties (Nova Scotia) show very large catches which were subject to much variability from 1890 to about 1933 (Figure 4). Since that time catches have remained low with only moderate fluctuations (Figure 4). For districts 43 and 44 combined (Minas Basin and

Cobequid Bay sections of Cumberland and Cobequid Bay) there is a further reduction in catches around 1970 with a slight increase in the early 1980's (Figure 4).

Huntsman (1931) indicated that early in the 1900's the commercial landings of Minas Basin and Cobequid Bay exhibited a 9.6 year periodicity. However, commercial landings for statistical districts 43 and 44 from 1960 until the fishery was closed show peaks roughly every 11 to 12 years.

It is useful to compare the sport and commercial fisheries to determine the impact each is having on stocks. Sport landings begin in the early 1960's at a level below that of the commercial fishery (Figure 5). However, after 1970 the sport landings maintain a level higher than commercial landings (for statistical districts 42 and 43 - Cobequid Bay). The level of harvest maintained by the sport fishery of Cobequid Bay since 1970 is greater than the sustained commercial catch since 1947 (although there were 2 peaks near 2000 salmon in the commercial fishery). It is possible that the sport fishery in recent years has been removing more salmon than the stocks can support.

Sport landings are probably not the best measure of stock health. Over the past several years, the Anadromous Fish Division of the Department of Fisheries and Oceans has been conducting parr surveys on the Stewiacke River (Amiro, pers. comm.). This information when it becomes available may provide a better understanding of stock dynamics.

4. Environmental Factors

A number of environmental factors are thought to affect the abundance of Atlantic salmon. Some of these factors include water chemistry, precipitation, river discharge, and water temperature.

4.1 Water Chemistry

The chemical variables which are most likely to be a problem for Atlantic salmon are pH and dissolved oxygen. Critical values of dissolved oxygen for Atlantic salmon are levels below 4 mg/l. Below a pH of 4.7 salmon are unable to spawn successfully because of death of eggs and/or alevins (Farmer et. al., 1980).

Chemical characteristics of the rivers in the upper Bay of Fundy have not been well monitored. Most of the rivers were regularly sampled through the 70's but few were sampled after 1979 (Table 2). The Kennebecasis, Wallace and Margaree Rivers have the best chemical data sets (mid 1960's to late 1988). The Wallace River is in close proximity to many rivers of the upper Bay and drains land of similar geology. It may therefore be representative of the upper Bay rivers. The mean oxygen values are all above 10.0 mg/l, and are well above the minimum required by Atlantic salmon (Table 2). Variability is low indicating that the dissolved oxygen content of these rivers is relatively constant. The high and stable oxygen levels are due to the rivers are all being fast flowing, maintaining near saturation oxygen levels. These would not be expected to change unless there was a recent blockage or input of organic wastes. Before the 1980's, pollution from a pulp mill on the St. Croix River, New Brunswick reduced the oxygen level over several kilometres of the river, effectively blocking salmon migration above the mill (G. Howell, pers. comm.).

Situations leading to a reduction in O_2 levels should be guarded against and corrected when found.

The acid content of precipitation in Nova Scotia has increased by a factor of 10 or more since the 1952-54 period (Watt et al, 1983). Half of the land area in Nova Scotia is underlain by granitic and hard metamorphic rocks. There is a marked correlation between geology and surface water pH. Since there is little buffering capacity in the soil in regions with granitic geology severe acidic conditions of surface waters (pH<5.4) are common. The pH is also affected by flow. In years when flow is high, pH is low. Usually maximum pH levels are recorded in late summer and minimum levels in midwinter before the ice thaws. Salmon rivers with mean annual pH<4.7 and minimal neutralization capacity no longer have salmon runs (Watt et al, 1983). Rivers with pH between 4.7 and 5.0 recorded decreases in salmon stocks since 1954. Rivers with pH above 5.0 do not show any significant trend.

The pH values of the rivers of the upper Bay of Fundy are all well above the minimum required by salmon (Table 2). The soils over most of the region have a high capacity to buffer acidity in precipitation. With the exception of the Shubenacadie River, all of the rivers of the upper Bay for which data were obtained are at or above pH 6.0. Variability is low, indicating that there is little fluctuation in pH. Most fluctuation in river pH is due to heavy rainfall or high spring runoff. In these conditions, the water from precipitation may enter the rivers without percolating through the buffering soils. Ashfield et al (1987) indicated that most low pH values were recorded in the winter. A number of rivers were sampled on the North Shore of Cobequid Bay in both July and December and without exception the December pH values were lower (Ibid.) (Table 3).

Farmer et al (1980) indicated that apart from spawning failure due to low pH levels the other critical period is in the first several weeks after the parr begin to feed. At a pH of 6.5 mortality was considerably lower than at a pH of 5.0. As the parr grew they became less sensitive to low pH (Ibid). Therefore it appears that the most critical periods of pH sensitivity on Atlantic salmon are in late fall when the adults are spawning and in the spring after the alevins have absorbed their yolk sacs and begin to feed.

There are however several methods of lessening the impact of acidic waters on salmon populations. Farmer et al (1980) enhanced the survival of Atlantic salmon parr at the Mersey hatchery by treating the water from the Mersey river. The water was pumped through a filter containing calcium carbonate. Calcium carbonate buffers the acidic waters, increasing the pH. A mortality rate of 30.3% was recorded in untreated water compared with only 2.9% mortality in the treated water. Liming has been suggested as a remedy for acidic conditions. This practice would prove costly and impractical in inaccessible rivers. A reduction in industrial emissions, possibly related to increased public awareness and industrial guidelines, in addition to sparse liming of severely affected rivers may result in rebound of some depleted salmon populations.

The data obtained show that with the exception of the Shubenacadie River and perhaps the Big Salmon River in New Brunswick, pH is not a problem. However, a thorough monthly sampling regime of several of the upper Bay rivers may better indicate if there are sudden declines in river pH at these critical periods of spring and fall.

4.2 Discharge and Rainfall

Discharge is a direct measurement of the amount of water flowing out of the river, and is recorded for a number of rivers by the Inland Waters

Directorate of Environment Canada. Discharge data has been compiled for only 3 rivers in the upper Bay region: the North, Shubenacadie and Salmon Rivers (Appendix 3). The data available from these stations are for the period up to 1987 beginning in 1977, 1965 and 1975 for the North, Salmon and Shubenacadie Rivers respectively.

Rainfall is recorded for many locations around the upper Bay of Fundy by the Atmospheric Environment Service of Environment Canada. Since precipitation is significantly correlated with river discharge for most months of the year (Table 4), it will be used for comparisons with salmon catch statistics. The Truro weather station has been operating more or less continuously since 1911. Since this station has a long record of environmental conditions and due to its centralized location in the Cobequid Bay area, the conditions reported here were assumed to be representative of the rivers in this area. Rainfall was used to compare salmon abundance with water levels.

Correlation analysis was used to determine the effect of changing water levels on salmon abundance.

The effect of variable discharge on salmon abundance was determined by correlating salmon catches with monthly mean precipitation, since the latter was assumed to be a good index of river discharge. The rivers were divided into 3 groups: Cobequid Bay rivers; other rivers in the Bay of Fundy to Annapolis and St. John; and 3 rivers of the Gulf region.

Mean monthly precipitation for the Truro weather station was compiled (Figure 6). Missing values for Truro were estimated using multiple regression predictors from the Parrsboro and upper Stewiacke weather stations (Table 5). There was considerable variation in precipitation from year to year as indicated by the scatter around the mean (Figure 6) (Appendix 4). Patterns in the precipitation data were not evident although in recent years January, March, May and December precipitation were frequently above the mean values for the month. September precipitation appears to have decreased since 1976 (Figure 6).

