BIOLOGICAL FACTORS AFFECTING SEA SURVIVAL OF ATLANTIC SALMON SALMO SALAR L., IN WESTERN ARM BROOK AND, AN ANALYSIS OF SELECTION BY THE COMMERCIAL FISHERY OF NEARBY ST. BARBE BAY, NEWFOUNDLAND

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Biological Factors Affecting the Survival of [illegible] Salmon

Salmo salar L., at Western Arm Brook and An Analysis of

Selection by the Commercial Fishery of [illegible] St. [illegible] Bay, Newfoundland

by

[illegible]

A dissertation submitted to the Department of Biology in partial fulfillment of the requirements for the Degree of Bachelor of Science (Honours)

Department of Biology
Memorial University of Newfoundland

April [illegible]

St. John's Newfoundland

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ABSTRACT

The problems faced by scientists in charge of managing Atlantic salmon (Salmo salar) stocks are : i) how to maintain spawning runs consisting of repeat spawners and large multi-sea-winter (MSW) adults in the face of selective homewater and distant commercial fisheries and, ii) how to more accurately predict returns of adults .

Using data from scales collected from maiden Atlantic salmon grilse from two locations on the northern peninsula of Newfoundland, St.Barbe Bay and Western Arm Brook, their length at smolting was back calculated. These data were then used to examine whether the St. Barbe commercial fishery is selective for salmon of particular smolt age and/or size.

Analysis indicated that the commercial fishery selected larger, but not necessarily older adults than those escaping to Western Arm Brook over the period of this study, 1978 - 1987. It was determined that less than average size smolts survived better than above average size smolts.

Selection for repeat spawners, large MSW salmon, and larger grilse has meant reductions in the proportions of these adults in the spawning runs on Western Arm Brook. This may impact the Western Arm Brook salmon stock by increasing the population instability.

Sea survival was significantly correlated with selection by the commercial fishery.

Characteristics of adults in Western Arm Brook during the period of study (1978 - 1987) did not help in explaining yearly

variation in sea survival. The characteristics of smolts, however, when subjected to multiple regression analysis explained 57.2 percent of the yearly variation in sea survival.

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1. INTRODUCTION

The ability to predict the number of adult Atlantic salmon (Salmo salar) that will return to a river is a very important part of salmon management. Estimates of spawning escapements, i.e. returning salmon, are central in any assessment plan. They provide estimates of potential egg deposition which can in turn be used in production/recruitment relationships (Chadwick 1982).

Ideally, one would like to have complete and accurate counts of smolts which leave the river and adults which return. Unfortunately, such information is only attainable from rivers equipped with counting traps or fishways. Since not every river in Atlantic Canada is equipped with these facilities, such data are usually only available for so called index rivers. Index rivers are relatively small rivers with stable flow regimes which minimizes the chances of sudden washouts and allows total counts of fish to be made. If meaningful comparisons and relationships are to be made, index rivers should also be representative of surrounding rivers in terms of basin relief, drainage area, environmental conditions, substrate composition, water chemistry , and a number of other characteristics. A prime example of an index river is Western Arm Brook, located approximately 2 km southeast of St.Barbe (51°11'N and 56°46'W) on the northern peninsula of Newfoundland .

The role Western Arm Brook (WAB) has played in Atlantic salmon research has changed since 1971, when it was studied along with four other rivers on Newfoundland's northwest coast to assess their possible role as a source of adult salmon for the stocking of Torrent River, 90km south of Western Arm Brook (Riche 1973). It was decided that Western Arm Brook was the best suited as a donor river because of its healthy salmon population.

The transportation of adults from Western Arm Brook to Torrent River commenced in the summer of 1972, and from then until 1976 an estimated 600 adults were transported to the upper reaches of Torrent River. This stocking program has proven very successful with annual migrations of salmon on Torrent River today of 2,000 to 3,000 fish (Conrad Mullins, personal comm.).

Since 1976, when the last transplants of fish from Western Arm Brook to Torrent River were made, Western Arm Brook has served as an index river for statistical area N, that part of the Great Northern Peninsula north of Pointe Riche to Cook's Harbour (Fig 1). Western Arm Brook is an index river for eight nearby rivers, all shallow rivers with similar basin relief. They drain sedimentary bedrock, and all have predominantly 1SW (grilse) salmon stocks (Chadwick 1985).

Complete counts of salmon migrations on Western Arm Brook have been recorded since 1976, with the only exception being 1979 when the first part of the smolt run was missed (Chadwick 1982). Consequently, Western Arm Brook data represent one of the longest time series of Atlantic salmon data collected from an Atlantic Canadian river. Only the Miramichi and Restigouche Rivers of New Brunswick have longer data series.

As a consequence of this long data series, Western Arm Brook served as Chadwick's (1982) model for the first stock/recruitment relationship developed for a Canadian salmon stock. Chadwick (1982) analyzed the population dynamics of Atlantic salmon from Western Arm Brook, and also utilized commercial fishery data from the nearby St.Barbe Bay salmon fishery in his study.

The utility of index rivers, such as Western Arm Brook, becomes apparent when one considers the difficulties that would be encountered if scientists had to treat every salmon stock in Atlantic Canada separately. With an estimated 350 stocks (Chadwick 1985), and only a handful of biologists to manage them, it would very difficult to treat each one separately.

Using index rivers allows research for particular areas to be concentrated on one river, or on one distinct stock. The following data should, therefore, be viewed as data collected from one stock (Western Arm Brook), which are used to manage stocks from eight other rivers in Statistical area N.

Chadwick (1982) defines sea survival of Atlantic salmon in Western Arm Brook, as the number of 1SW (grilse) salmon moving upstream, expressed as a percentage of the number of smolts moving downstream the previous year. If sea survival was a constant, then the number of smolts alone would be sufficient to predict returns of grilse . However, sea survival for Western Arm Brook salmon has fluctuated over the years from a high of 12.06% in 1978 to a low of 0.8% in 1984 (Chadwick 1982,1985). Sea survival of salmon in Big Salmon River (N.B.) fluctuated by a similar amount (16.7% to 1.0%) for the years 1966 to 1971 (Jessop 1986).

For Western Arm Brook, 40% of the annual variation in sea survival was associated with variation in the number of smolts counted the previous year at Western Arm Brook (Chadwick, 1986). Hence, 60% of the variation is caused by other factors. This 60% unexplained variation has prevented scientists from making more accurate estimates of the size of the adult salmon run.

