DYNAMICS OF AN ATLANTIC SALMON STOCK (SALMO SALAR) IN A SMALL NEWFOUNDLAND RIVER

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IN A SMALL NEWFOUNDLAND RIVER

by

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ABSTRACT

Dynamics of an Atlantic salmon stock (<u>Salmo salar</u> L.) were studied in a small Newfoundland river, Western Arm Brook. The study examined dynamics of smolts, parr and adults. Smolt production was influenced by annual variation in year-class strength, smolt age, sex ratio and size. Year-class strength was significantly correlated with egg deposition. This was the first stock-recruitment relationship to be developed for Atlantic salmon. Supportive evidence was found on two other Newfoundland rivers, Indian and Little Codroy. On Little Codroy River, year-class strength of smolts was correlated ($P < 0.01$) with potential egg deposition of adults counted as kelts. On Indian River, egg to fry survival was correlated ($P < 0.01$) with winter temperature and discharge. On Western Arm Brook, smolt age was significantly correlated ($P < 0.01$) with annual mean monthly air temperature. Evidence was presented for density-dependent influence on both smolt age and sex ratio. Size of smolts had the lowest annual variation of all biological characteristics. Fork length, weight, ovarian weight and especially annual instantaneous growth rates of smolt were significantly ($P < 0.01$) different between smolt ages. Ovarian weight of smolts was inversely correlated ($P = 0.01$) to sea age of adult salmon in 34 Newfoundland rivers.

Biological characteristics of parr were significantly different between the four habitat types: steadies, riffles, outflows and lakes. Parr from riffles were smaller and younger. Parr in outflows grew most during the summer season. However, parr did not remain within habitats and there was a net downstream movement. Downstream

movement of parr was significantly correlated with the size of the smolt run in the same year. Mean production in lake and steady habitats was 0.07 g m^{-2} y^{-1}, and it was 2.23 g m^{-1} y^{-1} in riffles and outflows. Maximum production was estimated to be 5.47 g m^{-2} y^{-1}. Only 33% of smolts were produced in riffles and outflows; the remainder were produced in lakes and steadies which comprised 98.6% of habitat accessible to salmon. Production was correlated with standing stock and over 50% was contributed by the second and third age groups.

This paper presented the first evidence that a commercial fishery selected larger and older 1SW salmon. 1SW salmon spend one year at sea before first spawning. Grilse taken in the local fishery of St. Barbe Bay were significantly ($P < 0.01$) greater in fork length, whole weight, condition and smolt age than grilse entering the river. Selection for older smolt ages was due to a significant correlation between size and smolt age. The fishery also selected a greater proportion of repeat spawners and almost all 2SW salmon. Consequently fish which spawned were smaller and younger than in unexploited populations. There was also a considerable loss of iteroparity as a result of exploitation.

A model was proposed to describe Alantic salmon stocks in exploited and unexploited states. The model was based on density-dependent growth in freshwater. At low stock densities, salmon parr grew faster and went to sea at younger smolt ages. Faster growth induced precocity in male parr and shifted the sex ratio of the smolt migration to be predominantly female. At carrying capacity, smolt ages increased and smolt production was stabilized due to overlapping of year-classes. The economic benefit of increased stream biomass was a stable yield to the fisheries. The model was compared to trends in the commercial fisheries which included a 40 yr cycle of abundance, and declines in sea age and smolt age. A significant correlation between stock abundance and smolt age corroborated the proposed biomass model.

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1. INTRODUCTION

There are several phases in the life history of an Atlantic salmon (Salmo salar Linnaeus 1758) stock: parr, smolts, and adults. This paper examines the dynamics of each phase in a small Newfoundland river. A stock is a self-perpetuating system (Larkin 1972); it is a group of interbreeding fish spawning in particular lakes or streams (or parts of streams) at the same time (Ricker 1972). Dynamics of a stock are the patterns of change which can be measured as annual fluctuations in biological characteristics such as size, sex, age, and abundance. A study of dynamics usually attempts to explain mechanisms behind annual variations. One example of an important mechanism is a stock-recruitment relationship, where recruits to a fishery can be predicted from egg deposition. Other examples are the influence of environmental or density-dependent factors on the survival or growth of a stock.

A serious gap in fisheries science is lack of information on the dynamics of discrete stocks. We are unable to understand the causes of variations in stock abundance and to develop stock-recruitment relationships. There are several reasons for this: stocks are difficult to identify because they migrate in unknown patterns; abundance of stocks is usually estimated from indirect methods, such as catch statistics or tag recaptures; and it is difficult to obtain samples of biological characteristics which are representative of the stock. The greatest difficulty, however, is obtaining a time series of information where repeated estimates of stock abundance and biological characteristics have only a small error. A 25%

error in annual estimates of abundance is likely to mask a significant stock-recruitment relationship (Walters 1981). Thus, to improve our understanding of fisheries science, more work is required on time series of discrete stocks.

This is also true for Atlantic salmon, where the dynamics of stocks are not well studied due to the lack of adequate time series. As a result there are no documented stock-recruitment relationships; we have been unable to predict harvests to our fisheries; and with the recent interest in river harvest, there is no method for determining optimal spawning requirements. To date, spawning requirements are estimated from experiments with hatchery fry (Elson 1975). However, a recent Atlantic salmon modelling workshop found these values to be inadequate (Anon. 1982).

There has been considerable work on biological characteristics of Atlantic salmon stocks. But it has been devoted to distinguishing between stocks rather than to describing annual variation within them. Most of this work can be divided into three groups: genetic, environmental and density-dependent. The genetic school believes that genetic isolation between adjacent river systems is demonstrated by homing to natal rivers (Payne _et al._ 1971). This school also believes that genetics plays an important role in determining biological characteristics, such as time of upstream migration (Elson 1973; Saunders 1967), juvenile migrations (Ritter 1975), smolt age (Refstie _et al._ 1977), and sea age (Elson 1973; Piggins 1974). This paper does not deal with the genetic component of stock variation, but I assume that phenotype is ultimately under genetic control (Boyce 1981).

The environmental school believes biological characteristics of Atlantic salmon are related to climatic conditions because they live in seasonal environments. For example, year-class strength has been related to high summer discharge (Lishev and Rimsh 1961; Lind 1980), warm springs (Mottram 1931; Grimas and Nilsson 1965), and solar activity and its associated increased precipitation (Birman 1969). Smolt age and sea age have been found to increase with latitude (Dahl 1916, 1937; Sedgwick 1953; Shearer 1966; Symons 1979; Power 1982), with smolt age being inversely correlated with stream temperature (Elson 1957a). However, these studies were based on correlation analysis between environmental variables and average stock characteristics that were sampled by different methods and at different times and locations. Therefore, it is possible that the correlations are spurious. Similarly, there are no studies to provide a mechanism and supporting evidence for these correlations. This can only be accomplished by examining the dynamics of an individual stock.

Many researchers feel that density-dependent mechanisms must influence salmonid dynamics. There are several examples of density-dependent freshwater growth of Atlantic salmon. Lindroth (1965), Ferno et al. (1976) and Gibson (1978) reported greatest growth at the lowest population densities. Similar conclusions have been found for Salmo trutta (Brown 1946), Oncorhynchus kisutch (Chapman 1965) and O. nerka (Foerster 1944, Johnson 1965, Burgner et al. 1969, Mathisen 1969). There is only one example of density-dependent survival in Atlantic salmon (Gee et al. 1978) but it is assumed to exist by salmon managers (Elson 1975). Most of the above studies consisted of experiments of stocking fry at different densities and may not be applicable to wild systems. Convincing evidence for density-dependent mechanisms will be found only in studies on individual stocks over a suitable time period.

In terms of management, smolts are the most important phase in the life history of Atlantic salmon. This is because smolts provide a measure of freshwater production; they are probably the only index of recruits to the fisheries; and they are monitored fairly easily. Average river production can only be calculated when there is some measure of net energy flow from all habitats. Smolt migrations are such a measure. They also provide comparable annual estimates of production. A series of annual estimates is necessary for understanding the influence of climate and density on the dynamics of populations.

The focus of this paper is the Atlantic salmon stock of Western Arm Brook, Newfoundland. The paper is divided into five parts. The first part examines the dynamics of smolt migrations and particularily, the nature of their annual variation. This involves an analysis of the variables which embody a smolt migration, such as size, sex, and age. It also includes an analysis of factors which might influence these variables, such as climatic conditions and density-dependent growth and survival.

In spite of great interest in smolt migrations and their suitability to careful monitoring, there has been little study on their population dynamics. There has been much work on the physiological mechanism of smoltification (see review by Hoar 1976) and its reponse to environmental stimuli (Osterdahl 1969; Wedemeyer <u>et al</u>. 1980). Smolts have been studied to determine migration routes at sea (Murray 1968a; Kerswill 1971; Ritter 1972; Pratt et al. 1974; Jessop 1975) and there has been considerable research on artificial rearing of smolts (Piggins 1974; Foda and Henderson 1977; Knutsson 1979). But in the past, there was no desire to just count smolts without doing some sort of manipulation, and wild populations were neglected.

The second part of this paper examines the dynamics of Atlantic salmon parr. This part concentrates on the effect of four different freshwater habitats on the abundance and biological characteristics of parr. The movements of parr are examined to see if the parr remain isolated in the different habitats. The question being asked is, do parr from different habitats develop into smolts of different biological characteristics?

Freshwater habitat is considered important as Atlantic salmon parr occupy habitats other than riffles. Throughout Newfoundland, they are found in lakes (Pepper 1976) and in waters with slow currents. The biological characteristics of parr in these habitats could be different from typical riffle habitats. For example, Gibson and Galbraith (1975) found that the outflow of lakes on the Matamek River supported a more productive invertebrate fauna, where parr grew faster than in other parts of the river. Kalleberg (1958) found that heterogenous substrates permitted a tighter packing of individual territories than homogenous substrates. A greater growth rate in one type of habitat could mean that these fish would have reduced smolt ages. Consequently, the biological characteristics of smolt might be influenced by the nature of their freshwater habitat.

The third part of this paper examines the dynamics of adult Atlantic salmon, in terms of sea survival and selection by the local commercial fishery. Sea survival is calculated for ten years from wild and untagged smolts to escaping 1SW adults. One-sea-winter (1SW) salmon spend one year at sea before first spawning (Allan and Ritter 1977). Sea survival is compared to biological characteristics of the smolt and adult migrations and to environmental factors. Selection of 1SW Atlantic salmon by the local commercial fishery is examined over a 5-yr-period by comparing biological characteristics of grilse sampled in Western Arm Brook to those of grilse harvested in the local fishery.