In order to determine the effect of mean monthly precipitation correlation analysis was performed with a 0-6 year lag (correlating catch in year i with precipitation in year i - x , where x = 0-6). This should relate the effect of precipitation to various stages of the life cycle of the salmon (Table 6). These data present for each month and lag the number of rivers which had a significant (defined as p<.10) positive or negative relationship with precipitation. Many of the combinations result in no significant relationships. However there were a number of important correlations both positive and negative. Since all of the rivers around Cobequid Bay produce predominantly grilse the lags in the catches might identify potentially sensitive periods throughout their life. The 0 year lag represents the year the grilse return to the river to spawn and are caught. The 1,2,3 and 4 year lags represent the 2+ parr (smolts), 1+ parr, fry and egg stages respectively. Therefore a significant correlation in the 4 year lag represents an effect on the egg stage. A number of interesting correlations occurred at the various life stages of the salmon. In the year that eggs were produced for a given year class we see significant positive correlations only in January and August. The significance of January may be an artifact of the data and not a real effect. However, high rainfalls in August possibly increase the number of fish which run upstream and spawn. Negative correlations in that same stage were seen in September, October and December. The negative correlations in September and October may be related to the success of the harvest. Research indicates salmon are more likely to be angled in years of high flow (Alabaster, 1970). The negative relationship with December precipitation may be related to the location of the redds. In low flow years the redds will be located in deeper channels and will be less prone to exposure if winter flows are low. Chadwick (1982) indicated that if there is high river discharge at spawning then the redds are more prone to exposure and freezing during the winter.

There were a number of significant correlations with precipitation for the year fry hatch. April precipitation resulted in a negative correlation. This may be due to a reduction in river pH with high discharge. Farmer et. al. (1980) indicate that low pH at the period of first feeding and the 4 weeks afterward can be detrimental to survival. High precipitation in April combined with runoff from melting snow may result in a depression of river pH at the time of first feeding, resulting in reduced year class success. Conversely, fry survival showed a positive correlation with high precipitation in the period from July to October. This was probably due to reduced predation by fish-eating birds since low water levels will result in greater visibility of the fry. Increased survival may also be indicative of reduced habitat competition with older parr. If water levels are low the area of the stream bed is reduced, limiting the amount of habitat available for the territorial parr. In years of low precipitation the older parr may exclude the fry from the safer hiding places making them more vulnerable to predators. The 1+ parr showed negative relationships with precipitation in 4 months: March, August, September and December and a positive relationship with June. Factors which may cause the significant negative correlation are unclear. The positive correlation in June was possibly a result of better predator avoidance. Avian predators such as kingfishers would be feeding young at this time and the deeper water would result in poor visibility and more habitat in which to find hiding places. The year of smoltification (2+ parr) for the Cobequid rivers showed positive correlations with precipitation in February, March, August, September and December. Negative correlations were present in May and

November. It is unclear what the cause of these relationships would be. The positive correlations in August and September may be due to lowering of the salinity in Cobequid Bay which may have some survival value for the smolts and post-smolts. The negative correlation with November was likely due to the high discharge at this time of the year and inland waters being cooler than the water of the Bay. This may result in lower growth and higher winter mortality.

For the year in which the grilse return to spawn there were positive correlations with 3 months, February, May and July. The first 2 may be artifacts of the data or caused by some unknown factor at sea. The positive correlation with July may have resulted in the fish returning to the rivers earlier and being vulnerable to the sports fishery for a longer period of time.

A number of significant correlations were produced by examining the effects of precipitation in the 2 years prior to spawning. The most striking were the March and April correlations with the 5 and 6 year lags, respectively. This may give support to the idea that habitat limitations for parr and fry are critical. High flows in March and April would reduce the survival of the fry and 1+ parr, decreasing the competitive pressure in subsequent year classes.

The same analysis was carried out on the 7 other Bay of Fundy rivers examined in this study. There were fewer significant correlations, probably since fewer rivers were used and many of them are far from the Truro weather station and are likely influenced by different weather patterns. However, many of the significant correlations were the same as exhibited by the Cobequid Bay populations (Table 7). Another factor that may influence some of these populations was stock characteristics, some of which are very different from the Cobequid stocks. The Annapolis was historically an early run population and the St. John stock produces a number of MSW individuals.

Therefore considering differences in stocks and using local precipitation data may result in more similar relations becoming evident.

Correlation analysis for the rivers of the Gulf region also produced very few significant correlations (Table 8). This is most likely due to the small number of rivers used and the distance from the Truro weather station. Very few of the correlations were similar to the Cobequid populations, however differences in the marine environment may be a contributing factor to the lack of similarity.

Since river flow is frequently the result of precipitation over a several month period the previous analysis was repeated using the 3-month mean precipitation. For example, the analysis done for January included the mean precipitation for the period November, December and January.

The results of this analysis for the 10 rivers emptying into Cobequid Bay show a similar pattern as the previous analysis (Table 9). The main exceptions were seen with the 3, 5 and 6 year lags. By including the precipitation of the previous 2 months the positive effect of heavy precipitation in the spring (5 year lag) was more evident than when using the monthly means. The negative effect of heavy rainfall in the 3 year lag was also intensified. This may support an hypothesis that fry are negatively affected by large numbers of older parr. The 6 year lag from this analysis resulted in a significant negative effect with high discharge in the late fall. This may support the hypothesis that high river levels at the time of spawning decreases yearclass survival. The fact that this relationship was apparent in the 6 year lag suggests that increased survival of parr 2 years prior to spawning was detrimental to a yearclass because of fry-parr interactions.

Analysis with 3 month running means for the other seven rivers of the Bay of Fundy revealed many of the same characteristics as the Cobequid

Bay populations (Table 10). Most noticeable of the similarities were the negative effect of high fall precipitations in the 6 year lag and the positive effect of high discharge in the spring. Less noticeable, although still present, were the negative effects of high discharge with a 3 year lag and the positive survival effects on fry with high discharge in the late summer and fall. One + parr also showed an increased survival with high summer discharge.

Three month running mean analysis for the River Phillip and Margaree River yielded little useful information (Table 11). However, there were significant negative correlations with winter and early spring precipitations for the 3 and 4 year lags.

Generally catch per unit effort was a better measure of population trends since it provided an estimate of the number of fish caught in relation to a standardized unit (i.e. per rod day). Therefore a final set of correlations were calculated using CPUE and mean monthly precipitation. The result of this analysis for the Cobequid Bay populations revealed few of the same patterns (Table 12). There was a significant positive correlation with high discharge in late fall of the year of spawning (4 year lag) as well as a negative effect of high spring discharge on fry (3 year lag). Using CPUE in the correlation analysis indicated a negative effect of high discharge in the early fall for 1 + parr (2 year lag). However, many of the other relationships do not appear. For other rivers of the Bay of Fundy the patterns remained essentially the same as those calculated from catch (Table 13). Many of the correlation patterns previously observed for the Gulf region rivers were not apparent when CPUE was taken into account (Table 14).

Differences in the above relationships when using CPUE and number of salmon caught indicates that one or both of the parameters used to estimate the number of fish returning to spawn may not be accurate. In this case it appears the CPUE estimate for the Cobequid Bay rivers may be the problem. When considering CPUE in calculations of the other rivers of the Bay of Fundy, the same relationship was found as when using just catch. This similarity, and the fact that the pattern was the same as when using catch for the Cobequid Bay populations, suggests that there may be problems with CPUE estimates for Cobequid Bay. Two possible factors affecting CPUE were 1. that rivers of Cobequid may support a finite number of anglers before they start interfering with one another; and 2. it is possible that the measurement of effort is poor. The first possibility seems likely since the upper limit to salmon passage for many of the rivers is less than 20 km which may limit the number of fishermen each river can support. The measurement of effort, the rod day defined as any part of a day spent fishing by one person, does not appear very accurate since someone fishing for 10 hours is considered the same as someone angling for 1 hour. Possibly hours per day as a measure of CPUE would be a more accurate measure.

4.3 Sea Surface Temperatures

Data for sea temperatures of the Bay of Fundy are generally lacking. Sea surface data for the Minas Basin are mainly available only in thesis and reports originating at Acadia University and suffer from being extremely sporadic. Most studies which measured temperatures did so near shore once or twice a month or were limited to a several month period during the summer when most student research was undertaken. (The effort required to compile these would require more time than we had available during this exercise). The best data set for the entire Bay of Fundy is from the St. Andrews sea surface temperature monitoring station in Passamaquoddy Bay. This data set covers a period from 1921 to present (Appendix 8) (Figure 7).

Correlation analysis was used to determine if there were any significant relationships between sea surface temperature and the sum of the sport catch for the rivers of Cobequid Bay. There were significant ($p<.10$) positive relationships with December, March, April, and June sea surface temperatures. Unfortunately we have no explanation at present why these months would show positive correlations.