One biological characteristic of migrating smolts which correlates positively with sea survival is fork length. Ritter, (1977) showed that for smolts produced by Atlantic Canadian hatcheries (in N.B. and N.S.), the length of the smolts at release was correlated to sea survival. It was shown that smolts in the 19 - 21cm range had better sea survival than smolts below this size. Smolts larger than 21cm showed greater survival in some cases, but poorer sea survival in other cases. It was concluded that the sea survival of smolts > 21cm was inconsistent, suggesting an optimal size of between 19 to 21 cm which maximized sea survival.

Larsson (1977), using smolts from Swedish hatcheries, also showed that larger smolts had greater sea survival (as manifested by a greater percent return of tags) than smaller smolts. Bilton (1984), showed a size dependent sea survival in juvenile Chinook salmon (<u>Oncorhynchus</u> <u>tshawytscha</u> (Walbaum 1792)). He found that larger smolts gave a substantially higher percent return of tags than did smaller smolts; 1.9% return for 6g smolts as opposed to 9.6% for 12g smolts.

These studies used tagged smolts rather than wild untagged smolts. Tagged smolts have been shown to have lower sea survival than wild smolts (Saunders 1968, Murray 1968), therefore, the applicability of these studies to wild smolts may be questionable. Nevertheless they are a good starting point for the discussion of the effect of smolt size on sea survival (Chadwick 1986). Chadwick (1982), using wild, untagged smolts, studied the effects of biological and environmental factors on the sea survival of salmon. He found that sea survival was constant from 1971 to 1976, at approximately 6% and that it fluctuated from 12.06 % to 3.1 % over the last four years of the study, from 1977 to 1981.

Sea survival was positively correlated to the number of smolts in the migration, a relationship expected due to autocorrelation (Chadwick 1982). There was also a negative correlation between sea survival and size of returning grilse, such that sea survival was greatest when grilse size was smallest. There was also a positive correlation between sea survival and surface temperatures (Chadwick 1982). However, these correlations were statistically non - significant

The local commercial fishery also affects the population by selecting older, grilse (Chadwick 1982).

The commercial fishery also selected against larger multi - sea winter (MSW) salmon (>62.5cm) and repeat spawners, with only 1% of the river escapement at WAB being MSW and repeat spawners (Chadwick 1982, 1986). Also when sea survival was highest (i.e. 1978), there appeared to be less selection for larger and older adults by the commercial fishery (Chadwick 1982).

The purpose of my study was to gain insight into the relationship between biological factors associated with the smolt run of Western Arm Brook and the ability to predict adult returns more accurately based on these relationships. As well I wanted to test the hypothesis that the commercial fishery in St.Barbe Bay selects larger older adults, by comparing adults sampled from Western Arm Brook and St.Barbe Bay.

2. METHODS

2.1 Scale collection

Scales from adult salmon were collected at two sites, WAB (counting fence) and St.Barbe Bay, by DFO personnel during the years 1978-1987. The only year in which no scales were collected from St.Barbe Bay fishermen was 1982.

Scale collections from salmon caught by the commercial fishery in St.Barbe Bay were made during daily trips to the local wharves in Pigeon Cove and Anchor Point (Fig 2). These collections commenced during the middle of June and continued until the middle or end of August, when salmon nets were taken out of the water. The sampling procedure involved measurement of forklength to the nearest 0.1cm, weight to the nearest 0.1kg, and determination of sex by presence or absence of a kype. Occasionally when the head or lower jaw was missing, an internal examination of gonads was also made. All information, including the date and fisherman's name, was recorded on scale envelopes . A scale sample was taken from each specimen with a scalpel or table knife. Scales were collected from a region posterior to the base of the dorsal fin; between the dorsal fin and the lateral line (Fig 3).

This region was scraped in the head to tail direction with the back of the knife to remove mucous and dirt, then in the tail to head direction to remove enough scales for a sample (ca. 20). The scales were then deposited on a piece of paper and placed in the scale envelope containing the information on that fish.

If there were no scales present on the left side of the salmon, scales were taken from the same location on the right side.

Chadwick (1982), estimated that from 1977 to 1981 50% of the salmon landed from St.Barbe Bay were sampled, and since the methods have changed very little, it seems reasonable to assume that since 1981 50% or more of the commercial catch has been sampled.

Samples taken at WAB differed on two accounts. First, adults were sampled as they passed through the counting fence and second ,adults were sexed by external means only. The counting fence trap was checked three times daily from May 9-16 to the end of October or until ice encrusted the river. From 1978 to 1981, one out of every six adults was sampled, and from 1982 to 1987, one out of every three adults was sampled. The data collected were the same as those for commercially caught adults.

Scales were mounted on glass slides and later aged by DFO technicians at WAB and Moncton after 1983, and at DFO St.Johns prior to 1983.

2.2 Scale measurements and analysis

Historically studies on sea survival of salmon have used a tagging study design. Both Atlantic and Pacific salmon smolts used in these studies are measured, weighed, sexed, have a scale sample removed, and are finally tagged using any one of a number of techniques. The smolts are then released and counted when they return on their spawning migration. These methods introduce variation because of the higher mortality of tagged smolts compared to untagged smolts (Saunders 1968, Murray 1968). My study used no tagged fish and only scales from virgin 1SW adult salmon. Due to scheduling conflicts and equipment failure, scales collected in 1979 were not analyzed.

Scales were divided into two groups, commercial scales and river scales. The latter included scales from angled fish in years when angling was permitted (1978,1981,1984 1985,1987). Comparisons were made using these two groupings.

A random sample of fish was chosen for each year by using a table of random numbers (Rohlf and Sokal 1969). Scales from fish chosen in this manner were examined under a microprojector to find a scale that was suitable for measurement. Commercial scales for 1978 were measured using a Bausch and Lomb microprojector. Scales for the remaining years were measured using a Fisher Ken-A-Vision (model X-1000-1) microprojector. The Fisher microprojector gave a much sharper scale image, but there was no significant difference in measurements made with the two instruments.

Scales mounted between two glass slides were placed onto the stage of the microprojector and projected downward onto a piece of blank white paper taped into position approximately 50.5cm from the stage. The image of the scale was focused using 40X magnification in a darkened room to give the clearest possible projection. From the projected image two measurements were taken using Vernier callipers.