There has been considerable interest in the sea survival of salmonids. Some studies have related sea survival to factors intrinsic to the smolt migration. For example, large smolts had better sea survival than smaller smolts (Ricker 1962; Larsson 1977; Ritter 1977); or, sea survival was inversely correlated to the size of the smolt migration (Peterman 1978). Other studies have suggested that sea survival was related to factors in the marine environment, such as capelin abundance (Reddin and Carscadden 1980). However, there are difficulties with interpreting these studies. This is because they were usually based on tagged smolts which have a greater mortality rate than untagged smolts (Saunders and Allen 1967; Murray 1968a). Similarly, it is difficult to separate natural sea survival from fishing mortality. A recent review on this subject concluded rather pessimistically that there were insufficient data to provide any meaningful relationships between smolt size and sea survival (Walters et al. 1978).

The selective harvest of certain sizes and types of fish is an important consideration in the dynamics of Atlantic salmon. The type of fish that survives to spawn can have a critical influence on the fitness of future generations. Fitness can be measured as the ability to carry more eggs and to spawn further upstream or as the heritability of certain traits, such as smolt age (Reftsie et al. 1977) and sea age (Møller 1970). It is generally believed that commercial fisheries tend to select early run and multi-sea-year salmon and there is considerable indirect evidence from tagging studies that this is true (Calaprice 1969). However, in Newfoundland, 1SW salmon form the bulk of both the commercial and recreational fisheries and there is no documentation on the selective harvest of this type of fish.

The fourth part of this paper examines stock and recruitment. Counts of spawning adults and year-classes of smolts are used to measure stock and recruitment, respectively. Smolts are a good index of recruitment for two reasons: first, they are the last measure of abundance of Atlantic salmon before harvest in the fisheries; and second, the abundance of smolts is correlated with the abundance of 1SW salmon in the following year (unpublished data). Similar data from two other Newfoundland rivers, Little Codroy and Indian, are also used for comparison.

An important objective in management of Atlantic salmon is to develop stock-recruitment relationships. Relationships between eggs deposited (stock) and their offspring (recruits) are necessary to manage both discrete and mixed-stock fisheries. Currently, in

Newfoundland and Labrador most salmon are exploited in coastal, mixed-stock fisheries. There is considerable criticism of this type of fishery because it is difficult to manage for individual stocks without having an impact on others. However, to change the fisheries toward river harvest, biologists must calculate optimal spawning requirements for individual stocks. Stock-recruitment relationships are also necessary to predict abundance of stocks well before harvest. Predictions of stock size made several years in advance allow fisheries to be properly regulated with a minimum of economic hardship. Finally, enhancement of stocks requires stock-recruitment relationships to measure the costs and benefits of enhancement against natural propagation.

Earlier attempts to obtain predictive stock-recruitment relationships for Atlantic salmon were based on the Ricker model (Ricker 1954). Harvest statistics were assumed to reflect stock and recruitment of individual populations; biological characteristics such as smolt age, sea age and sex ratio were usually assumed to remain constant; changes in environmental conditions were also assumed to have negligible impact. Not one of these assumptions was entirely valid. This was due to unknown harvest of individual stocks in mixed-stock fisheries, large annual variations in biological characteristics and possibly due to environmental influences on year-class strength, such as changes in water temperature (Lishev and Rimsh 1961; Hunt 1969; Lind 1980) and discharge (Azbelev 1960; Havey 1974; Havey and Davis 1970). Consequently, attempts to develop stock-recruitment curves on Ellidaar River (Mundy et al. 1978), Foyle River (Elson and Tuomi 1975), Miramichi River (G. Turner, Fisheries and Oceans, Halifax, N.S., pers. comm.) and rivers of Labrador (Dempson 1980), insular Newfoundland (Chadwick, unpublished) and St. George's Bay (B. Dempson, Fisheries and Oceans, St. John's, Nfld., pers. comm.) have not been successful.

The longest time series to study stock and recruitment is on Western Arm Brook, Newfoundland. This time series covers 6 generations and provides complete counts of smolts and adults. The watershed is free of human influence, and the population had been handled only to obtain small scientific samples. Although this time series is still fairly short, it is sufficient to examine for evidence of a stock-recruitment relationship.

The fifth part of this paper examines freshwater production. Production in typical salmon rearing habitat is calculated from samples of parr. The smolt migrations are used to calculate production from all habitats combined. Production in lakes and steadies is calculated indirectly from the difference between the two methods.

The estimates of freshwater production in Western Arm Brook are unique for two reasons. First, they provide an estimate of annual variation in production which other studies have been unable to do (examples are: Meister 1962; LeCren 1965; Egglishaw 1970; Egglishaw and Shackley 1977; Gee et al. 1978). This is because the latter were based on samples of salmon parr and they could not be compared between years due to potential movements of fish and local changes in habitat. In contrast, the smolt migrations on Western Arm Brook provide estimates of net stream production which are comparable between years. The second reason is the ability to estimate production in habitats which are difficult to sample. Tagging, electrofishing and seining of juveniles are adequate only in certain habitats under ideal conditions. Consequently, estimates of production from lakes and steadies are usually not available.

Finally, the five parts are assembled into one picture of an individual fish stock. A comparison is made between the relative variation and interrelationship of each part. A possible relationship between freshwater production and optimal egg deposition is also examined. This is done, not only to arrive at tangible values for available harvest, but also to emphasize the importance of integrated research on small, experimental rivers, like Western Arm Brook, as a rational basis for Atlantic salmon management.

2. STUDY AREAS

2.1. LOCALITY

Western Arm Brook lies on the west coast of the Great Northern Peninsula of Newfoundland and enters the sea at the head of the western arm of St. Barbe Harbour (51°11'25"; 56°45'48"), 2 km southeast of St. Barbe (Fig. 1). The river has a drainage basin of 150 km^2, a basin relief of 98 m, an axial length of 32 km (Fig. 2) and contains 83 lakes with a total surface area of 2560 ha. In the headwaters, the river meanders through a series of dish-like lakes on poorly-drained, peat barrens. Western Arm Brook has two forks which join into the fourth order stream about half way to the mouth and just above Western Brook Pond (Fig. 1), which is the largest lake in the system (820 ha). The river picks up momentum and becomes mostly a series of riffles, pools and long, narrow steadies down to the river mouth. The estuary is a shallow delta which is submerged at high tides.

2.2. HISTORY

In 1971, studies were initiated on Western Arm Brook as a potential donor of Atlantic salmon stock to near by Torrent River (70 km south). The smolt, kelt and adult migrations were counted annually (Traverse 1972; Porter and Davis 1974; Pepper <u>et al</u>. 1975). After spawning salmon are called kelt until they return to sea. In 1972, the watershed was surveyed by helicopter and estimated to have 998 rearing units of suitable habitat accessible to Atlantic salmon (Porter et al. 1974); a rearing unit is 100 m^2 of gravel, cobble, rubble or boulder substrate. Over five years, 1972-76, a total of 600 fish were transferred to Torrent River. In 1981, the salmon migrations continue to be counted.

The river drainage is free of farms, dwellings, large scale logging, mining, insect spraying, hydro electric impoundment and other pollution. St. Barbe, the nearest community, has a population of 300 and a ferry terminal between insular Newfoundland and Blanc Sablon, Quebec. A fish plant is proposed for this community, but has not yet been constructed. The river is crossed by one road, Highway 73, also at the mouth; and is accessible to man only by foot, canoe or snowmobiles. The latter are used extensively in the winter for trout fishing, snaring of rabbits and small scale logging. Most of the watershed is crown reservation land, but from Western Brook Pond to the source there are mineral concessions to Reid Newfoundland Development Company and timber concessions to Bowaters Newfoundland. At present, neither of these concessions are being utilized, however 30 to 50 years ago, there was extensive logging in the headwaters of Western Arm Brook by Bowaters. The trees (mostly spruce) were cut during the winter and dragged by ponies over to St. Genevieve River where they were driven to the sea in the spring and taken to Corner Brook for processing into pulp and paper. Today there is little evidence of this activity.

2.3. ENVIRONMENT

The climate in this area is characterized by cold winters and a rather cool, short, summer season. The climate is greatly influenced by the cold, ice-laden Labrador current. A summary of the air temperature is as follows: mean annual temperature, 0°C; mean January temperature, -10.0 to -7.5°C; mean July temperature, 12.5 to 15.0°C; frost free days, <100; and average freeze over of lakes, 15 November to 15 May. The area is outside the zone of scattered permafrost (Hydrological Atlas of Canada 1978). The area receives 30-35 k cal cm^{-2} y^{-1} solar radiation and is exposed to strong north and west winds (op. cit.). Precipitation is slightly less than average for insular Newfoundland (Murray and Harmon 1969), about 1000 mm y^{-1} (Fig. 3). Meteorological information is recorded in Monthly Record (Anon. 1963-80) for St. Anthony since 1950 (Table 1). St. Anthony is located 90 km north of St. Barbe (Fig. 4). Air temperatures recorded at St. Anthony were used to represent water temperatures in Western Arm Brook.

Waterflow in Western Arm Brook was estimated from daily readings of water discharge collected on St. Genevieve River from 1970 (Table 2). These values are published in Historical Streamflow Summaries 1977 (Anon. 1977). St. Genevieve River is adjacent to Western Arm Brook (Fig. 4) and has a very similar type of drainage basin, relief, physiography and vegetation.

The water chemistry of Western Arm Brook is similar to other rivers on the northwestern coast of Newfoundland. The watershed lies on a flat plain of Ordovician bedrock, as a result, average values for pH, conductivity, total hardness and total alkalinity (Table 3) are higher than have been found in most Newfoundland rivers (Murray and Harmon 1969; Jamieson 1974). Rivers throughout the remainder of the island typically flow over igneous or metamorphic bedrock and have softer waters. Humic acids, originating from the bogs, impart a light, tea colour to the water of Western Arm Brook, otherwise it is fairly clear (turbidity = 1.3 JTU). In the headwaters, these humic acids form a flocculent precipitate with calcium ions which can form thick deposits at river bends that release methane gas when disturbed. Pockets of marine clay are found throughout the lower section of the river. The remains of _Pecten_ sp. and other molluscs which are present in these sediments, indicate that part of the watershed was inundated with seawater until fairly recently, about 7,000 B.P.

The watershed is almost equally shared by peatland and, on the higher ground, coniferous forest. The peatland consists primarily of sphagnum mosses and lichens together with _Vaccinium_ sp., dwarf _Betula_ sp. and _Salix_ sp., _Myrica gale_, _Andromeda glauciphylla_, _Ledum groenlandicum_, _Kalmia polifolia_, _Sarracenia purpurea_, _Drosera_ sp., _Utricularia_ sp., _Larix laricina_ and _Picea mariana_. The forest community includes mature stands of _Picea glauca_, _P. mariana_ and _Abies balsamifera_. Riparian vegetation is predominantly _Alnus crispa_, _Potentilla fruticona_, _Cornus stolonifera_ and occasional _Ribes glandulosum_. In the long marshes near the river mouth, there are extensive stands of _Equisetum_ sp. and _Carex_ sp., otherwise aquatic vegetation is not abundant.