The data for St. Andrews show a number of months with low temperatures during the past several years. December temperatures in 1986 were the lowest since 1972. The mean temperature for June in 1985 was lower than it has been since 1964. March and April surface temperatures show decreases in recent years but are no lower than they were in the late 1970's. There may be a critical effect of recent June and December sea surface temperatures which has increased post-smolt mortality in recent years.

It may prove worthwhile to examine the effect of sea surface temperatures on longer data sets such as commercial catches or sport catches once the data before 1960 become available (possibly within the next year).

5. Predators

5.1 Birds

The belted kingfisher (Megaceryle alcyon) is known to ingest a wide variety of prey items, including crustaceans, insects, frogs, lizards, snakes, mice, berries and small fish. Investigation into the diet of kingfishers on the Margaree river has shown that large quantities of fish are ingested (White, 1936). Diet analysis was done both by collection of birds and by examination of disgorged pellets which are frequently found around kingfisher perch sites. The birds seem to take parr during their last year in the river (Huntsman, 1941), possibly because by then they have attained an optimal prey size. Large numbers of parr were present in pellets collected from certain areas of the river (78.3% of pellets). However, the large number present was probably related to kingfishers preying on the most abundant prey type. In other habitats, pools and backwaters, the pellets contained large numbers of sticklebacks (95.0%). The kingfisher is thought to concentrate on the prey which are most easily obtained. This theory is supported by the fact that kingfisher predominantly took salmon when the water was low (Huntsman, 1941) and the parr were easy to catch.

The common merganser (Mergus merganser), and the red breasted merganser (Mergus serrator) are fish-eating birds, however diet analysis has shown that a small proportion of insect and vegetative material is also ingested (White, 1936). A study in the Margaree river showed that concentrations of mergansers were found in areas where salmon and trout were abundant, although other areas abounded with species such as eels, sticklebacks, killifish and suckers. It is not known if the concentrations of mergansers were related to the large numbers of salmon and trout. Mergansers also tend to take prey that are easily obtained, therefore predation on salmon and trout is high (salmon consisted 82.2% and trout 6.3% of the diet). Parr and trout were abundant where numbers of mergansers were reduced by culling, however salmonid abundance was low where natural merganser numbers existed (Elson, 1962).

The double-crested cormorant (Phalacrocorax auritus) and the great cormorant (Phalacrocorax carbo) are large fish-eating birds whose numbers have experienced significant increases in recent years (Milton and Austin-Smith, 1983). Cormorants have been persecuted due to the belief that they feed on important commercial and sport fishes (Gallant, 1988). Studies have shown however that the diet of cormorants is largely composed of commercially unimportant fish such as sticklebacks, killifish and silversides. Craven and Lev's work (1987) agrees with these findings, noting that cormorants in Lake Superior forage on sticklebacks, sculpin and burbot. Kehoe (1987) examining the effects of cormorants on salmon genetics, came to the same conclusions. Kehoe (ibid) noted that increases in cormorant numbers had coincided with decreases in return rates of tags. Cormorant collections for gut analysis and examination of colonies for tags produced low estimates of predation (0.1-0.2%), and showed that the effect of cormorant predation was relatively minor. Increases in cormorant numbers in recent years may be due to increased protective legislation (Drury, 1973, 1974).

The osprey (Pandion haliaetus) is a large fish eating raptor. In the past, populations had been threatened due to low reproductive success related to the use of the pesticide DDT. Since the use of DDT has been prohibited, the osprey numbers have gradually increased. Greene (1987) studied the feeding behaviour of ospreys at the Cow Bay estuary in Halifax Co. N.S., where a colony of 11 nests is located. The diet of osprey was concentrated on 4 species accounting for 90% of the diet: winter flounder, pollock, alewife and smelt. The majority of the diet consisted of the 3 schooling species (pollock,alewife and smelt). Members of the colony were found to initiate foraging when a bird would return to the colony with a schooling species. Since Atlantic salmon are known to school, they might be attractive prey for ospreys.

The great blue heron (Ardea herodias) is a large wading bird commonly breeding in colonies in Eastern Canada. They are opportunistic feeders preying on small vertebrates, usually fish (Quinney, 1979). Quinney (ibid) studied the diet of the great blue heron on Boot Island in the Minas Basin, N.S. The diet was sampled from collections of regurgitated food of adults and juveniles. Large numbers of mummichog and silversides were ingested. Eels, gaspereau and pollock were also taken. No salmonids were taken, however it is not known if this was due to their lack of presence in the waters around Boot Island. Peifer (1979) found that herons in central Minnesota preyed on bullheads, sunfish and various small mammals. These studies seem to indicate that salmonids do not form part of the diet of great blue herons, and they are probably not a threat to the Atlantic salmon population.

5.2 Fish

A potential predator of young salmon in freshwater is the American eel (Anguilla rostrata). Godfrey (1957) in a study on the diet of eels in New Brunswick noted that larger eels (over 152 mm long) are important predators of parr and fry. White (1933) found the remains of 429 salmon fry in the stomach of a large eel (50 cm). However Smith and Saunders (1955) concluded that eels avoid the cooler spring-fed waters where young salmon and brook trout are abundant. Parey (1985) hypothesized that eels are important predators of salmon since they may ingest large numbers of eggs when redds are excavated. His findings, however, disprove his hypothesis since he found the main food of eels consisted of benthic invertebrates. Because the habitat requirements of young salmon and eels do not entirely overlap and the studies relating to salmonid predation reveal little interaction, the amount of salmon mortality due to eels may be low.

The Atlantic cod (Gadus morhua) is a potential predator of the salmon in the marine stage of the salmon life cycle (Granger and Priest, 1988). Cod are voracious feeders ingesting a variety of invertebrates as young adults and juveniles, however fish are the predominant food once they exceed 51 cm in length (Leim and Scott, 1966). They do not concentrate on a single fish species but may take herring, sand lance, mackerel, redfish, hake, flounders, blennies, cunner, sculpins, silversides, shad, gaspereau, young cod and haddock. Predation of salmon has been reported in Europe (Hvidsten and Lund, 1988). In the estuary of the River Orkla of Norway, predation on wild and hatchery-reared salmon was estimated at 20%. It is possible that cod do take salmon on occasion. However, since cod prey on many other species and they themselves are the target of commercial fisheries at a variety of locations which maintain their ocean population size at low levels and their predation on Atlantic salmon is probably not significant.

The striped bass (Morone saxatilis) is noted for its piscivorous habits as adults and to some extent as juveniles. In a study of the diet of juvenile striped bass in Long Island, the majority of prey items were invertebrates. For the most part, the fish taken were of minimal commercial or sport value and no salmonids were recorded. Larger fish (600 mm or more) fed predominantly on fish, however invertebrates were still an important part of the diet. Rulifson and McKenna (1987), in a study of striped bass in the upper Bay of Fundy found that invertebrates were important in the diet of juveniles while the adults were mainly piscivores. None of the fish prey items were salmonids. The striped bass are probably not a major predator of salmon, although it is possible that they would take one on occasion.

5.3 Mammals

The river otter (Lutra canadensis) is an important furbearer which is a potential game fish predator (Knudsen and Hale, 1968). Fish were the most important prey item of otters in the Great Lakes region (Knudsen and Hale, 1968) as well as in Idaho (Melquist and Hornocker, 1983) however invertebrates, birds, mammals and reptiles are also taken. In Idaho, diet contained kokanee salmon in small percentages (2%), however large numbers of unidentifiable salmonids were also present in scat remains (17-31%). The most common type of fish present in the diet of otter in the Great Lakes were forage fish. The rate of predation on trout was from less than 1% to 11%. The variability in the percentages ingested was due to varying abundance of trout. Ryder (1955) concluded that otters capture prey according to their abundance and that otters may actually benefit trout by eliminating some of the competitors which are usually more abundant than the trout. The otter is probably not a threat to salmon for the same reason. Otter population numbers have not experienced noticeable increases therefore the impact is probably not significant.

The mink (Mustela vison) is a small furbearer found near marshes and in close association to streams and rivers. Wilson (1954) examined digestive tracts and scat samples in order to identify the winter diet of mink in North Carolina. Mink eat a variety of prey including fish, birds, mammals, invertebrates, amphibians and reptiles. Fish remains were found in 61% of digestive tracts and 13% of scats. None of the fish species were important for commercial or sport fishing (killifish, yellow perch, catfish, sunfish, eels, pickerel). In agricultural areas of Michigan, the diet is composed mainly of mammals however the fish which were taken are not sport or commercial species (Sealander, 1943). The diet of mink varies with what is available in their habitat. The impact on salmon is probably not significant since the diet is varied and numbers of mink are reduced by trapping.