First a measurement was taken along the longest axis of the scale from the focus to the proximal end of the scale . This distance was designated the total scale length (totlth) (Fig. 4). The second measurement was taken along the same axis from the focus to the last river circulus - the end of freshwater growth. This distance was designated the freshwater length (fwlth) (Fig 4). The length of a fish at smolting was estimated using back-calculation based on the following equation: (Anon 1984)

csmolth = adlth (fwlth/totlth) where :

adlth = the forklength of the fish when the scales were removed

fwlth = the distance from the focus to the last river circulus; freshwater length

totlth = the distance from the focus to the end of the scale; total scale length

csmolth = the predicted length of the fish when it left the river as a smolt, or when the last river circulus was laid down.

All statistical analysis was performed using the BMDP statistical package available on the VAX mainframe. Using adults sampled from Western Arm Brook and, the commercial fishery (St.Barbe Bay), yearly means were computed for the following biological characteristics: adult forklength, back-calculated (adult) smolt forklength, weight and age. Mean characteristics of smolts sampled from Western Arm Brook were obtained from DFO files.

Mean adult forklength, adult smolt length, and age were compared each year between adults sampled from both locations using paired t-test analysis. This was also done for the overall means of these characters (i.e. the mean of all the yearly means). Mean adult whole weight was also compared using paired t-test analysis for all years except 1978.

The mean smolt length of adults sampled from Western Arm Brook, and St.Barbe Bay (year i+1) were compared to the forklength of smolts sampled from Western Arm Brook (year i) using paired t-tests. Also, the mean age of 1sw adults from Western Arm Brook (year i+1) and the mean age of smolts from Western Arm Brook (year i) were compared using paired t-tests.

Both biological characteristics of smolts and adults are believed to affect sea survival of salmon. Smolt characteristics used included, mean forklength, mean age, mean weight, and number of smolts migrating. These were compared to sea survival using best subset multiple correlational analysis.

Characteristics of Western Arm Brook adults were compared to sea survival using best subset multiple correlational analysis; these included mean forklength, mean back-calculated smolt fork length, mean whole weight, mean age, mean fwlth, and mean totlth. Western Arm Brook adults were used because they are the adults used to calculate sea survival.

Three dominant smolt age classes are present in Western Arm Brook, ages 3+, 4+, and 5+. The possibility that these age classes may have different sea survivals was tested by comparing the mean survival of 3+, 4+, and, 5+ smolts using analysis of variance (ANOVA). Sea survival for the different smolt age classes was calculated using the following formula:

number of age x+ adults returning (year i+1) / number of age x+ smolts leaving (year i) X 100, where x+ is one of ages 3+, 4+, or 5+.

The difference in the mean forklength, mean back-calculated smolt length, mean whole weight and age between adults from Western Arm Brook and those from St.Barbe Bay was used as a measure of the selection by the commercial fishery (Chadwick 1982). This selection was computed for each characteristic for each year and compared to sea survival using best subset multiple correlational analysis.

3. RESULTS

Biological characteristics of adults sampled from Western Arm Brook and, St.Barbe Bay varied from year to year (Table 1, 2).

For Western Arm Brook the largest adults occurred during the 1980 run, while the smallest adults occurred during the 1984 run (Table 1). Adult (back-calculated) smolt length was greatest for adults of the 1983 migration and, smallest for adults of the 1982 run (Table 1). Mean age varied from 4.13 to 3.59 during the 1982 and, 1978 migrations respectively (Table 1).

For St.Barbe Bay, in terms of forklength and whole weight, the largest adults were caught in 1980. In terms of forklength, the smallest adults were from 1978 and 1983. In terms of whole weight, the smallest adults were from 1984 (Table 2). The mean age of adults varied from 4.10 in 1984 to 3.42 in 1978. The mean age of adults from St. Barbe Bay was consistently 4+ (Table 2).

Smolt forklength varied from 16.3 cm to 17.8 cm with a mean of 16.9 cm (Table 3). Smolt weight ranged from 39.2 g to 50.3 g in 1985 and 1979, respectively (Table 3). The mean smolt age ranged from 4.08 in 1982 to 3.62 in 1987, with the mean smolt age for the majority of smolt runs being 3+ (Table 3).

The number of smolts emigrating has varied from a high of 20,653 in 1984, to 8,349 in 1979 (Table 3). Sea survival has fluctuated greatly from a high of 12.07 in 1978 to a low of 0.60 in 1987 (Table 4). Prior to 1979 sea survival was stable at approximately 6.0 % (Chadwick 1982). Since 1979 the decline in sea survival for WAB has been alarmingly steady (Fig 5). Sea survival for age 3+ smolts ranged from 15.4 % to 0.7 %, for age 4+ smolts from 14.8 % to 0.9 %, and for age 5+ smolts from 15.8 % to 0% (Table 5)(Fig 5). The mean sea survival for each age class is similar : 4.6% , 4.5% and, 4.7% respectively. The difference is not significant according to analysis of variance (Table 5).

Selection by the local commercial fishery for larger older smolt - age adults was studied by comparing adults sampled from WAB and St. Barbe Bay. Comparisons were made between mean adult forklength, mean adult smolt length, mean whole weight, and mean age (Table 6,7,8,9).

Mean adult forklength was significantly different between the locations for all years except 1978. For all other years adults caught in the commercial fishery were larger than those sampled from WAB (Table 6), (Fig 6). Mean adult smolt length was significantly different between the locations for all years except 1978.

For all other years the back calculated smolt length of adults caught in the commercial fishery was larger than that of adults sampled from WAB (Table 7)(Fig 7). The same was true for mean whole weight, for all years except 1978 adults caught in the commercial fishery were heavier than adults sampled from WAB (Table 8). The mean age of adults was different between the locations for 1980, 1981, 1984 and 1986. For these years adults caught in the commercial fishery were older than adults sampled from WAB. For the remaining years there was no difference in the age of adults from the two locations and, in fact adults sampled from the two locations in 1987 had the same mean age, 3.88 (Table 9).

Another measure of selection was the difference between the mean smolt length of smolts sampled from WAB and, the smolt length of adults sampled from both locations the next year. This comparison allows for the determination of how well the average size smolt survives. The mean smolt length of adults returning to WAB was significantly smaller than the mean forklength of smolts sampled from WAB the previous year. For the commercial fishery mean adult smolt length was smaller than the mean forklength of smolts from WAB for four of the seven years sampled, yet there was no significant difference between the overall mean forklength of smolts from WAB and the mean adult smolt length of adults sampled from St. Barbe Bay (Table 10).