The river is accessible to salmon throughout 90% of the watershed. There are three falls on the system: the first are 1.5 m high and located 0.2 km from the mouth; the second and largest falls (4 m) are 0.3 km upstream of lake N; and the third falls (1 m) are at the outlet of lake G. None of these obstructions would impede fish migration during normal discharge, but the second and third falls and several beaver dams (Fig. 2) would be partial obstructions to adult migrations at low discharge. In 1972, a channel was cut into the limestone bedrock at the second falls to assist fish migrations at all levels of discharge.

Seven species of fish were encountered either at the fish counting fence or during electrofishing. Salmo salar, Salvelinus fontinalis and Gasterosteus aculeatus were by far the most numerous species and they were found throughout all accessible habitats in varying proportions. Usually the latter two species were most abundant in ponds and steadies, while salmon predominated riffle areas. Anguilla rostrata were not abundant, but were found at most stations. Pungitius pungitius had a peculiar distribution; in 1979 it was present in most of the electrofishing stations, but in 1978 it was absent. Osmerus mordax were found in small numbers at only two stations but were encountered in greater numbers at the counting fence. Several Alosa sapidissima were found at the counting fence each year, probably on their upstream, spawning migration, but no specimens were collected during the three years of electrofishing.

The occurrence of aquatic birds and mammals was noted during the several years of field work. Birds which could be potential fish predators are listed in order of decreasing abundance:

Larus marinus, Larus argentatus, Corvus brachyrhynchos, Megaceryle alcyon, Mergus merganser, Gavia immer, Pandion haliaetus, Bubo virginianus and Botaurus lentiginosus. Fish eating mammals were less abundant but included, Mustela vison and Lutra canadensis. Castor canadensis were common, but apparently not as abundant as they were a decade ago. Small headwater streams and ponds had numerous, decaying beaver houses and old dams which indicated a decline in numbers.

2.4. FISHERIES

The commercial salmon fishery is prosecuted from five berths in St. Barbe Harbour (Fig. 5). Three fishermen, Messrs. Tom Genge, Doug Gibbons and Isaac Toope provided most of the samples. The season opens on 20 May but nets are not put into the water until mid-June. Every effort is made to fish 100 fathoms of 133 mm multifilament net continuously at each berth until the beginning of August, when all nets are usually removed. Quite often, strong winds fill the nets with seaweeds, rendering them ineffective for capturing salmon until they are cleaned. During certain periods there are blooms of larvaceans which also cover the nets making them visible to salmon. The catches of salmon are not great, usually less than ten fish per berth per day, with the best catches occurring during overcast weather. Most of the catch is sold locally and not recorded. However when salmon are plentiful, they are sold to fish buyers in St. Barbe and Anchor Point. Landings have been recorded for these communities since 1970; landings for Area N, which includes all communities on the northwestern coast of the Great Northern Peninsula, have been recorded since 1952 (Table 4). It is difficult to ascertain where else Western Arm Brook stocks are harvested, but they are probably exploited to a limited degree by communities up to St. Anthony and possibly in White Bay.

The recreational fishery in Western Arm Brook is prosecuted mostly in a 100 m stretch between the bridge and the counting fence. Most anglers stop on the bridge to see if there are salmon before deciding it is worthwhile to start angling. Fish are captured by fly fishing; most are taken in the early evening during the month of July; and landings have been recorded continuously since 1953 by river guardians (Table 4). Since 1971, field staff at the counting fence have recorded angling harvest. In 1978 and 1979 angling was prohibited due to low water levels. As a rule, angling activity is not encouraged by field staff. In 1980, the highway from Deer Lake to St. Barbe was resurfaced which has increased pressure to fish on this river. Western Arm Brook is known today as a grilse river, but there are historical records of "medium-sized salmon", about 5 kg (Palmer 1928; Western Arm Brook was called South Brook).

2.5. Habitat

Western Arm Brook was divided into four habitat types which are accessible to Atlantic salmon (Fig. 2). The habitats were called riffles (26 ha), steadies (45 ha), lakes (1972 ha) and outflows (3 ha). Areas were estimated from topographic maps, aerial photographs and ground truthing by canoe (Table 5). Riffles included riffle and pool habitats which are generally considered typical for the rearing of juvenile salmon (Allen 1969). Riffles had a water velocity >0.5 m sec^{-1}, with cobble, rubble, boulder or bedrock substrates and usually a mean depth <1 m, but often included deeper pools. Steadies were usually slow, meandering sections of river, with a water velocity <0.1 m sec^{-1}, a depth 1-3 m and mud or flocculent substrates. The numerous lakes varied in size but were usually shallow with a mean depth of 1-2 m. The small lakes usually had mud substrates with occasional patches of shale-like rubble and large boulders of sedimentary bedrock. The large lakes tended to have a greater proportion of rock substrate, especially in the littoral zone. Outflows occurred where lakes drained into the river, frequently as a shelf of sedimentary rock, followed by turbulent pools and rapids.

Habitats were sampled at 30 stations which covered three stream orders (Table 6). There were no stations on primary streams which were small, meandering ditches of humic water that drained peatland and usually flowed into shallow lakes. They were often intermittent, either frozen solid in winter or a thick, black ooze in summer, and contained only 3-spine sticklebacks.

There were nine stations sampled in secondary streams. Three stations were associated with the first tributary, 0.7 km upstream from the mouth of Western Arm Brook: station 30 was a shallow 7.5 ha lake, surrounded by peatland and patches of scrub spruce, which formed the headwaters to the tributary; station 4 was at the outflow of the lake and, station 2 was just above the confluence with the main river. Stations 16 and 22 were both steady habitats and located on tributaries which also drained small lakes. Station 23 was a riffle habitat located on a very narrow stream, <1 m in width. Stations 27, 28 and 29 were located above the lower third order tributary of Western Arm Brook; they were all riffle habitats; and, station 29 was thought to be inaccessible to salmon.

There were eight stations on the upper third order tributary. This tributary alternated between slow, wide deep steadies with peat banks riddled by tunnels of Ondatra zibethica and Castor canadensis and shallow riffles with large boulders partially-exposed. Stations 18, 19 and 20 were located in steady habitat; stations 17, 24 and 25 were located in riffle habitat and stations 21 and 26 were located at the outflows of lakes K and M, respectively.

The remaining 13 stations were located on the fourth order main stem of Western Arm Brook. There were seven riffle stations: station 1 was located 150 m upstream from the river mouth and just above the zone of tidal influence; station 3 was located just above the confluence of the first tributary; stations 5 and 6 were 200 m below long, narrow steadies; station 7 was located in a small run-around beside the main river, below the outlet of Lake N; station 8 was located on the widest side of an island located 0.5 km upstream of Lake N; and station 9 was also located on a run-around, 0.5 km upstream of the main falls, and was almost entirely on bedrock substrate. There were two steady stations: station 6 on Lake W was sampled only during the winter; and, station 11 was located just above Lake I, at the outlet of a muddy bog which was carpeted with Equisetum sp. There were two outflow stations, stations 10 and 14. Both were at the outlets of large lakes, Western Brook Pond and Lake G, respectively, and consisted of limestone shelves followed by turbulent pools. Western Brook Pond was sampled at two locations, stations 12 and 13. The latter was at the outflow of a small beaver pond.

3. METHODS

3.1. SMOLT

Smolt migrations were counted at a fish counting fence (Anderson and McDonald 1978) located near the river mouth. The counting fence was installed each year (1971-80) during the last week in May and removed at the end of the smolt run which was usually mid-July. Almost the entire run was enumerated in all years except 1979 when the early part of the run was missed. The part that was missed was estimated from the proportion of the total migration in other years which had occurred before the first peak in daily abundance, and it was calculated to be 15%. In 1977 and 1978 the fence was also installed from early September to late October to check for possible fall smolt migrants.

The fence was efficient at capturing all downstream migrating fish greater than 16 mm in thickness. This included the full range of smolt sizes and other fish with a body thickness greater than 16 mm. These other fish included salmon parr, kelt, trout, eels, smelt, shad and 3-spine sticklebacks.

The traps were checked at 0600, 1200, 1800 and 2400 h during the peak migration and at 0800, 1200 and 1600 h during the off-peak periods. In 1971, the trap was checked four times daily throughout the run. The fish were counted as they were dipped from the two traps and released downstream.

Samples of smolts were taken in several ways. In 1975, 1976, 1977, and 1979 the last five smolts of each 200 counted were taken as a sample. In 1978, five of each 400 smolts were sampled and in 1980, five of each 300 smolts were sampled. In 1972, one of each 25 smolts was taken until 75 fish were sampled, then one of each 50 smolts until a further 75 fish were sampled, and for the remainder of the run, one of each 25 fish was taken. In 1971, 1973 and 1974 the exact method of sampling was unknown, but it was distributed throughout the runs.

The samples of smolt were used to determine a number of biological characteristics including fork length, weight, condition factor, sex ratio, smolt age, vertebral counts, and gonad weight. Fork lengths (mm) and ages were determined for samples taken in all years. Blotted wet weights (g) were measured in 1972, 1973 and 1977-80; sex was determined in 1971-73 and 1977-80; ovarian weights were obtained 1977-80; and, vertebrae were counted in 1977. Fish were aged from scale samples which were removed from the left side of the fish in the area between the dorsal fin and the lateral line and were mounted between glass slides or rolled onto acetate strips. The scales were aged at 40x magnification with a Bausch Lomb microprojector, and annuli were discerned by standard criteria (Havey 1959). Sex was determined by gross examination of the gonads. In 1979-80, male fish which had spawned were identified by their enlarged testes. Ovaries were dried at 40°C for 12 h then allowed to cool in a dessicator before weighing to 10^{-4}g. Vertebrae were counted from x-ray photographs of whole smolts. Condition factor (CF) was calculated using the equation $CF = (W/FL^3) \times 100$, where W = weight (g) and FL = fork length (cm).

The first group of analyses examined variation in biological characteristics that were measured directly on the smolt migrations. Fork length, weight and condition of smolts were compared using three-way analysis of variance between three main effects which included: years, smolt ages and sexes. All possible interactions among the main effects were also tested. The contribution of each source of variation to the total explained sum of squares was compared for the three variables. Computation was done with GLM package program (SAS 1979).