Considerable blame for depredation of salmon stocks has been placed on seals. The 1986 Report of the Royal Commission notes that the grey seal appears to be the only species taking salmon, although harbour seals (Phoca vitulina) take salmon on the West coast (Spalding, 1964). Mansfield (1963), however, indicated that harbour seals on the Atlantic coast also take salmon. Both of these seal populations are presently distributed along the Nova Scotian coastline, but grey seals (Halichoerus grypus) are found within the Bay of Fundy only from Brier Island to Grand Manan (Stobo, pers. comm.). The total population estimate in 1977 for grey seals in the Gulf of St. Lawrence, eastern Nova Scotia and Sable Island was 30,080. The estimated food consumption for a population this size was 47,083 metric tons (Mansfield and Beck, 1977). With an estimated rate of population growth of 9% per year (Ibid.), the grey seal population in 1988 would be around 77,000. A population of this size would be estimated to ingest 121,080 metric tons of food. The annual grey seal pup production on Sable Island (Canada) alone, has undergone an increase from approximately 370 pups in 1962 to 4450 in 1982 (Gulland, 1987). Since the population growth has increased the incidence of predation on commercially important species has probably also increased. Most of the seal predation on salmon is thought to occur where the salmon enter narrows and in river mouths during their spawning migration. Harwood and Greenwood (1985) stated that even if only a few salmon are taken by seals, since the salmon stocks are not large, the impact on the salmon population may still be considerable. Gulland

(1987) also suggested that most of the prey taken are sick or in poor condition however, observations abound of seals pursuing very rapid swimming salmon. Ongoing research in Newfoundland (Ni, pers. comm.) on assessment of salmon-seal interactions may result in a management policy which will adequately resolve the problems of seal predation.

There are other potential predators on which there is little information in the literature. The brook trout (Salvelinus fontinalis) is known to feed on almost any living organism (Scott and Crossman, 1973), however no references of predation on Atlantic salmon were found in the literature. Pollock (Pollachius virens) are voracious feeders in the ocean (Scott and Crossman, 1973), however no mention was made of the possibility of taking salmon. Spiny dogfish (Squalus acanthias) have been reputed to take many commercial species including salmon (Scott and Crossman, 1973). Since it is such a voracious opportunistic feeder in the ocean, it seems that this predator might have an impact on the salmon population. A study on the West coast to determine if predation on salmonids occurred revealed no evidence of this nature (Robinson et al, 1982). None of the collected dogfish contained remains of salmon in their digestive tracts. No study of this nature has occured on the East coast and it might be timely to consider the diet of dogfish of the Atlantic since their numbers have increased dramatically in recent years (Scott and Scott, 1988). No information on bear predation was located in the literature, however Granger and Priest (1988) suggested that it might be important. Valle (1985) reported that gulls and Caspian terns were observed preying upon salmon smolts. However, Arctic and common terns on the East coast of North America are probably too small to prey on post-smolts (R. Newell, pers. comm.). No other record of gull predation was found in the literature. In Valle (1985) large numbers of these smolts were ingested from 1-30 days after tagging.

Predation may then have been increased due to tagging mortality and/or the smolts being in an altered state.

The predators of salmon which are of major concern are those where population sizes have increased in recent years. Among these are double-crested cormorants, seals and dogfish. The diet of these populations has not been studied intensively on the Atlantic coast. Because of this, it has not been possible to accurately determine the effect that these predators might have on salmon. Future studies examining the proportion of salmon in these predators diets might help determine the impact of these potential predators.

6. Aquaculture

The aquaculture industry in the Bay of Fundy, New Brunswick side has increased dramatically from 1 farm in 1979 to 34 in 1987 (Cook, 1988). Aquaculture operations are particularly concentrated within Passamaquoddy Bay, N.B. The industry is obviously of considerable importance in this region. Development of aquaculture has been slower on the Nova Scotian side of the Bay of Fundy. Presently 3 hatcheries are operating in this area: the first is a federal hatchery located on the Cornwallis River, Kings Co.; privately run hatcheries are located on the Moose River, Annapolis Co. and the other on the Sissiboo River, Digby Co. No salmon farms are known to be in existence on the Nova Scotia side of the Bay of Fundy.

7. Local By-Catch:

Reports on the catch of salmon as by-catch in the commercial fishery are few. One possible concern is the recent increase in herring seining for the herring roe industry. The gear used in this fishery is of a suitable size to capture both post-smolts and returning adults. Although there are no reports of the capture of salmon in this fishery it is a possibility. If the fishery impacts on salmon abundance , changes in salmon landings should show a correlation with herring fishery effort. It was not possible to find an estimate of herring fishing effort for the Inner Bay of Fundy but for the whole of the region 4WX the number of seine sets were 2295, 1850, and 2213 for 1985, 1986, and 1987 respectively. The catches for those years showed a similar trend with catches for 1986 being lower than the other two years (Stephenson and Power, 1988).

Trends in the catches of area 4WX indicate relatively high catches in the mid to late '70's with a decrease in the early '80's and a resurgence in 1985 to present (Table 15). Estimates of landings for the upper Bay of Fundy (calculated from log books) from 1977 to 1987 show a sharp reduction in herring landings from 1982 to1986. It is likely that this represents a reduction in effort. M. Power (pers. comm.) indicated that there was a closure of the upper Bay of Fundy herring seine fishery for a short period but it was reopened in 1986.

If the seine fishery is affecting post-smolt survival, then there should be a resulting decline in salmon stocks in the year after the re-opening of the herring fishery. An increase in salmon stocks for the period from 1983 to 1986 when the herring fishery appears to have dropped considerably should also occur. There is a surge in salmon catches in the rivers around Cobequid Bay in 1983, the year after the decline of the upper bay herring fishery. The salmon stocks however, did not remain at a high level for the entire period of the reduction of the herring fishery (Figure 1). If there is a relationship between the herring fishery and salmon landings, correlation analysis should indicate a significant relationship. The results of correlation analysis with salmon and herring landings showed no significant correlation for the 0 to 5 year lags.

The lack of a significant correlation between salmon catches and herring landings suggests that herring seine operations probably do not impact upon salmon. More conclusive information could be obtained by periodic checks of herring seiners by fisheries observers to determine if salmon are caught but not reported.

8. Greenland Fishery

The Greenland fishery may have a considerable effect on Atlantic salmon stocks of the Maritime provinces, especially the multiple-sea-winter salmon. Inner Bay of Fundy salmon stocks are probably not significantly affected by the Greenland fishery since most are grilse rivers and grilse are able to pass through the mesh size used in the Greenland nets. Reddin and Shearer (1987) noted that all grilse taken off west Greenland were thought to be of Greenland origin. Before the fishery commenced in the early 1960's, about 22% of tagged salmon were noted returning to their river of origin (either by angler capture or by noting tags at counting fences). After the Greenland fishery had just been initiated, the returns dropped to 18%, and further dropped to 9-12% by 1968 (Paloheimo and Elson, 1974). Salmon catches peaked at 2,689 tonnes in 1971. A quota in 1976 reduced allowable catches to 1,190 tonnes. In 1984 and 1985, quotas were further reduced to 870 and 852 tonnes respectively (Reddin and Shearer, 1987). The percentage of North American origin fish was also quite high. During the period 1969-1980, the percentage of North American fish in the Greenland fishery was between 34-58%. The fishery took between 132,000 and 5,765,000 pounds of salmon from 1960 to 1971 (Paloheimo and Elson, 1974). These figures indicate high mortality of North American salmon. Paloheimo and Elson (1974) noted that although the direct loss of salmon through fishing is considerable, the reduction of spawning stocks and future long-term loss of production may be even more serious. The Greenland fishery can thus be considered a significant mortality factor for some salmon stocks but perhaps not for the inner Bay of Fundy.

9. Diseases

Bacterial kidney disease (BKD) is a common condition reported in hatchery operations and it has been noted in wild populations (Paterson et al, 1979). The disease is caused by the bacteria Renibacterium salmoninarum (Shortt et al, 1988). Laboratory examination of infected individuals revealed the characteristic grossly enlarged suppurative lesions. The condition is apparent in field observations of kidneys of heavily infected fish, which show "white boils" in various areas. Cornick et al (1988) noted that this disease affected cultured fish from fresh and saltwater sites in Nova Scotia and New Brunswick.