Smolts of less than average forklength survived better than smolts of average or larger forklength.

The difference between the mean age of smolts from WAB and adults sampled from the two locations the next year were also compared.

The correlation of sea survival with characteristics of smolts sampled from WAB showed no significant relationships between individual characteristics and sea survival (Table 12). The correlation between sea survival and numbers of smolts emigrating was not significant (P value equal to .23). The remaining characteristics, although positively correlated with sea survival, have very large P values and are not significant (Table 12).

Multiple regression analysis combined the characteristics into groups to come up with the best set of variables to predict sea survival. The best set of predictor variables were forklength, weight, age, and numbers emigrating. The least squares multiple regression line predicted by these characteristics is :

Y = 182.1-17.0(forklength)+2.63(weight)-1.51(age) +4*10exp-4(smolts counted)

with a R^2 value of .572 (Table 12). Thus, 57.2% of the variation in sea survival is associated with the combination of these factors.

The correlation between sea survival and characteristics of adults from WAB revealed no significant relationships (Table 13). The correlation coefficients (R^2) were all smaller than the .50 value expected due to chance (Table 13).

Multiple regression analysis combined the adult characteristics into groups to come up with the best set of variables to predict sea survival.

The best set of predictor variables from the list of adult characteristics was the set incorporating all characteristics i.e., forklength (X1), adult smolt length (X2), whole weight (X3), age (X4), fwlth (X5) and totlth (X6). This gave a non significant relationship (P value =0.92).

In terms of adult characteristics there were no significant correlations with sea survival.

The multiple correlation analysis of sea survival and selection by the commercial fishery was carried out to ascertain the relationship, if any, between the two. The best subset regression analysis determined the best set of predictor variables to be difference in forklength (X1), difference in age (X3), and difference in adult smolt length (X4). This set of variables gave the following least squares multiple regression equation : $Y = 20.73 - 11.01(X1) + 31.45(X3) - 2.53(X4)$, with a R^2 value of .8986 and a P value of .019 (Table 14b). This equation indicates that as much as 90% of the annual variation in sea survival of WAB smolts is associated with selection by the commercial fishery for adult characteristics: forklength, age and, adult smolt length.

In years such as 1978, when sea survival was very high selection for the characteristics sampled, especially forklength and adult smolt length, was low (Table 14a,b).

In years such as 1984 when selection for adult smolt length and age were very high, 3.4 and .43 respectively, the sea survival was very low (Table 14a,b).

4. DISCUSSION

This discussion will concern itself mainly with two points: i) an analysis of selection by the commercial fishery in St. Barbe Bay and, ii) a description of biological characteristics affecting sea survival.

4.1 The commercial fishery of St. Barbe Bay

The purpose of studying the commercial fishery was to investigate two points suggested by an earlier study: i) that the commercial fishery is responsible for selecting larger, older grilse than those returning to Western Arm Brook and, ii) sea survival is highly correlated to selection by the commercial fishery (Chadwick 1982).

The first question was studied by a comparison of mean characteristics of adults sampled from the two locations.

The comparison of adult forklength (Table 6) revealed that the mean size of adults sampled from St.Barbe Bay was significantly larger than that of adults sampled from Western Arm Brook for every year between 1978 and 1987. The proportion of adults in the larger size classes is higher for the group from St. Barbe Bay than for the group from Western Arm Brook (Fig.6).

That the commercial fishery selectively takes the largest fish was further demonstrated by a comparison of adult whole weight. In all years except 1978 the whole weight of adults from St. Barbe Bay was significantly greater than the whole weight of adults from Western Arm Brook (Table 8).

With respect to age, analysis showed that the mean age of adults from the two locations was significantly different in only four of the years studied . For these years the adults from St. Barbe Bay were older than those from Western Arm Brook (Table 9). Since 1982, the age of adults from St. Barbe Bay has been significantly different from those at WAB for only two years; 1984 and 1986. Therefore, while the adults sampled from the commercial fishery in St. Barbe Bay have been consistently larger they haven't always been older.

A further comparison of smolt age of smolts from Western Arm Brook (year i) and age of adults from the two locations revealed that adults in both locations were older as smolts than the mean age of smolts from the previous year (Table 11). This would suggest that smolt age affects sea survival. The comparison of age class survival rates (Fig 5) and Chadwick (1982) show that tremendous variation exists in the sea survival of the three dominant smolt age classes. When taken over the length of this study the variations in age class sea survival are balanced out and the mean survival for the three age classes are not significantly different (Table 5). The commercial fishery selects the largest individuals from all the age classes present in Western Arm Brook and not only individuals from the older age classes.

Comparison of adult smolt length between the two locations revealed that adults sampled from St. Barbe Bay were larger as smolts than those adults escaping to Western Arm Brook in all years except 1978 and 1985 (Table 7). This is also shown in the graph of adult smolt length class distribution for the two locations (Fig

7). The proportion of adults in the larger size classes is greater for the St. Barbe Bay group than for the Western Arm Brook group. The comparison of smolt length of adults from both locations and forklength of smolts from Western Arm Brook the previous year (Table 10) shows that for every year of study the smolt length of adults returning to Western Arm Brook was significantly smaller than the mean forklength of smolts from Western Arm Brook the previous year. The smolt length of adults from St. Barbe Bay although greater than that of Western Arm Brook adults, was less than the forklength of smolts from Western Arm Brook the previous year in five of the seven years studied.

These results suggest that sea survival is affected by smolt size. It could also be said that survival (to WAB) is greater for less than average sized smolts (approximately 16 - 17 cm) than for larger smolts, a result not in agreement with findings of (Larsson 1977, Ritter 1977).

Chadwick (1982) reported that in years of high sea survival selection by the commercial fishery was low and in years of low sea survival selection by the commercial fishery was high. While these factors (sea survival and selection) were highly correlated, the relationship was not significant. He concluded that a longer data series would indicate a significant relationship (Chadwick 1982). As predicted by Chadwick my results (Table 14a,b) show that selection by the commercial fishery for adult characteristics is significantly correlated with sea survival.

Aside from selecting larger maiden grilse, the commercial fishery has also been shown to select repeat spawning grilse and large multi-sea winter (MSW) adults (Chadwick 1982). A MSW adult is one which remains at sea for at least two winters and returns to its natal stream measuring >62.5 cm and weighing >3.0 kg , and is referred to as a "salmon" (Chadwick 1982b). A repeat spawning grilse is an adult which spawns for the first time as a 1sw (grilse) adult and survives to migrate to sea for one winter after which it returns to the river to spawn again.