Variation between years and smolt ages was also examined with one-way ANOVA for several biological characteristics. Smolt age was tested for significant annual variation. Ovarian weights were tested for significant differences between smolt ages. An index of ovarian weights was also tested for differences between smolt ages. The index was used to remove the effect of smolt size and it was calculated from (GW x 10,000/W), where GW = ovarian weight (g x 10^{-4}).

Vertebral counts for smolts sampled in 1977 were compared between the three dominant smolt ages. Comparisons between means were done with a 't'-test by comparing $t_s = (Y_1 - Y_2) \div \sqrt{((S_1^2 \div N_2) + (S_2^2 \div N_1))}$ to tabulated values of t, where Y_1 and S_1^2 equal the mean and variance of sample 1, and Y_2 and S_2^2, the mean and variance of sample 2. N_1 and N_2 represent the numbers in samples 1 and 2, respectively.

Possible changes in smolt fork length throughout the duration of the smolt migration were tested for the 1979 migration. The smolt run was divided into 8 time periods of 5 days each and the mean of each time period was compared using analysis of variance.

Sex ratio, as percentage males, was compared between smolt ages and years using the chi-squared statistic. The expected sex ratio was assumed to be the value for all years combined.

Relative annual variation was compared for all biological characteristics. A coefficient of variation (CV) was calculated from (M/SD) x 100, where M = mean of annual means, and SD = standard deviation. Characteristics with high CV's had greater variation between annual means.

Several biological characteristics were estimated indirectly from the smolt samples. These included standing stock of smolt migrations, annual growth increments for each smolt age, back-calculated growth increments, and year-class strength measured as smolts. Standing stock of smolt migrations was calculated from $N_i \bar{w}_i$, where N = number of smolts in a migration of year i and $\bar{w}_i$ = mean weight of the smolt sample taken in that year. Mean weights were not available in 1971 and 1974-76 and in these years standing stocks were calculated using the average mean smolt weight of 46.8 g for all samples combined. Standing stocks were expressed in kg.

Annual growth increments were calculated using $(\ell n\ W - \ell n E)/SA$: where W = the weight of a smolt in g; E is the weight of salmon fry at emergence (0.1 g) (unpublished data); and, SA = smolt age. Annual growth increments were compared between smolt ages with all years combined using analysis of variance.

Annual growth increments were also estimated from scales of smolts sampled during 1971-77. Fork lengths at each scale annulus were estimated by back-calculation. Scale growth and the growth of fish in length were assumed to be isometric (Havey 1959). The distances between scale annuli were measured from the focus along the longest oral radius (Tesch 1968). Relationship between total scale radius and fork length from the 1977 smolt samples was used for the back-calculation. The relationship was FL = 5.79 + 0.21 SR, where FL equals fork length (mm) and SR equals scale radius in units of 0.025 mm. The relationship was very significant ($P<0.01$, $r = 0.90$, df = 161), and it was chosen over relationships from other years because of its greater significance. Growth increments between age groups were calculated by assuming fish to be 28 mm at emergence equal to that found on Noel Paul's spawning channel, Newfoundland (Unpubl. data). These values were separated into the year when growth occurred and an overall mean was taken. The mean was calculated only for age groups 0-1, 1-2, and 2-3 as the older groups had very small sample sizes.

Year-classes were calculated from smolt migrations. A smolt migration consisted of cohorts with different smolt ages. A year-class was the sum of cohorts born in the same year; it could be the sum of six cohorts, ranging in smolt age from 2 to 7 years. The predominant cohorts were 3+, 4+ and 5+ smolts and a year-class was considered complete if these cohorts were represented. Complete year-classes were available from 1968 to 1976. The data were extended by estimating the cohort size of 3+ smolts in 1967 and 5+ smolts in 1977 from mean values in other years. Mean fork length and smolt age were calculated for each year-class. They were tested for significant variation between year-classes using analysis of variance. The standing stock of each year-class at the time of the smolt migration was estimated from $N_i\bar{w}_i$ where N =abundance of a year-class i and $\bar{w}$ = mean weight (g) of smolt in year-class i. For most year-classes, $\bar{w}$ was not available and it was estimated from the mean smolt weight of 46.8 g. Annual variation in the size and standing stock of year-classes was compared to annual variation in smolt migrations using coefficients of variation.

The biological characteristics of year-classes were examined for the influence of density-dependent and density-independent factors. Density-dependence would be evident if correlations were found between either the size, sex ratio and mean smolt age of year-classes, or the standing stock of parr and their back-calculated growth in the same year.

Standing stocks of parr present in Western Arm Brook for the years 1969 to 1974 were calculated using estimated egg to smolt survival rates (Section 3.4.). Densities of fish were converted to biomass using average weights of 1.5 g, 4.7 g, 13.4 g, 30.2 g and 45.9 g for age groups 0+, 1+, 2+, 3+ and 4+, respectively. The total weights of age groups were added together and a rough estimate of standing stock of parr was obtained for each year. These were compared to estimates of juvenile growth in the same years.

Density-independence would be evident if correlations were found between environmental variables in the first year of life and sex ratio or mean smolt age of year-classes. Many authors feel that the first year of life is most sensitive to the influence of environmental variables. This is because the first year of life is the period of greatest growth and mortality. The two most important environmental influences in the life of Atlantic salmon are water temperature and water discharge. Water temperature was estimated from annual mean daily air temperatures at St. Anthony (Anon. 1963-1980). Water discharge was estimated from values available on St. Genevieve River. A multiple correlation was also calculated using both a density-dependent and density-independent factor. The dependent variable was smolt age of year-classes and the two independent variables were mean monthly temperature in the first year of life and size of the year-class as smolts.

3.2. PARR

The biological characteristics of parr were studied in four different types of habitat: riffle, steady, outflow and lake (Tables 5 and 6). The habitats were sampled at 30 stations, in 15 field trips from 1977 to 1979. Riffle and outflow habitats were sampled using a Coffelt VVP electrofisher, powered by a portable, gas-powered generator. Steady and lake habitats were sampled with beach seine, a gang of gillnets and by angling with small flies. The mesh size of the gillnets ranged from 2.5 to 6.0 cm and they were fished overnight. In 1977, all parr were measured for fork length (mm), and weight (g), a scale sample was removed for aging and sex was determined. In 1978, parr were measured for fork length and a scale sample was removed, the fish were then returned to the water. Parr which died during handling were also weighed and examined for sex. Sex was determined by examining gonads for oocytes under a microscope; sexually mature males were identified by their enlarged testes (Jones 1939). In 1979, parr were measured for fork length and weight and then released. All fish at station 3 were killed and examined for sex in the first electrofishing of this year.

Salmon parr were aged from scales. Scales were mounted in several ways including: on glass slides using balsam and cover slips, rolled between acetate strips and dry mounted between two glass slides using masking tape. This last method gave the clearest image. The scales were aged using a Bausch Lomb microprojector at 40X magnification.

Scales of salmon were usually not difficult to read. Annuli were often distinct as a crossing over of sclerites at the lateral radii of the scale. But there were exceptions. Scales of fish captured in May were sometimes difficult to age as the annulus was just being formed. There was no definite time period for annulus formation, although older fish formed their annuli later in the season. Narrowly-spaced 'winter' circuli were also formed at different times; they were noticed on the scales of several fish captured on 20 August, 1978 (station 10) and on the scales of most fish captured on 27 September, 1977 (station 1). It was sometimes difficult to age small 1+ fish as their scales had tightly spaced circuli with poor separation between zones of summer and winter growth. Examples of these slow growing fish were found at station 3. The scales of fish captured at stations 4, 10, 14 and 16 were easily read. This was due to faster growth of these fish.

There were three aspects to the study of parr: first, biological characteristics were compared between the four habitats; second, parr were examined to see if they remained within their particular habitats; and third, the density or standing stock of parr was estimated in riffle habitat.

The first aspect was analyzed as follows: biological characteristics of parr were compared between habitats and their variation was compared between seasons and stations within habitats. The analysis was accomplished with a series of ANOVAs. First, differences in fork length, weight, condition and mean age were tested between the four habitats. Samples within each habitat were combined together, regardless of sampling date and the analysis was restricted to parr of ages greater than 0+.

Second, fork length of parr was compared between habitats sampled in early and late summer. Early summer was the months May-July and late summer was August-October. The analysis was repeated for ages 1+, 2+, and 3+.

A third analysis tested for variation in fork length between stations within the same habitats. The analysis was restricted to samples taken during later summer from riffle and outflow habitats. There were insufficient sample sizes to include parr from other habitats. The analysis was repeated separately for ages 1+, 2+, and 3+.

Sex ratio, as percentage males, was compared between habitats, ages and years of sampling. The comparison was done using the chi-squared statistic and an expected sex ratio of 50% males. The comparison between the four habitats was done with all samples combined. The comparison between ages 0+, 1+, 2+, 3+, and 4+ was done separately for each year of sampling and for all years combined. A comparison was also done between the percentage of mature males in each age group.

The final comparison was made between the relative species composition at each habitat. Species composition was the percentage of salmon parr to the total abundance of salmonids. The other salmonid was brook trout. The comparison was made between habitats and stream orders but no statistical test was used. Species composition was also summarized for all stations and a qualitative comparison was made between successive samples at each station.

If the biological characteristics of parr between the four habitats are to be used to predict the biological characteristics of smolts, it is important that parr remain in specific habitats for a large part of their freshwater residence. The movements of parr within habitats and stations were examined in 1978 by tagging. A total of 1424 fish were tagged and released from 15 stations; this included 1027 salmon parr, 27 smolt, 311 trout and 59 eels. The latter two species were also tagged to provide a relative comparison of recapture rates between species.

The procedure for tagging was as follows. Fish from each electrofishing sweep were collected into a covered 40 ℓ fiberglass tub. Each fish was anaesthetized with MS-222 before handling. Salmon and trout were measured for fork length (mm) and a scale sample was removed with tweezers from below the posterior end of the dorsal fin and just above the lateral line. The scales were stored in a labelled envelope. Eels were measured for total length (mm) but they were not aged. A numbered Floy fingerling tag was sewn with needle and nylon thread into the insertion of the dorsal fin and tied with several knots to form a small loop. The fish were then put into a recovery tank. The procedure took about 30 seconds. Salmon and trout <70 mm were not tagged, instead their adipose fins were clipped. Species other than salmon, trout and eels were measured for total length and were released untagged. When all fish had recovered, they were placed in an eddy in the center of a station. All dead or dying fish were preserved in formalin.

Recaptures of tagged fish were compared with t-tests to the expected number of recaptures and they were examined for changes in mean size, growth and age structure. Expected recaptures were calculated assuming an annual survival rate of 40% (Elson 1962a) and a value determined for the efficiency of electrofishing. The possibility of age-selective mortality on tagged fish was tested by comparing their mean age to those recaptured. The possibility of any increased mortality of tagged fish was examined by comparing size and growth rate of recaptured fish to mean values for the untagged population.