Furunculosis is another bacterial disease and is caused by Aeromonas salmonicida . The bacterium is presumed to enter via the digestive tract, thereafter spreading in the bloodstream. The external symptoms of affected fish are gross lesions in the body musculature (Fish, 1937).Herman (1968) considered the status in Canada of the furunculosis disease as isolated or reported from wild fish. Furunculosis is primarily a problem in hatcheries, but, the incidence of the disease in the wild is increased during periods of low discharge (Smith, 1962). It is also suggested to be most common during the summer when in addition to low water levels the water temperatures are high (Smith, 1960). Furunculosis is found only in New Brunswick and is endemic in several systems where smolts are grown (Cornick et al, 1988). The latent state of A. salmonicida cannot be detected, even with bacterial culture techniques. This means that salmon stocks might be carrying the disease without showing symptoms.

Enteric red mouth (ERM) is caused by the bacteria Aeromonas hydrophila (Klontz and Anderson, 1970). The disease is systemic and the major symptoms are inflammation of the areas around the head and mouth, hence "redmouth disease" (Ross et al, 1966). The disease occurs in New

Brunswick in wild stocks and in Nova Scotia in both wild and cultured stocks (Cornick et al, 1988).

Furunculosis, ERM and BKD are the most important diseases to consider when stocking or transferring fish. Infectious pancreatic necrosis (IPN) and vibriosis are also diseases which are known to affect salmonids, however these are restricted to aquaculture situations. IPN is present in all Maritime provinces in the carrier state, while vibriosis is present in all provinces and is restricted to marine culture.

The effects of diseases are most devastating in hatchery situations, where the fish are concentrated and the chance of an epidemic is increased. In these situations, losses due to disease can be heavy. The diseases can spread through the water, however this occurs only when animals are exposed to large numbers of bacteria. Epidemics in the wild are rare because of this, therefore disease is probably not a major mortality factor in wild salmon. There have been no known outbreaks of disease in wild salmon stocks in the Bay of Fundy region.

10. Stream Blockages and Point Source Pollution:

Obstructions to salmon migration were considerable in the 19th and early 20th century (Granger and Priest, 1988). The importance of the logging industry resulted in the construction of many dams on the rivers of the upper Bay of Fundy, especially in New Brunswick. When the lumbering industry collapsed, maintenance of the dams ceased resulting eventually in their destruction. Two rivers which are well documented are the Upper Salmon and Point Wolfe Rivers of Fundy National Park. The dam on the Upper Salmon River collapsed in 1954 resulting in the gradual increase of the salmon stocks (Dadswell, 1968). The dam on the Point Wolfe River was not destroyed until 1985 when half of the dam was removed (Granger and Priest, 1988). This river underwent a stocking program from 1982-1985 in anticipation of the construction of a fishway. The stocking has resulted in the establishment of a small naturally spawning population of Atlantic salmon. Presently there are four rivers in the upper Bay of Fundy region which are blocked or altered. The west branch of the Bass River is reportedly blocked by logs about one kilometre from its junction with the Bass River (Hall, 1987). The Gaspereau and St. Croix Rivers are altered for the production of hydro-electric power generation and has a series of dams along their course. The Avon River is blocked by a tidal causway at the seaward end of its estuary. These dams have a good system of fish passages associated with them to allow for the passage of anadromous fish species. In the case of the Gaspereau River the magnitude of the gaspereau fishery on the lower portion of the river indicates the fish passage system is very effective. The Chiganois and Great Village Rivers both have aboideaus constructed at their mouths to protect farm lands from high tides but these are not thought to hamper fish passage.

The rivers of the upper Bay of Fundy are remarkably clean and free of pollution. The only exceptions appear to be the Salmon, North, and Stewiacke Rivers. The North and Stewiacke Rivers have high silt loads during periods of high surface run-off. Siltation in the North River is associated with the operation of a number of gravel pits along the course of the lower section of the river. The Stewiacke River siltation is mainly the result of agricultural activities in its large drainage basin. The high flow and steep gradients of most of these rivers results in little of the silt being deposited in the area of spawning habitat. The Salmon River is the only river of the upper Bay of Fundy that has significant pollution sources. The towns of Truro and Bible Hill both empty their sewage into the Salmon River below the head of the tide. In addition to the sewage, three industries in the Truro area dump effluent into the Salmon River. The cheese factory releases whey products. Despite the construction of a settling pond there is still a milky effluent escaping into the river (Hall, pers. comm.). Stanfields produces an effluent that contains fabric dyes, and the Domtar wood treatment plant is reported to release creosote-based chemicals (Ibid.). In recent years as a result of public pressure there has been a reduction in the amount of effluent released by industry. Therefore it is unlikely that changes in pollution levels caused a decrease in salmon stocks.

The pollution and siltation in the Salmon and Stewiacke Rivers is concentrated in the main channels towards the lower end of the rivers. As a result, the habitats for spawning and rearing of salmon are not heavily affected. It is unlikely that the pollution or siltation could affect upstream migration of adults or the downstream migration of smolts.

11. Exotics

The introduction of exotic species can often be detrimental to the survival of native stocks, especially when they are closely related. The possibility that there will be conflicts between the introduced and native species may be related to overlap in habitat or diet requirements and predation of either species on the other may occur. There might also be aggressive interactions which could produce reduced growth rates due to energy loss from territorial fighting. Introduction of exotics must be thoroughly examined to reduce the risk of jeopardizing an existing species for the sake of another.

Introductions of the coho salmon, Oncorhynchus kisutch , have been undertaken in the New England states between 1971-1982. Since the original stocking attempts, several records of coho have been reported in New Brunswick and Nova Scotia (Martin and Dadswell, 1983). The possibility that spawning populations may become established has produced concerns regarding the effect that coho might have on Atlantic salmon. The coho salmon spawn later than the Atlantic, leading to possible destruction of Atlantic salmon redds. Also, interspecific competition, the predation of Atlantic salmon parr and fry by the coho salmon parr, which have a greater growth rate, are possible detrimental effects. Since coho have a greater growth rate than Atlantic salmon, they have a greater competitive advantage because large fish are dominant over small fish (Gibson, 1981). It is also possible that since the 2 species are closely related, that diseases or harmful parasites could be transmitted to the Atlantic salmon population.

A second non-native species present in the Maritime provinces is the rainbow or steelhead trout, Salmo gairdneri. The rainbow trout was introduced in New Brunswick in 1900, Nova Scotia in 1899 and Prince Edward Island in 1924 (MacCrimmon, 1971). This species spawns in the spring (mid-

April to late June) in redds excavated by females in fine gravel. Atlantic salmon prefer a coarser substrate than rainbow trout, and conflict between the two species for spawning habitat is probably minimal. Rainbow trout however are more aggressive than Atlantic salmon (Gibson, 1981). Juvenile rainbow trout may therefore displace salmon parr from favourable habitat (Whoriskey et al, 1981). Rainbow trout feed on a variety of invertebrates, other fishes (usually not rainbow trout), and fish eggs (commonly those of salmon). Rainbow trout have also been found to ingest young salmon in Alaska during certain times of the year (McPhail and Lindsey, 1970). Young rainbow trout compete successfully with other salmonids for food (Scott and Crossman, 1973). The rainbow trout is said to be the host of many parasites too numerous to list, and is a carrier of salmonid bacterial diseases such as furunculosis and bacterial kidney disease. The introduction of rainbow trout in western North America has resulted in interbreeding and ultimately the loss of many populations of salmon (Beland et al, 1981). The rainbow trout may then be a threat to the Atlantic salmon as a predator, interspecific competitor, possible source of detrimental parasites and diseases.

Another introduced species which possibly interacts with Atlantic salmon is the brown trout (Salmo trutta). It is native to Europe and western Asia and was first introduced to Canadian waters in Newfoundland in 1884. All Canadian provinces have had successful introductions with the exception of Prince Edward Island. Introductions were undertaken in New Brunswick in 1921 and Nova Scotia in 1923. Between 1952 and 1957, 394,953 brown trout were stocked in the Stewiacke river (Morantz, 1978). Spawning of brown trout occurs in late autumn to early winter, in shallow gravel beds in streams. The female creates a shallow depression in the gravel. Brown trout have similar requirements as brook trout and are often in competition for resources, however brown trout are more tolerant to higher temperatures. Brown trout are carnivorous, and eat other salmonids. Brown trout are also carriers of the bacterial disease furunculosis.