Approximately 8% of the commercial catch of adult grilse has been shown to consist of repeat spawning grilse, whereas, only 1% of escaping adults in Western Arm Brook were repeat spawning grilse (Chadwick 1982, 1982b and 1986). In the past as much as 5% of the adults harvested in the commercial fishery were MSW salmon destined presumably for Western Arm Brook (Chadwick 1982). Over the last three years only two MSW salmon have returned to Western Arm Brook and only ten have returned since 1983 (DFO unpublished data).

This can be compared with Big Salmon River, N.B. where no commercial fishery is prosecuted from its homewaters. On Big Salmon River repeat spawners constitute from 20 to 47 percent of the spawning run (Jessop 1986).

Grilse in Western Arm Brook have shown great potential to express the repeat spawning phenotype as evidenced by counts of kelts in Western Arm Brook which indicate that as high as 90 percent of the adult spawners survive spawning and leave the river the next spring (Chadwick 1982, 1982b, 1986; DFO unpublished data). This strongly suggests, given the Big Salmon River example, that removal of the St. Barbe Bay commercial fishery would result in a significant increase in repeat spawners in Western Arm Brook.

The reduction or elimination of the commercial fishery in the homewaters of Western Arm Brook would stabilize the salmon population of Western Arm Brook by allowing larger grilse, repeat spawners and large MSW salmon to become members of the spawning runs. The inclusion of such adults has been stressed as an important factor for the continued growth of salmon stocks in such Maritime rivers as the Miramichi (Randall et.al 1985a) and Restigouche (Randall et.al 1985b) where homewater and distant commercial fisheries threaten to limit the availability of such adults.

4.2 Biological characteristics affecting sea survival

The simplest means of measuring sea survival is to count the number of smolts and adults for a particular river (Chadwick 1986). Forty per cent of the annual variation in sea survival of Western Arm Brook salmon was explained by variation in smolt counts, the remaining sixty percent is reasoned to be due to biological and environmental factors (Chadwick 1986). This study looked at some biological characteristics of smolts and adults to help explain the annual variation in sea survival, and to gain a clearer estimate of sea survival.

Characteristics of migrating adults showed no significant correlations with sea survival (Table 13). The negative correlation between sea survival and adult forklength reported in Chadwick (1982) was not observed in this study . A probable explanation for this is that the correlation reported in (Chadwick 1982) was not significant and the more recent returns have shifted this relationship.

Characteristics of migrating smolts have been shown to be correlated to sea survival, particularly smolt forklength (Larsson 1977, Ritter 1977, and Bilton 1984). Indeed in this paper it has already been pointed out that smolt forklength does affect sea survival.

When taken by themselves positive correlations were expressed between smolt forklength, weight, age and sea survival. These relationships, however, were shown to be statistically non-significant. This would indicate that taken separately these characteristics would not help explain the annual variation in sea survival any more than already can be done using smolt counts.

The correlation between sea survival and number of smolts counted was able to be used to predict returns of adults to statistical area N until 1985 (Chadwick 1985). The low sea survival in 1985 was not predicted in that a high smolt run (20,653) had been recorded. The low survival may have indicated that a number of the assumptions used were not being realized (Chadwick 1986).

The multiple correlation analysis showed that when considered together the smolt characteristics were significantly correlated to sea survival. A line of least squares was calculated to be :

Y = 182.1 - 17.0(forklength) + 2.63(weight) - 1.51(age)

+ 4.0*10exp-4(smolts counted)

with a multiple correlation coefficient (R-sq) of .572, this equation explained 57.18 per cent of the variation in sea survival. This is an improvement of almost 18 percent over the method using smolt counts.

Future research on this topic should study environmental factors of the marine environment to assess their role in affecting sea survival of Atlantic salmon. Environmental conditions during the first few months at sea are very important in terms of their probable effect upon smolts. Factors such as ice cover, water temperature, salinity, turbulence and atmospheric weather patterns are just a few of the many environmental factors which may explain some of the variation in sea survival.

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Table 1 Biological characteristics of adult Atlantic salmon sampled from Western Arm Brook.

Year		Biological characteristic							
		mean adult forklength (cm)		mean adult smolt length (cm)		mean whole weight (kg)		mean age	
	N	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1978	61	52.8	3.1	15.1	2.2	-------		3.59	.50
1980	38	54.2	2.9	15.2	3.0	2.08		3.84	.60
1981	55	52.4	2.7	15.4	2.3	1.62	.29	3.75	.55
1982		53.0		14.2		1.84		4.13	
1983	106	51.5	2.1	15.9	2.8	1.56	.32	4.03	.50
1984	57	51.1	2.5	14.7	2.8	1.46	.24	3.67	.65
1985	60	52.5	2.8	15.1	2.6	1.55	.31	3.90	.48
1986	32	53.0	2.9	14.7	2.1	1.65	.28	3.79	.59
1987	54	53.6	2.6	14.7	2.4	1.62	.28	3.88	.57

Table 2 Biological characteristics of adult Atlantic salmon sampled from St.Barbe Bay.

Year		Biological characteristics							
		mean adult forklength (cm)		mean adult smolt length (cm)		mean whole weight (kg)		mean age	
	N	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
1978	25	53.1	3.1	15.4	1.9	-----		3.42	.48
1980	114	56.0	2.7	16.3	2.8	2.06	.32	4.01	.65
1981	107	54.5	2.7	17.0	2.7	1.89	.29	4.02	.60
1983	102	53.1	2.9	16.9	3.2	1.77	.26	4.02	.59
1984	35	53.3	2.7	18.1	4.8	1.74	.31	4.10	.77
1985	27	54.3	2.9	15.7	1.9	1.87	.27	4.03	.55
1986	127	55.1	3.1	17.2	3.2	1.94	.41	4.08	.53
1987	54	54.8	2.4	16.9	2.6	1.95	.41	3.88	.60

Table 3 Biological characteristics of Atlantic salmon smolts sampled from Western Arm Brook.