Movement of parr was examined in greater detail at stations 2 and 3 and the counting fence. A downstream trap was installed at the lower end of station 2. Station 2 was located on a second order tributary just above its confluence with the fourth order stream. The trap was checked several times a week from late May until the end of June 1978-79. The trap was constructed of galvanized wire screen and it was designed to capture all fish moving downstream. Station 3 was depopulated in early summer 1979; and it was electrofished again in late summer of the same year. The mean size, mean age and standing stock of parr were compared between both sampling dates using t-tests. Quantitative estimates of parr densities and standing stock were made at 12 stations. Six stations were in riffle habitat, four were outflow and two were steady habitat. The stations were blocked by nets of 7 mm mesh set at the downstream and upstream end of the station. The bottoms of the nets were secured with rocks and the tops were held above the water with poles. The station was electrofished by working upstream in a zig-zag fashion. Fish were usually captured in a net on the anode ring or by an assistant who carried a dip net and bucket. A third person was necessary to keep the cable free of entanglements. A sweep usually lasted from 30 to 45 minutes. A complete fishing consisted of four sweeps of equal duration. A pause of 30 to 60 minutes was held between sweeps. During this interval some fish would be processed, but all fish were held in fiberglass live-cars until the electrofishing was completed. They were then processed, tagged and released. All mortalities were preserved.

The efficiency of electrofishing was examined at station 3. Electrofishing is vulnerable to several sources of error: it tends to capture larger and older fish (Mahon 1981); it excludes a certain portion of fish that lodge themselves between stones (Heggberget and Hesthagen 1979); and it is not as effective in deep, turbulent or turbid waters. The first two sources of error were crudely tested by comparing the number of tagged fish released in an enclosed area to those recovered in a series of electrofishing sweeps. The third source of error was not so important in riffle habitats as only a small portion of the river was too turbulent or too wide. However, large steadies and lake habitats could not be sampled quantitatively.

Total parr abundance was estimated by plotting catch in each sweep against accumulated catch and extrapolating to the ordinate (Zippin 1958). Total salmonid abundance was estimated by combining salmon and trout. Density was calculated by dividing abundance by area (m^2) of the station that was electrofished.

Standing stock was calculated from the weight of all fish captured divided by the area (m^2) of the station. The mean weights of parr sampled in 1978 were estimated from a fork length-weight regression calculated in 1979. The regression was calculated from all parr combined and no attempt was made to account for possible differences in condition factor between stations. The equation was $\ell nW = 2.79\ \ell n\ FL - 10.28$, where W = weight in g, and FL = fork length in mm, and it was very significant ($P<0.01$, $r = 0.96$, $df = 664$).

Density and standing stock were compared in several ways. Variation between repeated estimates of density and standing stock was examined at station 1. Variation between age groups was also examined. A coefficient of variation was used in all comparisons. A second analysis compared standing stock between three habitats; riffle, outflow and steady. The habitats were also divided into stations on small and large order streams and they were compared on the basis of the percentage contribution by each age group. The standing stock and density of salmon parr and salmon and trout combined were compared for all stations, except station 1. The mean values were compared using t-tests and coefficients of variation.

3.3. ADULTS

Adult salmon were examined for sea survival and selection in the local commercial fishery. Sea survival was calculated as the percentage of 1SW salmon counted moving upstream in Western Arm Brook to the number of smolts counted in the previous year. Sea survival included both natural and fishing mortalities, as grilse had been exposed to several commercial fisheries before returning to their natal river. Fishing mortality was probably greater than 50% (unpublished data), but it was not possible to estimate accurately. Instead, fishing mortality was assumed to be constant; that is, the same relative proportion of the stock was assumed to be harvested each year. The only evidence to support this assumption was from six years of kelt tagging, where the proportion of tag returns was not different between years (unpublished data).

I examined two types of factors for their influence on sea survival. The first type were intrinsic factors or biological characteristics of smolts and returning grilse. They included smolt age, fork length, weight, condition and numbers in the migration. Mean values of each factor were compared to sea survival rates over the ten year time interval using correlation analysis. Finally, sea survival was compared between the three smolt ages using one-way ANOVA.

The second type were extrinsic or environmental factors which occurred at the time of the smolt migration and during the first year at sea. Presumably the earlier sea life would be most vulnerable to mortality. A number of environmental factors were examined, including, June, July and annual mean monthly air temperature at St. Anthony (Monthly Record 1963-80); total annual discharge and discharge during the twenty days of peak smolt migration as a percentage of total annual discharge in St. Genevieve River (Anon. 1977, 1978-81); total discharge for the months of June, July and August in St. Lawrence River; ice conditions in the Straits of Belle Isle during the peak of the smolt migration; and, the sum of mean May, June, July and August salinities and water temperatures for 1-20 m at station 27 near St. John's (S.A. Akenhead, pers. comm.). Station 27 was the nearest continuous time series of oceanographic information. Each factor was compared to sea survival over the ten year period using correlation analysis. In all analyses, percentages were normalized with a square root arc sine transformation.

An important aspect of the study on selectivity of adult salmon is the assumption that a large proportion of grilse caught in the commercial fishery of St. Barbe Bay was destined for Western Arm Brook. There was evidence to suggest this assumption was valid. Western Arm Brook is the major river of two salmon rivers which flow into the relatively small St. Barbe Bay (Fig. 5). All fishermen with catches that were sampled had berths located within the bay, at distances of 1-2 km from the mouth of Western Arm Brook. A tagging study in 1977 indicated that the local commercial fishery comprised 40-50% of salmon destined for Western Arm Brook (unpubl. data). This study was based on 100 recaptures of 246 tagged salmon; 24 fish were recaptured in Western Arm Brook, and a further 29 fish were recaptured in commercial nets near the mouth of the river.

Biological characteristics of salmon were sampled at two locations; from three commercial fishermen in St. Barbe Bay and at the counting fence on Western Arm Brook. Approximately half of the total landings in St. Barbe Bay were sampled from 1977-81. The catches were sampled daily throughout the entire fishing season. Salmon were sampled for fork length (0.1 cm), whole weight (0.1 kg), sex and a scale sample obtained. Sex was determined by internal examination of gonads.

In Western Arm Brook, one of every six spawners counted at the counting fence was sampled for biological characteristics and released upstream. The salmon were sampled as in the commercial fishery with the exception of sex. Sex was determined externally by examining the lower jaw. Fish with a small kype, a small hook, were considered to be males. Sea age and smolt age were determined for all samples by examining scales.

Only biological characteristics of virgin grilse or 1SW salmon were considered in the main analysis. Fork length, whole weight, and condition were compared using four-way analysis of variance between four main effects which include: locations, years, smolt ages, and sexes. All possible interactions among the main effects were also tested. The contribution of each source of variation to the total explained sum of squares was compared for the three variables.

For each year of sampling, mean smolt age of grilse was compared between locations and between mean age of smolts in the preceding year. Smolt ages of smolts and grilse from Western Arm Brook were available for the years 1971-81. Paired t-tests were used in all comparisons (Sokal and Rohlf 1969).

The expected sex ratio, as percentage males, was assumed to be the total sex ratio for all smolt ages and years combined in each of three analyses. The three analyses included grilse sampled in both St. Barbe Bay and Western Arm Brook and smolts sampled in the preceding year. In each analysis, the expected sex ratios were compared to observed values for the three dominant smolt ages and for each year of sampling. The three expected sex ratios were also compared. All comparisons were made using chi-squared goodness of fit tests (Sokal and Rohlf 1969).

A qualitative comparison was made between the timing of grilse runs in both the commercial fishery and in the river. Throughout 1981, the daily catches of all five commercial fishermen in St. Barbe Bay were collected by telephone. The combined grilse catches of the fishermen were compared to counts of grilse in Western Arm Brook by plotting the daily abundance of each on the same graph.

In 1979, there were sufficient sample sizes to test for changes in biological characteristics throughout the season for both grilse in St. Barbe Bay and Western Arm Brook. The season was divided into eight intervals. The first interval was the month of June, afterwards each interval was 7 days in length. Fork length, whole weight, and mean smolt age were compared between intervals using ANOVA. The analysis was restricted to female grilse.

Abundance, smolt age, and sex ratio of 1SW repeat spawners were also compared to 1SW virgin salmon.

3.4. STOCK AND RECRUITMENT

Migrations of Atlantic salmon smolts and adults have been counted on Western Arm Brook for 11 years (1971-81). Details on the size and biological characteristics of the migrations are presented elsewhere (Section 3.1.). The stock-recruitment relationship was calculated using natural logarithmic transformations on both number of eggs deposited and year-classes of smolt which hatched in the following year.

The time series on Western Arm Brook was enough to follow five complete year-classes from egg deposition to their recruitment as smolts. It was possible to estimate a sixth year-class by assuming that the size of the 5+ cohort was equal to the mean of other years. However, only five year-classes were included in the regression; the 1972 year-class was considered to be an outlier and it was not included in the analysis.

Evidence to suggest that the 1972 year-class was anomalous relative to other year-classes was obtained by comparing egg to smolt mortality rates to environmental information during the first year of life history. The first year of life history is usually considered to be most sensitive to environmental influence. Two environmental factors were examined: winter air temperature and a ratio of fall and winter water discharge. Winter air temperature was taken from the sum of mean temperatures for December, January, February, and March at St. Anthony. Temperatures in °F were taken from Monthly Record (Anon. 1963-80) then converted to °C. Water discharge was taken from St. Genevieve River (Fig. 4) (Anon. 1977). A ratio was used to express the difference between water discharge at the time of spawning and during the coldest winter months. The ratio was calculated from the sum of mean monthly discharges in January, February and March as a proportion of the sum of mean monthly discharges in September, October, and November in the previous year. I assumed that egg or fry survival was impaired in cold years with a low water discharge (Power 1958; Taylor 1973).

Spawning stock or egg deposition on Western Arm Brook was calculated from the 1971-80 adult migrations. Fecundity (F) was estimated from mean fork length (FL) of each year using $\ell og_{10} F = 2.3345 \ \ell og_{10} FL - 0.582$ (Pope et al. 1961). Several assumptions were required. First, the sex ratio was assumed to be 74% females in all years. Unfortunately, sex ratios were not reliable in some years because of small sample sizes. The 74% value was based on external sex determinations of 780 adult salmon of which, 574 fish were female. Secondly, mean fork length was calculated for both sexes as there was negligible difference between the size of males and females in the river. The third assumption was that there was a constant, but negligible, mortality of spawning adults after they had been counted at the fish trap.