The brown trout is closely related to the Atlantic salmon. For this reason, concerns have been raised about the possibility of hybridization between the two species. Wild hybrids of Salmo salar x Salmo trutta have already been collected from the Stewiacke River, Nova Scotia (Beland et al, 1981). It is suggested that if hybridization occurs frequently enough, the result would be significant genetic introgression between the two species and ultimately the loss of salmon or trout breeding populations. The hybrids appear to be a good example of "hybrid vigor" (Nyman, 1970), demonstrating high survival rates, faster growth and earlier maturation than the parent species. With the hybrids possessing these advantages over the parents, the consequences of a high frequency of interbreeding would probably signify that the hybrids would eventually outcompete both parental species. The incidence of hybridization in 1978 was apparently low (Beland et al, 1981), however a larger scale study might prove worthwhile.

A single sockeye salmon (Oncorhynchus nerka) is rumoured to have been taken in the Tusket River system. The kokanee, the freshwater form of the sockeye, has been introduced in Maine, Connecticut and New York, as well as the Great Lakes (Scott and Crossman, 1973). It is not known if these may occasionally wander into salt water or if it may be expanding its range. If this is the case the sockeye may become an important competitor of the Atlantic salmon in the future.

12. Summary

Many of the factors which may effect the survival of Atlantic salmon at any stage of the life cycle (egg, fry, parr, smolt, post-smolt, adult) are poorly understood. This project has identified a number of possible negative factors.

The presence of exotic species is not a problem at the present time, however, if such species continue to expand they may result in reduced Atlantic salmon stocks. Coho salmon, rainbow trout, and brown trout are found in the upper Bay of Fundy and all are known to compete with Atlantic salmon. The rainbow trout is a very aggressive species and the coho grows faster than the Atlantic salmon giving it a competitive advantage.

Negative effects of aquaculture and disease are also not believed to be a problem at the present time. Aquaculture is not carried out in the upper Bay of Fundy with the exception of a government fish hatchery on the Cornwallis River. There may be negative effects with wild salmon encountering the area of intense aquaculture activity at the mouth of the Bay. However, there is little disease at present in the cultured stocks of the Bay of Fundy and and there have been no known outbreaks of disease in wild stocks.

Predation on salmon is poorly understood. Kingfishers and mergansers are known to be heavy predators but are not known to be increasing in abundance at the present time. Cormorants are presently increasing in number and are thought by some to be significant predators. However, the literature suggests that cormorant predation on salmon is highly exaggerated. Predators of salmon in the marine environment are poorly known. Many species such as pollack which might be potential predators are currently declining in abundance. Two possible predators which are currently on the increase are the spiny dogfish and seals. The spiny dogfish moves onto the Scotian Shelf and into the Bay of Fundy in early summer just after the smolts have migrated to sea.

Their diet is poorly studied, however, they may prey on smolts and post-smolts. Seal populations are also expanding. Grey seals are increasing in number around the mouth of the Bay of Fundy and harbour seals are thought to be increasing throughout the Bay. Once again the prey of these species is not well understood due to rapid digestion of food. Both species are known to ingest salmon to some degree. With large seal populations, numbers of salmon taken by each seal does not have to be large to exert a large impact on low salmon populations.

Two environmental variables are significantly correlated with salmon catches. Discharge (precipitation) appears to have a number of effects. High discharge at spawning has negative effects probably becuase of exposure and freezing of redds during low winter discharge. High spring discharge has negative effects on emerging fry. High discharge is often associated with a decrease in pH, a factor known to decrease the survival of young fry. High discharge in summer and early fall have a beneficial effect on fry and 1+ parr. This is thought to be the result of lower avian predator success and less competition for territories. Sea surface temperature was found to show significant effects. Low December and June temperatures coincide with reduced future adult runs. Sea surface temperatures for both December and June have been lower than average in recent years and therefore may have some responsiblity for the recent reduction in stocks.

Our review has identified certain topics where there is insufficient data with which to draw conclusions about their effects on Atlantic salmon stocks. All of the factors identified as possibly contributing to salmon stock reductions beg further study in the near future. To ensure a sport fishery for salmon in years to come a better understanding of the interactions between salmon and its environment is a necessity. The sport catch has increased to levels in excess of the recent commercial catches. There is a need for a review of the number of salmon retained by this fishery.

13. Recommendations

Based on the findings of this study, several recommendations are proposed in order to clarify questions about environmental and other factors which might affect salmon population numbers.

1) **Mandatory return of catch and effort data.** This is important since it will provide better estimates of sport catch and the actual time spent fishing. It is our recommendation that fishermen be required to complete a short questionnaire about how many fish were caught, as well as the location of the catch and the number of hours spent fishing. This will enable more accurate assessment of the stocks and will enhance management programs.

2) **Establishment of index rivers: suggested are the Point Wolfe River in New Brunswick and the Portapique River in Nova Scotia.** The Point Wolfe is presently closed to fishing, however several sources have suggested maintaining the closure permanently. The purpose of this action would be as a comparative site to contrast with exploited rivers. Studies on population dynamics of exploited versus unexploited populations may reveal information on mortality factors related to the sport fishery.

3) **Study the effects of environmental conditions on parr survival.** Environmental conditions such as pH, temperature, habitat quality and river discharge may be related to parr survival. Through data collection of environmental requirements for parr in major salmon rivers, critical stages of parr development and the environmental conditions which influence survival may be elucidated.

4) **Estimates of spawners could be assessed more accurately by swim -through surveys of spawning areas.** By determining the number of fish which actually spawn, it is possible to regulate the numbers taken in the sport fishery to ensure that a minimum number of eggs is laid. This would ensure maintenance of salmon populations and the sport fishery.

5) **Continued assessment of parr and spawning habitat.** Present studies depend mostly on aerial photographs and contour maps with minimal amounts of actual onsite assessments. Because of this, the potential salmon production area may be under or overestimated. Field studies on major salmon production rivers would result in more accurate measurement. Actual salmon production could then be compared to potential production. This information would be useful in producing management plans to optimize salmon production.

6) **Regulation of population levels through limiting exploitation rather than stocking.** Quite often stocking is undertaken indiscriminantly without having a complete idea of the number of parr already present. Problems arise when a river which is close to its parr carrying capacity receives additional numbers due to stocking. When this occurs, the wild parr will defend their territory against the hatchery parr and high levels of aggression result. The hatchery parr are not as well suited to wild existence having a narrow spectrum of food selection. Furthermore introduction to the wild where other salmonids such as brook trout occur may result in low survival. The end result is a few additional fish at high cost. Since wild parr have better survival rates, a better approach to regulating populations would be to allow more individuals to spawn. Reductions in exploitation could be imposed to accomplish this. In

addition, the revenue saved from stocking could be placed on habitat improvement, possibly to increase the carrying capacity of salmon rivers.

7) **Examine dogfish stomachs in the upper Bay of Fundy to determine the extent of predation on post-smolts.** Recent increases in dogfish populations have coincided with decreased numbers of salmon in the inner Bay of Fundy. Studies in the past have not reached conclusive evidence as to whether dogfish predation is a significant mortality factor.

8) **Thorough survey to determine the distribution of exotic species such as rainbow and brown trout as well as coho salmon.** Information is often available on the location, number and date of introductions of exotics. However, there have been few follow-up studies to determine the success of these introductions. Since exotics have been demonstrated to affect salmon in several ways, it is important to determine the numbers present and their distribution. Regular monitoring of these populations will help to predict possible fluctuations in salmon numbers. If the numbers of exotics are thought to be excessive and the negative effects of these species on salmon too great, action may be taken to offset their impact by eradication or other procedures.

9) **Determine the extent of seal predation on salmon.** Past studies have indicated that salmon remains have been found in the digestive tracts of seals, however the question of the magnitude of the impact of seals on salmon populations has yet to be resolved. Future studies should attempt to determine the impact of seals on the salmon population. (There are currently studies being done in Newfoundland on the diet of seals. The results of these studies should be available in the next year.)

10) **Attempt to determine grilse migrations.** Many questions have been raised about the extent of grilse migrations. A more thorough understanding of migratory patterns of post-smolts might indicate possible mortality factors while at sea.