Year		Biological characteristics					
		Forklength (cm)		weight (g)		age	number in migration
	N	mean	s.d.	mean	s.d.	mean	
1978	100	17.1	1.7	46.1		3.71	13,071
1979	195	17.8	1.3	50.3		3.82	8,349
1980	251	16.9	1.8	43.7	13.4	3.63	15,665
1981	174	17.2	1.6	46.5	12.2	3.90	13,981
1982	148	17.0	2.1	44.9	16.8	4.08	12,477
1983	129	16.6	1.4	40.7	10.6	3.78	10,552
1984	160	16.5	1.7	39.7	11.6	3.89	20,653
1985	129	16.3	1.7	39.2	13.4	4.02	13,417
1986	159	17.2	1.6	44.4	11.8	3.72	17,719
1987	199	17.1	1.8	42.7	12.9	3.62	17,029

Table 4 Total counts of upstream migrating adults and downstream migrating smolts at Western Arm Brook, and sea survival ratio of the number of adults (year i+1) to the number of smolts migrating (year i) * 100.

YEAR	NO.OF SMOLTS COUNTED	NO. OF ADULTS COUNTED	SEA SURVIVAL %
1977	9,899		2.95
1978	13,071	293	12.07
1979	8,349	1578	5.21
1980	15,665	435	2.90
1981	13,981	452	2.80
1982	12,477	390	9.14
1983	10,552	1141	1.14
1984	20,653	120	0.80
1985	13,417	165	1.88
1986	17,719	252	2.13
1987	17,029	378	0.60
1988	15,309	103	

Table 5 Comparison of sea survival (ratio of returning adults to smolts counted the previous year * 100) for the dominant smolt ages on Western Arm Brook, 1978 - 1987.

YEAR	SMOLT AGE CLASS SEA SURVIVAL (%) 3	4	5
1978	7.2	14.8	15.8
1979	4.1	5.1	9.9
1980	3.0	2.7	4.2
1981	2.7	2.2	1.5
1982	15.4	8.9	6.2
1983	2.7	2.0	1.9
1984	0.7	0.9	0
1985	3.8	1.7	0.5
1986	1.9	2.2	2.6
1987			-
MEAN	4.6	4.5	4.7

ANOVA

SOURCE	SS	DF	MSS	F-VALUE	TAIL
AGE	0.2552	2	0.1226	0.01	0.9945
ERROR	538.20	24	22.425		

Table 6 Comparison of mean forklength (cm) of maiden 1sw adult salmon from the St. Barbe Bay commercial fishery and Western Arm Brook, 1978 - 1987.

YEAR	ST.BARBE BAY			WESTERN ARM BROOK			T-STATISTIC
	N	MEAN	S.D.	N	MEAN	S.D	
1978	25	53.1	3.13	61	52.8	3.11	0.31 a
1980	114	56.0	2.66	38	54.2	2.86	3.63 *
1981	107	54.5	2.71	55	52.4	2.67	4.78 *
1983	103	53.1	2.86	106	51.5	2.14	4.23 *
1984	35	53.3	2.67	57	51.1	2.54	3.92 *
1985	27	54.3	2.88	60	52.5	2.75	2.84 *
1986	128	55.1	3.11	32	53.0	2.90	3.35 *
1987	55	54.8	2.45	54	53.6	2.61	2.59 *
ALL YEARS	**594**	**54.6**	**2.98**	**504**	**52.5**	**2.88**	**11.87 ***

N.B. * denotes all of the above relationships are significant at level = 0.01
(a) denotes a relationship which is non-significant

Table 7 Comparison of mean back-calculated smolt lengths (cm) of adults sampled from St. Barbe Bay and from Western Arm Brook 1978 - 1987.

YEAR	ST.BARBE BAY N	MEAN	S.D.	WESTERN ARM BROOK N	MEAN	S.D.	T-STATISTIC
1978	25	15.4	1.89	61	15.1	2.18	0.47 a
1980	114	16.3	2.83	38	15.2	2.98	2.05 #
1981	107	17.0	2.71	55	15.4	2.26	3.34 *
1983	103	16.9	3.24	106	15.9	2.85	2.49 *
1984	35	18.1	4.76	57	14.7	2.80	4.38 *
1985	27	15.7	1.90	60	15.1	2.59	1.13 a
1986	128	17.2	3.19	32	14.7	2.12	4.14 *
1987	55	16.9	2.55	54	14.7	2.35	4.67 *
ALL YEARS	**594**	**16.8**	**3.13**	**504**	**15.1**	**2.56**	**9.73 ***

N.B. * denotes relationship is significant at level = 0.01
# denotes relationship is significant at level = 0.04
(a) denotes a relationship which is not significant

Table 8 Comparison of whole weight (kg) of adult salmon sampled from St.Barbe Bay and from Western Arm Brook 1978 -1987.

YEAR	ST.BARBE BAY N	MEAN	S.D.	WESTERN ARM BROOK N	MEAN	S.D.	T - STATISTIC
1980	114	2.06	.320	38	2.08	.504	-0.13 a
1981	106	1.89	.290	55	1.62	.294	5.52 *
1983	102	1.77	.260	104	1.56	.321	5.20 *
1984	35	1.74	.307	57	1.46	.237	4.38 *
1985	27	1.87	.266	60	1.55	.308	4.65 *
1986	128	1.94	.408	32	1.65	.275	3.79 *
1987	54	1.95	.405	54	1.62	.277	4.93 *
ALL YEARS	566	1.91	.347	475	1.63	.686	8.58 *

N.B. a denotes a relationship which is not significant
* denotes the fact that these relationships are significant at level = 0.001.

The weight of fish from Western Arm Brook was not sampled for 1978, therefore, a comparison of the two locations for this year was not possible.

Table 9 Comparison of the age of adult salmon sampled from St.Barbe Bay and Western Arm Brook 1978 - 1987.

YEAR	ST.BARBE BAY N	MEAN	S.D.	WESTERN ARM BROOK N	MEAN	S.D.	T - STATISTIC
1978	25	3.42	.476	61	3.59	.504	-1.46 a
1980	114	4.01	.646	38	3.84	.601	1.47 #
1981	107	4.02	.601	55	3.75	.552	2.69 *
1983	102	4.02	.592	106	4.03	.503	-0.16 a
1984	35	4.10	.767	57	3.67	.653	2.81 *
1985	27	4.03	.550	60	3.90	.480	1.08 a
1986	127	4.08	.534	32	3.79	.592	2.75 *
1987	54	3.88	.604	54	3.88	.572	0
ALL YEARS	591	4.00	.610	475	3.85	.686	4.09 *

N.B. a is not significant
* is very significant at level = 0.01

Table 10 Comparison of the mean forklength (cm) of smolts sampled from Western Arm Brook (year i) and the back-calculated smolt length of adults sampled from Western Arm Brook and St.Barbe Bay (year i+1).
(Standard deviations in brackets).