The relationship between stock and recruitment was tested on data collected from Little Codroy River (Murray 1968a,b; unpubl. data). It was the only other river in Atlantic Canada with a 10-year continuous time series of relatively complete counts of smolts and kelts. Counts of escaping adults were not complete during the first several years of operation due to a run of large salmon in late October after the counting fence had been removed

(Anon. 1957). Thus kelts were considered as parental stock to calculate egg deposition and recruitment was calculated from their progeny as year-classes of smolts. The number of kelt was increased by 40% to account for fish which did not survive spawning. This value was obtained from Western Arm Brook where mean overwinter survival from spawning adults to kelts was 60%. A simple regression was calculated using a natural logarithmic transformation on both variables.

A multiple linear regression was used to test the influence of winter temperature and water discharge on egg to fry survival at the spawning channel on Indian River. Indian River was the only river in Newfoundland where this type of information was available. Mean monthly air temperatures were available for Springdale, near the mouth of Indian River from Monthly Record (Anon. 1963-80). The temperature of the month with the lowest mean was used as the X variable. The mean water discharge during the coldest month was subtracted from the month of greatest discharge prior to freeze up, either November or December. This value was used as the Y variable. Mean monthly water discharges were available for Indian River in Historical Streamflow Summary (Anon. 1977). Egg to fry survival rates were available on Indian River from 1963 to 1972 (Anon. 1978). They were treated with an arc sine transformation and used as the Z variable. A number of independent variables were also examined, including those that were used on Western Arm Brook (i.e. winter temperature and discharge ratio), but the only significant relationship to explain egg to fry survival was found using the variables described above.

3.5. PRODUCTION

Freshwater production was calculated using two methods. First net production from all habitats was calculated over a series of years from smolt migrations. Second, production from riffle and outflow habitats was calculated from the samples of parr that were collected in 1978-79. It was possible to estimate production in steady and lake habitats from the difference between the two methods.

Net production of salmon was estimated from year-classes of smolts. Only females were used in the calculations as they comprised 76% of the smolt run. It was assumed that production of males was equal to females, although most males did not go to sea. Production was calculated from $P = G \times B_0 (e^{G-Z}-1)/G-Z$ (Ricker 1975). B_o is the initial biomass and was equal to the estimated weight of eggs at spawning. An egg was assumed to weigh 0.1 g. G and Z are the instantaneous growth and mortality rates taken from egg to migrating smolt. G was the difference between natural logarithms of egg weight and mean smolt weight. Z was the difference between natural logarithms of estimated egg deposition and numbers of smolt in the resultant year-class.

Production and available production were calculated separately for each year-class (1972-76). Available production (A) was equal to the weight of a year-class at the time of migration. The turnover ratio (A/P) is an estimate of efficiency of smolt output from a given freshwater production; it was calculated for each year-class.

Freshwater production of salmon was also calculated independently for riffle and outflow habitats. It was calculated from estimates of standing stock and growth obtained during the sampling of parr in 1978-79. An exponential model of production was not used as accurate mortality rates could not be calculated. Instead, production was calculated from $G \times (B_1 + B_2)/2$, where G = growth rate, B_1 = standing stock of a cohort in 1978 and B_2 = standing stock of a cohort in 1979. Standing stocks were adjusted for the 73% efficiency of electrofishing. Growth rate was calculated as the difference between the natural logarithm of the mean individual weight for a cohort in 1978 and in 1979. Growth rates were calculated for 4 riffle stations and mean values were obtained for age groups 0-1, 1-2 and 2-3. Production in older age groups was assumed to be negligible. Production was calculated at four riffle stations and three outflow stations and all values were combined together into one estimate.

Production in steady and lake habitats were estimated indirectly. They were calculated from the difference between mean net production of smolt year-classes and the production of parr in riffles and outflows.

4. RESULTS

4.1. SMOLTS

The most important results from the analyses of the smolt migrations were as follows: size of migrations was the most variable biological characteristic; smolt age was next in annual variability; size of smolts was significantly different between smolt ages; size of smolt migrations was correlated to downstream movements of parr; temperature appeared to influence time of migration and smolt age of year-classes; finally, no direct evidence was found for density-dependent growth in freshwater. I will elaborate on these points.

The smolt migrations started in late May or early June and they usually lasted at least 40 days (Table 7). The smolt migrations appeared to be influenced by water temperature: they commenced when minimum water temperature was greater than 7°C and they peaked at or above 10°C (Fig. 6). There could be several peaks in daily abundance. This was most apparent when water temperature dipped below 10°C. Small smolt migrations also occurred in the fall. In 1977, 13 smolts were counted from 8 to 27 September and in 1978, 29 smolts were counted from 26 August to 24 October (Table 8). These latter migrations also occurred when water temperature was around 10°C.

The annual abundance of smolts appeared to be random, although the time series was too short for an adequate run test (Sokal and Rohlf 1968). The largest migration was in 1980 and it was 2.7 times larger than the smallest migration in 1971 (Table 8).

It appeared that smolts had the lowest annual variation in abundance when compared to other species. The coefficient of variation for smolts was 30%, which was half the value found for trout and one seventh the value for shad (Table 8).

The annual abundance of smolts was significantly correlated ($P < 0.05$) to the abundance of salmon parr, kelt and trout (Table 8). The correlation between smolts and downstream migrating salmon parr was significant at the 2% level and it is clearly seen in Fig. 7. The daily counts of parr and smolts were also closely correlated (Fig. 8). These observations suggested that similar factors influenced migrations of both stages of salmon. The correlation between smolts and kelt depended largely on the coincident, high values in 1980 and it was not significant if this year was omitted.

It was clear that salmon was the most numerous of species which migrated to sea (Table 9). Almost 90% of the 538 kg that were annually exported from Western Arm Brook were salmon smolts (Table 9). Eels were second in abundance, followed by brook trout and smelt.

Smolts were found with a wide range of smolt ages: smolt age ranged from 2+ to 7+. The predominant smolt age was 4+ and this age group comprised about 63% of the average smolt migration (Table 10). The two rarest smolt ages were 2+ and 7+. There were two age 2+ smolts from the ten year random sample of 1699 fish. The single 7+ smolt was found in 1972, however it was not taken from the random sample, instead it was taken from another sample of the 100 largest smolts in that migration. The mean age of smolts varied significantly between years (Table 11). Mean smolt age was 3.82 y and it ranged from 3.45 y in 1977 to 4.16 y in 1974. Variation in smolt age was mostly due to changes in the proportion of age 3+ and 5+ smolts (Table 10).

The main results of the three-way analysis of variance were as follows: variation in fork length, weight and condition was significantly different between years; variation in fork length and weight was also significantly different between smolt ages and significantly different between sexes; and annual variation in fork length and weight was complicated by a significant interaction of year with smolt age (Table 12). There were no other significant interactions which allowed for a clearer interpretation of the main effects.

The most important source of explained variation was the difference between smolt ages; that is, smolts were progressively larger at older smolt ages (Table 13 and Fig. 9). Differences between smolt ages accounted for 73% of the explained variation in fork length and 37% of the explained variation in whole weight (Table 14). There were no significant age differences for condition (Tables 12 and 13) which indicated that older smolts had the same body proportions as younger smolts.

Differences between years was the most important source of explained variation for condition factor, but the least important for fork length and weight (Table 14 and Fig. 10). It explained over 50% of the explained variation in condition. However, the interaction between years and smolt ages was important for all three variables (Table 14). This indicated that annual variation in these biological characteristics can be properly explained only if it is calculated separately for each smolt age; that is, variation between years was also due to variation between smolt ages. Mean values for each year are presented in Table 15. In 1979, smolts had greatest fork length and weight but lowest condition. In 1972, smolts were also large, but condition was greatest. The large size of smolts in 1971 could have been due to the small sample size.

There were also significant differences in fork length and weight between sexes. Sex contributed to 19% of the explained variation in weight (Table 14). These differences were almost entirely due to the large size of previously matured male smolts (Table 16). Otherwise there were no consistent differences between sexes; in half of the years sampled, males were slightly larger than females and the opposite was true for the other years.

The results of the other analyses were as follows; ovarian weights were significantly greater at older smolt ages (Table 17). Ovarian weight of 5+ smolts was double that of 3+ smolt. However, increase in ovarian weight with age was due to corresponding increase in somatic weight. The indices of ovarian weight were not significantly different between ages (Table 17).

There was no significant difference between vertebral counts at the three dominant smolt ages (Table 18). There was also no significant change in smolt size throughout the 1979 smolt run (Table 19), which suggested late migrants were not larger than early smolts. Finally, fork length of 4+ smolts was only barely significantly different ($P = 0.04$) between years (Table 20). There was no significant annual variation if the small values for 1980 were omitted from the analysis. This corroborated the results of the three-way analysis which indicated that any annual variation in size of smolts was largely due to an interaction with smolt age (Table 12).

Smolts were predominantly female (Table 21). Annual deviations in sex ratio were not significantly different from the overall value of 75.3% females. Similarly, there were no significant differences for sex ratio between the three dominant smolt ages. However, there appeared to be fewer males in older age groups. Annual fluctuations in sex ratio were more pronounced when sex ratio was divided into the three smolt ages, but this could have been partly a result of small sample sizes. Matured males were also present in smolt migrations and they comprised from 11% to 30% of males (Table 21).

Exceptionally large smolts (>30 cm) were encountered in 1971 and 1972. In 1972, all smolt greater than 20 cm were collected; 110 specimens were obtained with a mean size of 236 mm, ranging from 200 to 354 mm; they comprised <1% of the migration. Unfortunately only one of these fish, a female, was sexed. The average age of the large smolts was greater than the mean; one specimen was age 7+. Presumably these large smolts occurred in other years but were too rare to be sampled.

A summary of biological characteristics indicated that fork length and condition had the least annual variation and smolt age, sex ratio and the size of the migration had the most annual variation (Table 22). Annual variation in standing stock (Table 23) was similar to that for numbers of smolt (Table 22) and it suggested that annual changes in standing stock were due to fluctuations in numbers of fish and not to fluctuations in their average weight. Standing stock ranged from 268 kg in 1971 to 687 kg in 1980 (Table 23).

The main results of biological characteristics that were estimated indirectly from the smolt migrations were as follows: annual instantaneous growth rates were significantly different between smolt ages; there was no correlation between back-calculated parr growth and standing stock of parr; there was also no correlation between year-class strength of smolts and any biological characteristics of year-classes; and lastly, there was a significant relationship between mean annual air temperature and mean smolt age of a year-class. The first result indicated that the instantaneous growth rate of 3+ smolt was nearly double the growth rate of 5+ smolts (Table 24). Instantaneous growth rates were significantly different between all four smolt ages (Fig. 9). Thus, the increase in weight with smolt age (Tables 12 and 13) did not account for the considerable differences in growth rates between ages.