11) **A more regular monitoring program of important water chemistry parameters (i.e. pH).** Water samples could be taken at weekly intervals during the critical periods of the year (after the spring thaw and into June after most fry have hatched) and tested by interested individuals. A data series of this type would enable high and low mortalities due to pH to be predicted, and to monitor patterns of change in pH over time.

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Table 1: Rivers of the Inner Bay of Fundy for which some historical Atlantic salmon angling has been reported. Salmon stocks have been classified as: A, late run, predominently grilse and repeat spawners; B, early run, predominently two-sea-winter, few repeat spawners, and; C, unknown, i.e., little or no reported catches.

River	A	B	C
Cornwallis	X		
Gaspereau (Kings Co. N.S.)		X	
St. Croix (Hants Co. N.S.)	X		
Kennetcook	X		
Shubenacadie	X		
Stewiacke	X		
Salmon (Colchester Co. N.S.)	X		
North (Colchester Co. N.S.)	X		
Chiganois	X		
Debert	X		
Folly	X		
Great Village	X		
Portapique	X		
Bass (Colchester Co. N.S.)	X		
Little Bass	X		
Economy	X		
Harrington	X		
Diligent			X
Apple	X		
River Hebert	X		
Maccan	X		
Napan (Cumberland Co. N.S.)			X
Tantramar			X
Demoiselle			X
Crooked Creek			X
Shepody			X
West (Albert Co. N.B.)			X
Alma	X		
Point Wolfe	X		
Coverdale			X
Turtle Creek			X
Weldon Creek			X
Pollett	X		
Petitcodiac	X		
Big Salmon	X		
Irish			X
Mosher (St. John Co. N.B.)			X

from Amiro, 1987.

Table 2: Summary of dissolved oxygen (mg/l) and pH values (determined by the Water Quality Branch of Environment Canada) for selected rivers of Nova Scotia and New Brunswick.

River	Period of Samples	Oxygen Mean	Oxygen St. Error	pH Mean	pH St. Error
Annapolis	Jan. 1976-Jan. 1978	11.8	0.58	6.5	0.11
Big Salmon	Dec. 1970-Nov. 1973	--	--	6.0	0.06
Cornwallis	Apr. 1971-Oct. 1976	10.2	1.20	6.6	0.08
Kennebecasis	Aug. 1964-Sep. 1988	10.5	0.27	6.9	0.04
Maccan	Dec. 1974-Mar. 1978	11.9	0.52	6.7	0.11
Margaree	Aug. 1965-Sep. 1988	12.4	0.39	6.6	0.04
North	Jun. 1972-Mar. 1974	--	--	6.1	0.14
Phillip	Aug. 1971-Sep. 1977	12.0	0.50	6.3	0.12
Salmon	Apr. 1971-Feb. 1974	--	--	6.2	0.09
Shubenacadie	Apr. 1971-Jul. 1979	10.7	0.47	5.6	0.10
St. John	Jan. 1971-Oct. 1985	11.9	0.75	6.7	0.07
Stewiacke	Apr. 1971-Sep. 1977	11.2	0.49	6.0	0.08
Wallace	May 1966-Nov. 1988	10.7	0.88	6.6	0.03

Table 3: Summary of pH values for several Cobequid Bay rivers in 1984 indicating differences between summer and winter readings (Ashfield et. al., 1987).

River	Sample	August	December
Chiganois	1	6.99	6.31
	2	6.88	6.27
	3	8.40	6.84
Debert	1	7.25	6.49
	2	7.85	6.51
	3	6.92	5.87
Folly	1	8.15	6.55
	2	7.65	6.10
	3	6.61	6.44
Great Village	1	7.98	6.78
	2	7.50	6.10
	3	7.33	6.39
Portapique	1	7.12	6.52
	2	7.73	6.60
	3	7.30	6.48
Bass	1	7.08	6.32
	2	7.59	6.43
Economy	1	7.12	5.98
	2	6.75	6.15

Table 4: Correlation of Truro precipitation (mm) and Salmon River discharge (m^3/sec) on a monthly basis.

Month	N	r	p
January	11	0.82	0.002
February	11	0.57	0.063
March	10	0.82	0.004
April	10	0.37	0.289
May	11	0.66	0.022
June	9	0.80	0.010
July	7	0.66	0.103
August	8	0.64	0.088
September	9	0.48	0.194
October	10	0.84	0.002
November	10	0.82	0.004
December	11	0.88	0.001

Table 5: Conversion equations to predict Truro precipitation from Parrsboro and Upper Stewiacke precipitation data.

Month	Regression Equation	r^2
January	T = -1.25 + 0.39 P + 0.58 S	0.78
February	T = 23.74 + 0.09 P + 0.60 S	0.66
March	T = 9.99 + 0.29 P + 0.52 S	0.54
April	T = 11.14 + 0.19 P + 0.61 S	0.66
May	T = 6.17 + 0.22 P + 0.66 S	0.76
June	T = 2.77 + 0.23 P + 0.65 S	0.80
July	T = 10.10 + 0.28 P + 0.56 S	0.65
August	T = 12.31 + 0.19 P + 0.64 S	0.73
September	T = 16.35 + 0.32 P + 0.46 S	0.76
October	T = 0.75 + 0.30 P + 0.66 S	0.79
November	T = 12.29 + 0.22 P + 0.64 S	0.70
December	T = 9.11 + 0.28 P + 0.61 S	0.75

where T = Truro, P = Parrsboro, S = Upper Stewiacke

Table 6: Summary of mean monthly precipitation- salmon catch correlations for the rivers of Cobequid Bay. (Table based on analysis of 10 Cobequid Bay rivers.) Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

		Lag*						
Month		0	1	2	3	4	5	6
January	+	0	2	2	0	1	1	1
	-	0	0	0	0	0	0	0
February	+	1	1	0	0	0	0	0
	-	0	0	0	0	2	0	0
March	+	0	2	0	0	0	5	0
	-	0	0	1	0	0	0	0
April	+	0	0	0	0	0	1	7
	-	0	0	0	2	0	0	0
May	+	5	0	0	0	0	2	0
	-	0	1	0	0	1	0	0
June	+	0	0	4	0	0	0	1
	-	0	0	0	0	0	0	0
July	+	1	0	0	3	0	0	0
	-	0	0	0	0	0	0	0
August	+	0	1	0	1	2	0	1
	-	0	0	1	0	0	0	0
Sept.	+	0	2	0	2	0	1	0
	-	0	0	2	0	2	0	0
October	+	0	0	0	2	0	1	0
	-	0	0	0	0	1	0	3
Nov.	+	0	0	0	0	0	0	0
	-	0	3	0	0	0	0	0
Dec.	+	0	1	0	0	0	0	0
	-	0	0	2	0	1	0	0

Based on figures in Appendix 5A.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 7: Summary of mean monthly precipitation- salmon catch correlations for the rivers of Bay of Fundy. (Table based on analysis of 7 Bay of Fundy rivers). Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

		Lag*						
Month		0	1	2	3	4	5	6
January	+	1	1	0	0	0	0	0
	-	0	0	0	0	0	0	2
February	+	0	0	0	0	0	0	0
	-	0	1	0	1	1	0	0
March	+	0	0	0	1	0	1	0
	-	0	0	1	0	0	0	0
April	+	0	0	0	0	1	1	1
	-	0	0	0	0	0	0	0
May	+	2	0	0	0	0	1	0
	-	1	1	0	0	0	0	0
June	+	1	0	2	0	1	0	1
	-	0	0	0	0	0	0	0
July	+	1	0	0	0	0	0	0
	-	0	0	0	1	0	0	0
August	+	0	1	0	0	0	1	0
	-	0	0	0	0	1	0	0
Sept.	+	1	0	0	0	0	0	0
	-	0	0	1	0	0	0	0
October	+	1	0	1	0	0	1	0
	-	0	0	0	0	0	0	2
Nov.	+	0	0	0	0	0	2	1
	-	0	2	0	0	0	0	2
Dec.	+	0	0	0	2	0	0	0
	-	0	0	0	0	0	0	0

Based on figures in Appendix 5B.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 8: Summary of mean monthly precipitation- salmon catch correlations for selected rivers of the Gulf Region. (Table based on analysis of 2 Gulf Region rivers.) Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