YEAR (i)	FORKLENGTH OF WESTERN ARM BROOK SMOLTS (Year i)	BACKCALCULATED SMOLT FROM WESTERN ARM BROOK (Year i+1)	LENGTH OF ADULTS FROM ST.BARBE BAY (Year i+1)
1977	17.0 **(1.29)**	15.1 **(2.18)**	15.4 **(1.89)**
1978	17.1 **(1.69)**	----------NO SAMPLES----------	
1980	17.8 **(1.32)**	15.2 **(2.98)**	16.3 **(2.83)**
1981	17.2 **(1.58)**	14.2 **(1.92)**	-----
1982	17.0 **(2.08)**	15.9 **(2.85)**	16.9 **(3.24)**
1983	16.6 **(1.42)**	14.7 **(2.80)**	18.1 **(4.76)**
1984	16.5 **(1.67)**	15.1 **(2.59)**	15.7 **(1.90)**
1985	16.3 **(1.66)**	14.7 **(2.12)**	17.2 **(3.19)**
1986	17.2 **(1.65)**	14.7 **(2.35)**	16.9 **(2.55)**
1987	17.1 **(1.76)**		
MEAN	16.96 **(0.425)**	15.0 **(0.492)**	16.7 **(0.864)**

COMPARISON OF THE ABOVE MEANS (PAIRED T-TEST)

MEANS	TEST STATISTIC	P-VALUE
16.96 / 15.0	9.32	0.000
16.96 / 16.7	0.88	0.39

Table 11 Comparison of the age of smolts sampled from Western Arm Brook (year i) and adults sampled from St. Barbe Bay and Western Arm Brook (year i+1).

	Mean age		
Year (i)	smolts from Western Arm Brook (year i)	adults from Western Arm Brook (year i+1)	adults from St.Barbe Bay (year i+1)
1977	3.45	3.59	3.42
1978	3.71	3.88 *	3.91 *
1979	3.82 *	3.84	4.01
1980	3.64	3.75	4.02
1981	3.90	-------NO SAMPLES-------	
1982	4.08	4.03	4.02
1983	3.78	3.67	4.10
1984	3.89	3.90	4.03
1985	4.02	3.79	4.08
1986	3.72	3.88	3.88
1987	3.62		

N.B. * indicates that this data was obtained from Chadwick (1981).

Table 12 Correlation of characteristics of smolts sampled from Western Arm Brook and sea survival (ratio of returning adults to smolts counted the previous year * 100%).

Year	Sea Survival (%) Y	Biological Characteristics: forklength (cm) X1	weight (g) X2	age X3	number of smolts emigrating X4
1978	12.07	17.1	46.1	3.71	13071
1979	5.21	17.8	50.3	3.82	8349
1980	2.90	16.9	43.7	3.63	15665
1981	2.80	17.2	46.5	3.90	13981
1982	9.14	17.0	44.9	4.08	12477
1983	1.14	16.6	40.7	3.78	10552
1984	0.80	16.5	39.7	3.89	20653
1985	1.88	16.3	39.2	4.02	13417
1986	2.13	17.2	44.4	3.72	17719
1987	0.60	17.1	42.7	3.62	17029
Correlations		**0.346**	**0.535**	**0.165**	**-0.419**

Best set of predictor variables :

$$Y = 182.1 - 16.99(X1) + 2.63(X2) - 1.51(X3) + 4 * 104(X4)$$

$R^2 = 0.5718$

F statistic = 1.67

Table 13 Correlation of characteristics of adults sampled from Western Arm Brook and sea survival (ratio of returning adults to the number of smolts counted the previous year).

			Biological Characteristics				
Year	Sea survival (%) Y	Forklength (cm) X1	Adult smolt length X2	Whole weight X3	Age X4	Fwlth X5	Totlth X6
1978	12.07	52.8	15.1	-----	3.59	3.48	12.12
1980	2.90	54.2	15.2	2.08	3.84	3.44	12.40
1981	2.80	52.4	15.4	1.62	3.75	3.68	12.49
1982	9.14	53.0	14.2	1.84	4.13	3.47	12.90
1983	1.14	51.5	15.9	1.56	4.03	3.76	12.21
1984	0.80	51.1	14.7	1.46	3.67	3.53	12.34
1985	1.88	52.5	15.1	1.55	3.90	3.58	12.40
1986	2.13	53.0	14.7	1.65	3.79	3.62	12.30
1987	0.60	53.6	14.7	1.62	3.88	3.62	13.15
correlations :		**0.204**	**0.219**	**0.164**	**-0.111**	**-0.402**	**-0.114**

Best set of predictor variables are :

Y on X1 , X2 , X3 , X4 , X5 , X6 : R^2 = .432
F stat = 0.25
P value = .9193

Table 14a The correlation of sea survival (% smolts to returning 1 SW adults) and selection by the commercial fishery for various biological characteristics of adults sampled from St. Barbe Bay .

Biological Characteristic	1977	1978	Year 1979	1980	1981
forklength (cm)					
Bay	53.7	53.1	53.8	56.0	54.5
River	52.7	52.8	51.5	54.2	52.4
difference (x1)	1.0	0.3	2.3	1.8	2.1
weight (g)					
Bay	1.68	1.97	1.91	2.06	1.89
River	1.52	1.60	1.53	2.08	1.62
Difference (x2)	0.16	0.37	0.38	-0.02	0.27
age					
Bay	4.14	3.42	3.91	4.01	4.02
River	3.72	3.59	3.88	3.84	3.75
Difference (x3)	0.42	-0.17	0.03	0.17	0.27
smolt length (cm)					
Bay	----	15.4	----	16.3	17.0
River	----	15.1	----	15.2	15.4
Difference (x4)	----	0.3	----	1.1	1.6
Sea Survival (%)	2.95	12.07	5.21	2.90	2.80

Table 14b The correlation of sea survival (% smolts to returning 1SW adults) and selection by the commercial fishery for various biological characteristics of adults sampled from St.Barbe Bay 1983 - 1987.