There was no significant difference between back-calculated fork length and actual fork length in 15 out of 21 (71%) comparisons (Table 25). Back-calculated fork lengths also indicated that juvenile growth rates decreased with smolt age. Mean back-calculated fork lengths were significantly larger ($P < 0.05$) at each age group for 3+, 4+ and 5+ smolts respectively, except at ℓ_1 (fork length at the formation of the first annulus). At ℓ_1, differences in back-calculated fork lengths were not usually significant.

There was no apparent relationship between mean growth rate and standing stock of parr in the same year. The years of greatest growth were 1969, 1973 and 1974 and the least growth was in 1971 (Table 26). The years of greatest parr standing stock were 1971 and 1972 and the lowest standing stocks were in 1973 and 1974 (Table 27). Both estimates of growth and standing stock seemed to be quite constant and they did not have enough contrast in values to detect possible correlations between them.

Year-classes of smolts were calculated for eleven years, 1967-77. Year-classes ranged in size from 6074 smolts born in 1973 to 16,932 smolts born in 1977 (Table 28). There were no significant correlations between the size of year-classes and smolt age, fork length, weight or condition (Table 28). Annual variation in smolt age of year-classes was highly significant ($F_{11,1693} = 57.32$; $P < 0.001$). Annual variation in fork length was also significant ($F_{9,1621} = 3.15$; $P < 0.01$), but nevertheless, there was relatively little annual variation in mean fork length (Table 28).

There was good evidence that smolt age was influenced by environmental factors. Mean smolt age of year-classes was highly correlated ($P < 0.01$) with both annual mean daily and annual mean monthly air temperatures (Fig. 11) and their standard deviations Table 29). Smolt age decreased during cold years. Colder years tended to have greater standard deviations which accounted for the significant relationships between smolt age and standard deviation of temperature. There was also a significant relationship between mean smolt age and the number of days greater than or equal to 7°C (Table 29), which indicated that length of growing season was probably an important factor in this relationship. Smolt age was significantly correlated to both year-class strength of smolts and mean monthly temperature in a multiple correlation (Table 29); but this was almost entirely due to the latter independent variable. No relationships were found between water discharge and any biological characteristics of year-classes.

4.2. PARR

The main results of the study on parr were as follows: biological characteristics of parr were different between the four habitats, but there were also significant differences between seasons, years and stations within habitats; parr did not appear to remain within their habitats, except at downstream stations; and finally, average standing stock in riffle habitat was 3.5 g m^{-2}. I will deal with each result in more detail.

Parr sampled from riffle and lake habitats were smaller and younger than parr from other habitats (Table 30). However, lakes were the most poorly sampled habitat and it would not be wise to base conclusions on such small sample sizes. Similarly, steadies were not well sampled, but parr from these habitats were larger and older than parr from others (Table 30). Parr from riffles were significantly ($P < 0.05$) smaller in fork length and weight than parr from outflows, but they did not differ in condition factor. The mean age of parr from riffles and outflows was not significantly different when compared with a t-test ($P > 0.10$). This suggested that parr from riffles had slower growth than parr from outflows.

Seasonal variation in biological characteristics was an important aspect of the differences between habitats. For example, fork length was not significantly different between habitats when samples were taken in early summer, but it was significantly different at all ages for samples taken in late summer (Table 31). This suggested that either there was greater growth in outflow habitats, or larger parr were immigrating into these areas throughout the summer season, or that the opposite situation was occurring in riffle habitats. Nevertheless, it indicated that differences in biological characteristics between habitats occurred during the summer season.

The differences in size of salmon at outflow and riffle habitats are most clearly seen with fork length frequency distributions. Figure 12 illustrates the fork length frequency of parr sampled in these habitats in late summer of 1978 and 1979. In 1978, the distributions interdigitated almost exactly; this was not so apparent in 1979. This suggested a strong selection towards particular sizes in each of these habitats. Unfortunately, there were inadequate samples in lake and steady habitats to examine for similar size selection.

There was some variation of fork length between stations within the same habitat. In riffle habitats, mean fork length was significantly different between stations for ages 1+ and 2+, but not for age 3+ (Table 32). There were no significant size differences between stations at all ages for parr sampled in outflow habitat. Although there was significant variation between stations within riffle habitat, it accounted for less than 25% of the total explained variation in comparisons between habitats. Thus, the largest source of variation in fork length was due to differences between habitats.

Sex ratio was not significantly different between the four habitats (Table 33). Sex ratios were exactly equal in riffle and steady habitats. There was a preponderance of males in outflow and lake habitats, but this was not significant (Table 33). Sex ratio was also not significantly different between years (Table 34). However, at ages 0+, 3+ and 4+, sex ratios were significantly different ($P < 0.05$) from 50% males. The preponderance of females at age 0+ could have been due to the small sample size. The preponderance of males at ages 3+ and 4+ could have been a result of prolonged stream residence of sexually mature males. Over 60% of males in these age groups were sexually mature (Table 34).

Species composition was predominated by salmon. The percentage salmon was greatest in riffle habitats, but it increased with stream order in all habitats (Table 35). In the fourth order stream, about 80% of salmonids were salmon.

There were two points of note in Table 36. First, there appeared to be a marked consistency of the percentage of salmon at successive samples within most stations. This was very apparent at large riffle stations, such as 1, 3, 5, 6, and 7. Second, at small stations, there appeared to be a decline in the percentage salmon with successive samples. This was apparent at stations 2, 4, 16, 18, and 22, and it suggested that the immigration pressure was perhaps less at these stations.

The tagging experiment indicated that there was some stream movement and a high tagging mortality. Of 1027 salmon parr tagged in 1978, only 41 were recaptured in 1979: one tag at each of stations 2, 10, and 21; seven tags at station 1; and 31 tags were recaptured at station 3. The higher returns at the latter two stations diminished the possibility of poor sampling technique as all stations were sampled in the same manner. It was also noteworthy that stations 1 and 3 were nearest to the river mouth.

There was some evidence that any emigration or mortality occurred within two months after tagging. In the first year of tagging, 10% and 41% of the tags at stations 1 and 3, respectively, were recaptured after two months (Table 37). When these values were corrected for the 73% efficiency of electrofishing, they indicated an emigration rate or tagging mortality of 89% at station 1 and 44% at station 3. Both of these values were very similar to the annual rates. For example at station 1, 236 salmon were tagged in 1978 and only 7 fish were recaptured one year later. The expected number of tag recaptures was 69 fish (236 x 40% survival (Elson 1973) x 73% efficiency of electrofishing); this indicated a tagging mortality or emigration rate of 90%. At station 3, 173 salmon were tagged in 1978 and the expected number of tag recaptures was 51 fish. However, only 31 tagged fish were recaptured which indicated a tagging mortality or emigration rate of 39%. Although the values between stations were very different, there was a close similarity within stations between the seasonal and annual estimates. This suggested that the loss of tagged fish occurred shortly after tagging.

The loss of tagged fish did not appear to be age selective. At station 3, there was no significant difference ($P > 0.05$) between the mean age of fish tagged in July 1978 (1.69 y) and those recaptured one year later (2.71 y). Similarly, there was no difference between fish tagged in September 1978 (1.87 y) and those recaptured one year later (2.87 y). There were not sufficient recaptures to make a valid age comparison at station 1 (Table 37).

There was evidence that tagging suppressed the growth of fish. The mean annual growth increment for recaptured tagged fish was 11 mm for age 1+ and 9 mm for age 2+. This was considerably less than the expected 30-40 mm of annual growth (Table 26) at these age groups.

The reduced growth of tagged fish might imply an increased mortality, but there was also some indication of emigration. Two tagged fish were recaptured at stations other than at the site of initial tagging. One fish tagged at station 3 on 20 September 1978, was recovered the following day while electrofishing at station 2, a distance of 100 m downstream. The other fish tagged at station 4 was recovered one year later, 0.3 km downstream, at station 2.

Further evidence of the downstream movement of salmon parr was found at counting traps on the first tributary and at the river mouth. At the small counting trap on the first tributary, parr were counted moving downstream in both 1978 and 1979 (Table 38). Presumably these fish originated either from the 7 ha pond (station 30), or the 0.3 km of stream between stations 2 and 4. Parr were found moving through the trap only during late May and early June which was coincidental with the smolt migration. It was apparent at the main counting fence that the downstream movement of parr and smolt occurred at the same time of the year (Fig. 7 and 8) and there was little movement during mid-summer.

Further evidence suggesting significant movement of salmon parr was found at station 3. The station was electrofished in May 1979 and depopulated. Two months later the salmon population was found to be completely re-established with the same age structure and an almost equal biomass (Table 39). There were no significant differences for average size, age and condition between the two sampling dates.

The density and standing stock of salmon and trout were most similar in riffle and outflow habitats (Table 40). The combined densities of salmon and trout and the standing stock of salmon were equal in both habitats. By contrast, the density of salmon was significantly ($P < 0.01$) less in outflow habitat, and the combined standing stock of salmon and trout was significantly more ($P < 0.01$). This indicated that there were fewer salmon and more trout in outflows; and also, both salmon and trout were larger in these habitats. Density and standing stock of both species were much less in steady habitat than in either riffles or outflows (Table 41). Values were not available for lake habitats.

The distribution of salmon standing stock by age groups varied between habitats. Most of standing stock in outflow stations was in the 3+ age group (Table 42). Riffle stations shared 75% of standing stock between the 2+ and age 3+ groups. There was only a small standing stock in steadies, but 75% was in the 1+ age group. The standing stock of age 0+ salmon was low at all habitats.

Station 1 had the largest standing stock of salmon. The standing stock of 7.3 g m^{-2} (Table 43) was nearly three times the mean value for other riffle and outflow stations (Table 40). Station 1 also had the most constant repeated estimates of density and biomass; the coefficient of variation around the mean was only 13% compared to 38% for riffles and 19% for outflows (Table 40). Variation in repeated estimates tended to decrease with increasing age groups (Table 43). Station 1 was similar to other riffle stations in all aspects except that it was nearest to the river mouth; it was immediately above the counting fence.

The high value and constancy of standing stock at station 1 suggested carrying capacity had been reached. The carrying capacity was about 8 g m^{-2} and it could be shared by either salmon or trout. This threshold is indicated in Fig. 13. At high standing stocks of salmon, standing stocks of trout tended to be low, and vice versa. At station 1, standing stocks were almost entirely salmon. Further evidence to suggest a threshold standing stock of 8 g m^{-2} was the inverse relationship between salmon standing stock and condition factor (Fig. 14). Condition was lowest at stations with greatest biomass and it increased as biomass decreased. The correlation was significant ($P < 0.01$) but it depended very much on the value at station 1. I indicated a linear relationship, but it would be more likely curvilinear if there was validity to the threshold standing stock of 8 g m^{-2}.