		Lag*						
Month		0	1	2	3	4	5	6
January	+	0	0	0	0	0	0	0
	-	0	0	0	1	0	0	0
February	+	0	0	0	0	0	0	0
	-	0	0	0	1	0	0	0
March	+	0	0	0	0	0	0	0
	-	1	0	0	0	0	0	0
April	+	0	0	0	0	0	0	0
	-	0	0	1	0	0	0	0
May	+	0	0	1	0	0	0	0
	-	0	0	0	0	0	0	0
June	+	0	0	0	1	1	0	0
	-	0	0	0	0	0	0	0
July	+	0	0	0	0	0	0	0
	-	0	0	1	1	0	0	0
August	+	0	1	0	0	0	0	0
	-	0	0	0	0	0	0	0
Sept.	+	0	0	0	0	0	0	0
	-	0	0	0	1	1	1	1
October	+	0	1	0	0	0	0	0
	-	0	1	0	1	0	0	0
Nov.	+	0	0	0	0	0	1	1
	-	1	1	0	0	0	0	0
Dec.	+	0	0	0	0	0	0	0
	-	0	0	0	1	1	0	0

Based on figures in Appendix 5C.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 9: Summary of mean monthly precipitation for 3 month periods- salmon catch correlations for the rivers of Cobequid Bay. (Table based on analysis of 10 Cobequid Bay rivers.) Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

Lag*

Month		0	1	2	3	4	5	6
January	+	0	1	0	0	0	0	0
	-	0	0	1	0	0	0	0
February	+	0	0	2	0	1	0	0
	-	0	0	0	1	0	0	0
March	+	0	6	0	0	0	2	0
	-	0	0	1	3	1	0	2
April	+	0	2	0	0	0	5	0
	-	0	0	0	2	0	0	0
May	+	1	0	0	0	0	6	0
	-	0	0	0	0	0	0	0
June	+	1	0	3	0	0	1	2
	-	0	0	0	0	0	0	0
July	+	2	0	0	2	0	1	0
	-	0	0	0	0	0	0	0
August	+	0	0	2	3	0	0	1
	-	0	0	0	0	0	0	0
Sept.	+	0	0	0	4	0	0	0
	-	0	0	2	0	0	0	0
October	+	0	0	0	6	0	0	0
	-	0	0	1	0	1	0	2
Nov.	+	0	0	0	0	0	0	0
	-	0	1	2	0	0	0	4
Dec.	+	0	0	0	0	0	0	0
	-	0	1	0	0	0	0	2

Based on figures in Appendix 6A.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 10: Summary of mean monthly precipitation for 3 month periods- salmon catch correlations for the rivers of Bay of Fundy. (Table based on analysis of 7 Bay of Fundy rivers). Positive and negative rows r epresent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

		Lag*						
Month		0	1	2	3	4	5	6
January	+	0	0	0	0	1	0	0
	-	0	0	0	0	0	0	0
February	+	0	0	0	0	1	0	0
	-	0	0	0	0	0	0	0
March	+	0	1	0	0	0	1	0
	-	0	0	0	1	0	0	1
April	+	1	0	0	0	0	2	0
	-	0	0	1	1	1	0	0
May	+	2	0	0	0	1	1	0
	-	1	0	0	0	0	0	1
June	+	1	0	2	0	1	1	0
	-	1	1	0	1	0	0	0
July	+	2	0	1	0	0	0	0
	-	0	1	0	0	1	0	0
August	+	0	0	0	0	0	0	1
	-	0	1	0	0	2	0	0
Sept.	+	0	0	0	1	0	0	0
	-	0	0	0	0	0	0	0
October	+	1	0	0	0	0	1	0
	-	0	0	0	0	0	0	2
Nov.	+	1	0	1	1	0	0	0
	-	0	3	0	0	0	0	1
Dec.	+	1	0	1	0	0	0	0
	-	0	1	0	0	0	0	2

Based on figures in Appendix 6B.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 11: Summary of mean monthly precipitation for 3 month periods- salmon catch correlations for selected rivers of the Gulf Region. (Table based on analysis of 2 Gulf Region rivers.) Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

Month		Lag* 0	1	2	3	4	5	6
January	+	0	0	0	0	0	0	0
	-	0	0	0	1	1	0	0
February	+	0	0	0	0	0	0	0
	-	0	0	0	2	1	0	0
March	+	0	0	0	0	0	0	0
	-	0	0	0	1	1	1	1
April	+	0	0	0	0	0	0	0
	-	0	1	1	0	0	1	0
May	+	0	0	1	0	0	0	0
	-	1	0	1	0	0	0	0
June	+	0	0	0	0	1	0	0
	-	0	0	1	0	0	0	0
July	+	0	0	0	0	1	0	0
	-	0	0	1	0	0	0	0
August	+	0	0	0	1	1	0	0
	-	0	0	0	0	0	0	0
Sept.	+	1	0	0	0	0	0	0
	-	0	0	0	0	0	0	0
October	+	0	0	0	0	0	0	0
	-	0	0	0	0	0	0	0
Nov.	+	0	0	0	0	0	0	0
	-	0	0	0	1	0	0	0
Dec.	+	0	0	0	0	0	0	0
	-	0	0	0	1	0	0	0

Based on figures in Appendix 6C.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 12: Summary of mean monthly precipitation- catch per unit effort correlations for the rivers of Cobequid Bay. (Table based on analysis of 10 Cobequid Bay rivers.) Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

Month		Lag* 0	1	2	3	4	5	6
January	+	0	0	0	0	0	3	5
	-	0	0	0	0	0	0	0
February	+	2	6	2	1	1	0	0
	-	0	0	0	0	0	0	0
March	+	4	0	0	0	1	0	0
	-	0	0	0	0	0	0	0
April	+	1	2	2	0	0	0	0
	-	1	1	0	2	0	0	0
May	+	0	1	1	0	0	0	0
	-	0	0	0	0	1	0	1
June	+	0	0	0	0	1	0	0
	-	0	0	0	1	0	0	0
July	+	0	0	0	0	0	2	1
	-	0	0	0	0	0	0	0
August	+	0	0	0	0	0	0	1
	-	0	0	4	1	0	0	0
Sept.	+	0	0	0	0	3	1	2
	-	0	0	1	0	0	0	1
October	+	0	1	1	0	0	2	1
	-	0	0	2	0	0	0	0
Nov.	+	3	1	0	0	1	0	0
	-	0	0	0	0	0	0	3
Dec.	+	1	0	0	5	3	0	0
	-	0	0	0	0	0	0	0

Based on figures in Appendix 7A.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.

Table 13: Summary of mean monthly precipitation- catch per unit effort correlations for the rivers of Bay of Fundy. (Table based on analysis of 7 Bay of Fundy rivers). Positive and negative rows represent positive and negative correlations respectively. Numbers represent the number of rivers with a significant correlation in either the positive or negative direction.

Month		Lag* 0	1	2	3	4	5	6
January	+	0	1	0	0	1	0	0
	-	0	0	0	1	1	0	0
February	+	0	2	1	0	0	2	0
	-	1	0	0	1	1	0	0
March	+	1	0	0	0	0	2	0
	-	1	0	0	0	1	0	0
April	+	0	0	0	0	0	1	2
	-	0	0	1	1	0	0	0
May	+	1	0	0	1	1	1	0
	-	1	0	0	0	1	0	0
June	+	0	0	1	0	0	0	1
	-	0	0	0	0	0	0	0
July	+	1	0	0	1	0	0	0
	-	0	0	0	0	1	0	0
August	+	0	0	0	1	0	0	0
	-	0	0	0	1	0	0	0
Sept.	+	0	0	0	2	0	0	0
	-	0	0	0	1	0	0	1
October	+	0	0	0	0	1	1	0
	-	0	0	0	0	1	0	1
Nov.	+	0	0	0	0	1	1	0
	-	0	2	0	0	1	0	0
Dec.	+	0	0	0	0	0	1	1
	-	1	0	0	0	0	0	0

Based on figures in Appendix 7B.

*Lag refers to correlation of catch in year i with mean monthly precipitation in year i-j, where j corresponds to 0 to 6. i.e. Lag 4 refers to catch correlated with precipitation in that particular month 4 years previous. Significant effects for Lag 0 indicates effects of precipitation in the year in which the salmon return to spawn. Lag 4,3,2, and 1 represent effects on spawning/egg stage, fry, 1+ parr, and 2+ parr/smolts, respectively. Lags 5 and 6 represent possible complex competitive effects with older parr.