Biological Characteristic	Year 1983	1984	1985	1986	1987
forklength (cm)					
Bay	53.1	53.3	54.3	55.1	54.8
River	51.5	51.1	52.5	53.0	53.6
Difference (x1)	1.6	2.2	1.8	2.1	1.2
weight (g)					
Bay	1.77	1.74	1.87	1.94	1.95
River	1.56	1.46	1.55	1.65	1.62
Difference (x2)	0.21	0.28	0.32	0.29	0.33
age					
Bay	4.02	4.10	4.03	4.08	3.88
River	4.03	3.67	3.90	3.79	3.88
Difference (x3)	-0.01	0.43	0.13	0.29	0
smolt length (cm)					
Bay	16.9	18.1	15.7	17.2	16.9
River	15.9	14.7	15.1	14.7	14.7
Difference (x4)	1.0	3.4	0.6	2.5	2.2
Sea Survival (%)	1.14	0.80	1.88	2.13	0.60

The best set of predictor variables as determined by best subset regression analysis is :

Y on X1 , X3 , X4 with the following equation ;

$$Y = 20.73 - 11.01(X1) + 31.45(X3) - 2.53(X4)$$

$R^2 = .8986$

$P = 0.019$

Table 15. The legend for locations labelled on Fig.1 (p.45)

LABEL NO.	LOCATION
1	DFO statistical area N
2	Pointe Riche
3	Cook's Harbour
4	St.Anthony
5	Western Arm Brook (WAB)
6	St.Genevieve River
7	Castor River
8	Torrent River (Hawke's Bay)
9	River of Ponds Stream

Table 16 The legend for the locations labelled on Fig.2 (p.47)

LABEL NO.	LOCATION
1	Counting fence ; Western Arm Brook
2	Estuary ; Western Arm Brook
3	St.Barbe
4	Pigeon Cove
5	Black Duck Cove
6	Forrester's Point
7	Eastern Arm Brook
8	Anchor Point
9	Net locations of Mrs. Tom and Ken Genge
10	Net locations of Mr. Doug Gibbons

Fig. 1. Location of Western Arm Brook and nearby rivers of Department of Fisheries and Oceans statistical area N.

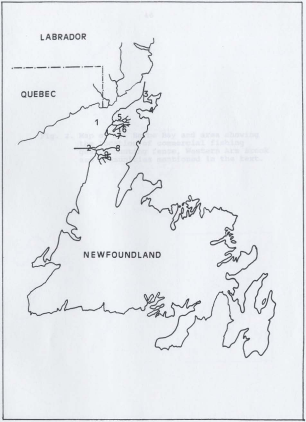
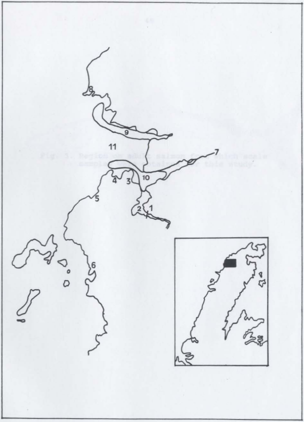

LABRADOR
QUEBEC
NEWFOUNDLAND
1
2
3
4
5
6
7
8
9

Fig. 2. Map of St. Barbe Bay and area showing the location of commercial fishing gear, counting fence, Western Arm Brook and communities mentioned in the text.



8
9
11
7
10
4
3
5
2
1
6

Fig. 3. Region on adult salmon from which scale samples were obtained for this study.

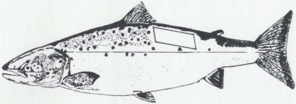
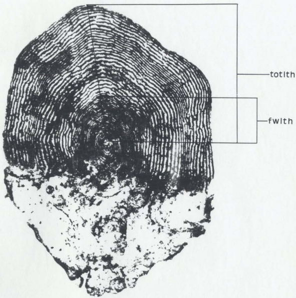
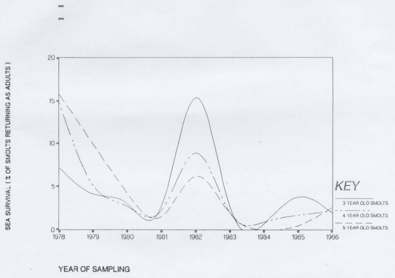


Fig. 4. Adult salmon scale showing the scale measurements defined in equation for back calculation used to estimate the smolt length of adults sampled from Western Arm Brook and St. Barbe Bay.



totlth
fwlth

Fig. 5. Sea survival of the three dominant smolt age classes found in smolts sampled from Western Arm Brook 1978-1986.



SEA SURVIVAL (% OF SMOLTS RETURNING AS ADULTS)
20
15
10
5
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
YEAR OF SAMPLING
KEY
3 YEAR OLD SMOLTS
4 YEAR OLD SMOLTS
5 YEAR OLD SMOLTS

Fig. 6. Distribution of adult forklength classes (cm) of adult salmon sampled from St.Barbe Bay and Western Arm Brook, 1978 - 1987.

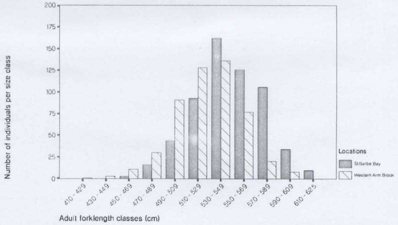
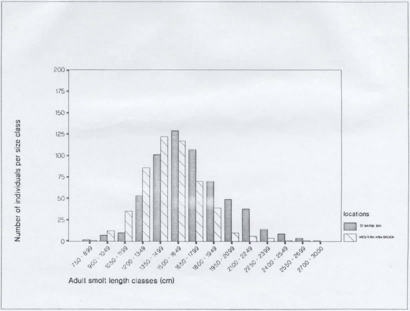

Number of individuals per size class
200
175
150
125
100
75
50
25
0
410 - 429
430 - 449
450 - 469
470 - 489
490 - 509
510 - 529
530 - 549
550 - 569
570 - 589
590 - 609
610 - 625
Adult forklength classes (cm)
Locations
St Barbe Bay
Western Arm Brook

Fig. 7. Distribution of smolt length classes (cm) of adults sampled from St. Barbe Bay and Western Arm Brook, 1978 - 1987.



Number of individuals per size class
200
175
150
125
100
75
50
25
0
750 - 899
900 - 1049
1050 - 1199
1200 - 1349
1350 - 1499
1500 - 1649
1650 - 1799
1800 - 1949
1950 - 2099
2100 - 2249
2250 - 2399
2400 - 2549
2550 - 2699
2700 - 3000
Adult smolt length classes (cm)
locations
ST BARBE BAY
WESTERN ARM BROOK