The mean values for standing stock of salmon in riffle and outflow habitats were corrected for the efficiency of electrofishing. The efficiency of electrofishing in riffle habitats was tested for fish larger than 70 mm at station 3. A total of 97 parr, 1 trout and 2 eels were tagged and released into the 'empty' station. Only 71 tagged parr, or 73% were recovered after three electrofishing sweeps. The Zippin (1958) method was not different. It estimated a density of 73 parr or 75% recapture of fish. The efficiency in other habitats was not tested, but it was likely less than 73%. The efficiency of electrofishing was assumed to be equal for salmon and trout. Thus the corrected estimate for mean standing stock of salmon in riffles and outflows was 3.5 g m^{-2} (2.5 g m^{-2} ÷ 0.73; Table 40). The corrected value for standing stock at station 1 was 10.0 g m^{-2} (7.3 g m^{-2} ÷ 0.73; Table 43).

A final observation was made on the biological characteristics of salmon and their distance from the river mouth. There were inverse correlations between distance upstream and mean size, mean age and standing stock of salmon (Table 44); in both years, two of three of these correlations were significant. Salmon sampled at upstream stations were usually smaller, younger and at lower standing stock than those sampled at downstream stations.

4.3 ADULTS

Adults in Western Arm Brook were almost entirely (99%) 1SW salmon (grilse). The biological characteristics of grilse were most variable between years. Fork length, whole weight and smolt age varied significantly between years (Table 45 and Fig. 15). Mean values of biological characteristics are presented in Table 46. The smallest grilse were observed in 1978, and the largest were seen in 1979. Condition did not vary significantly between years (Table 45). Whole weight was significantly different between smolt ages, viz. older grilse were larger than younger grilse. These aspects are examined in greater detail with the comparison between grilse in the local commercial fishery, but first I will discuss variation in sea survival.

Sea survival was very constant during the first six years of study. It was almost exactly 6% in each year. However, it fluctuated greatly over the last four years (Table 46). The very low sea survival in 1977 was followed by a very high sea survival in 1978, and by another very low survival in 1980.

Generally, sea survival was not correlated with any of the factors that I examined. There was one significant correlation with intrinsic factors: sea survival was positively correlated to the number of grilse (Table 46). This correlation was somewhat expected due to auto-correlation. There was also a negative correlation suggested between sea survival and size of returning grilse: survival was best for years when grilse were small, eg. 1978. Sea survival was not significantly correlated to any of the extrinsic factors that were examined (Table 47), but there was a positive correlation suggested between sea survival and ocean temperature.

Sea survivals between each smolt age were not significantly different (Table 48). The mean sea survival of 3+ smolt appeared to be greater than the other smolt ages, but there was considerable annual variation which may have masked the significance of any differences.

An important component of sea survival is selection in the local commercial fishery. Grilse from both the fishery and the river were compared for five years (1977-81). The main results of the four-way analysis of variance were as follows: variation in fork length, whole weight, and condition was significantly different between both locations and years; variation in fork length and whole weight was also significantly different between sexes; annual variation in fork length was complicated by a significant interaction between location; and, annual variation in condition was complicated by a significant interaction with smolt age (Table 49). There were no other significant interactions which allowed for a clearer interpretation of the main effects.

The most important source of explained variation was the difference between locations; that is, grilse sampled from St. Barbe Bay were consistently larger than those sampled in Western Arm Brook (Tables 49 and 50). This was true in all years and for the three dominant smolt ages (Fig. 16). Differences between the two locations explained well over half the variation in fork length and whole weight and over 30% of the variation in condition (Table 51).

Differences between years were the second most important source of explained variation. All three biological characteristics varied significantly between years (Table 49). Annual variation in condition was the most apparent; it was not as pronounced for fork length and whole weight (Table 51). Mean values for each year are presented in Table 52. In 1977, grilse had the lowest weight and condition; in 1979, grilse had the smallest fork length and the greatest condition; and, in 1980-81, grilse were very similar in all three biological characteristics.

There were also significant differences between sexes. Sexual dimorphism, in terms of fork length and whole weight, contributed from 16% to 10%, respeotively, of the explained variation (Table 51). Males were significantly longer and heavier than females in both St. Barbe Bay and in Western Arm Brook (Table 53, and Fig. 17). However, condition was not different between sexes, thus, males and females of the same fork length were also equal in weight.

The variation in biological characteristics between smolt ages was slightly more complex. Fork length and condition were different between smolt ages. Fork length of female grilse sampled in St. Barbe Bay was significantly greater at older smolt ages (Table 54). This was not the case for female grilse sampled in Western Arm Brook. Smolt ages accounted for 8% of the explained variation in condition (Table 51). Generally, condition increased with smolt age (Fig. 16) but this was not significant. However, there was a significant interaction between years and smolt age (Table 49) which means the annual variations in condition can be properly explained only if they are calculated separately for each smolt age.

There was only one other significant interaction. It was for fork length between year and location (Table 49). Again this means that annual variation in fork length can be properly explained only if it is calculated separately for location, that is, variation between years was also due to variation between locations.

The important results of the comparison of mean smolt ages were as follows: grilse sampled in Western Arm Brook usually had lower mean smolt ages than smolts which migrated to sea in the previous year and grilse sampled in St. Barbe Bay had greater mean smolt ages than grilse in Western Arm Brook (Fig. 18). Both of these results indicated that the commercial fishery tended to select grilse with older smolt ages but the results were not entirely conclusive and I will examine each comparison in greater detail.

There were nine years of comparisons between mean smolt age of Western Arm Brook grilse and smolts in the preceding year (Table 55). Grilse had younger smolt ages in six of the nine years and smolt ages were significantly younger ($P < 0.01$) in three of the years (Table 55). However, in two years, 1974 and 1979, mean smolt ages of grilse were significantly greater than the mean smolt age of smolts in the preceding year. Thus, the selection against older smolts returning as grilse was not consistent in all years and in some years there was a lower sea survival of younger smolts.

There were five years of comparisons between mean smolt age of grilse sampled in both Western Arm Brook and St. Barbe Bay. In all years, grilse in St. Barbe Bay had greater smolt ages; in three years smolt ages were significantly ($P < 0.01$) greater (Table 55). This was also found in comparisons between grilse from St. Barbe Bay and smolts in the preceding year. Thus, it could be concluded that the commercial fishery selected grilse of older smolt ages.

There were four important results from the comparison of sex ratios: first, the overall sex ratio of grilse in St. Barbe Bay was not significantly different from grilse in Western Arm Brook; in both cases, the sex ratio was about 30% males (Table 56). Second, the sex ratio of smolts contained a greater proportion of females (76.4%) than grilse in either St. Barbe Bay or Western Arm Brook. Third, sex ratio varied significantly between years for grilse but not for smolts (Table 56). Annual variation in sex ratio corresponded fairly closely between grilse sampled in the two locations (Fig. 18). For example, in 1980 there was a significantly ($P < 0.05$) lower proportion of male grilse in both St. Barbe Bay and Western Arm Brook, and in 1979, there was a greater proportion of males in both locations (Table 56). Fourth, sex ratio did not vary significantly between smolt ages for either smolts or grilse at both locations (Table 57).

Grilse were counted moving upstream in Western Arm Brook throughout late June, July, and August. The commercial fishery of St. Barbe Bay consisted almost entirely of fish that were migrating during June and July (Fig. 19). The frequency of daily abundance during July was similar for grilse in both the river and the bay. However, a number of grilse were caught in St. Barbe Bay before any were seen in Western Arm Brook.

There were few significant changes in biological characteristics of grilse throughout the 1979 season (Table 58). The only significant change between weekly intervals was found for whole weight in Western Arm Brook. These results suggested that slightly different timings in the migrations of grilse in St. Barbe Bay and Western Arm Brook should not account for any significant differences in biological characteristics between the two locations.

The final comparisons were made between virgin grilse and repeat spawners. There were three results of interest: first, the proportion of repeat spawners was usually greater in the commercial fishery of St. Barbe Bay than in Western Arm Brook. This was true in all years except 1980 (Table 59). Overall, about 9% of the grilse in St. Barbe Bay were repeat spawners compared to 1% of the grilse in Western Arm Brook. Second, the sex ratio of repeat spawners was 42.6% males which was significantly greater ($P < 0.05$) than the sex ratio of virgin grilse (Table 60). Third, mean smolt age was not significantly different between virgin and repeat spawner grilse (Table 61), in fact, it was almost identical.

There was an indication that selection in the local fishery influenced sea survival. The difference in size and smolt age between grilse taken in the fishery and those sampled in the river was correlated to sea survival (Table 62). Two multiple correlations were calculated: one used the difference in fork length and smolt age as independent variables to predict sea survival; and, the other used the difference in whole weight and smolt age as independent variables. Both correlation coefficients were greater than 0.80, but neither was significant. The lack of significance was due to the small number of years sampled, only five. Nevertheless, it was evident that when sea survival was highest, there was less selection against smolt age and size by the fishery (Table 62).

4.4 STOCK AND RECRUITMENT

Year-class strengths of smolts on Western Arm Brook were correlated with estimated egg deposition (Table 63 and Fig. 20). The regression was significant ($P < 0.01$). The sizes of the 1978-80 year-classes were calculated along with 95% confidence limits (Table 63). The 1980 year-class promises to be 77,000 smolts, which is more than six times current smolt production.

The 1972 year-class was omitted from the regression because its egg to smolt mortality rate was so much greater than the other five year-classes. This greater mortality rate can be related to both low winter discharge and cold winter temperature (Fig. 21 and 22).

Smolt year-class strength on Little Codroy River was significantly correlated ($P < 0.01$) with the potential egg deposition of kelts (Table 64). This indicated that kelts were either a good index of spawners, or the same environmental conditions affected both hatching success and overwinter survival of kelts.

Egg to fry survival on Indian River was significantly related ($P < 0.01$) to winter temperature and discharge (Table 65). Detailed examination of the data revealed there was low survival during cold winters with low water discharge, especially when there was high water discharge during spawnings. Thus, fish which spawned under conditions of above-average discharge had redds which were possibly more vulnerable to exposure and freezing.

4.5 PRODUCTION

The two methods for calculating production provided the following results: average freshwater production in Western Arm Brook was 1,960 kg y^{-1}; production in riffle and outflow habitats was 643 kg y^{-1} or 2.23 g m^{-2} y^{-1}; production in lake and steady habitats was 1317 kg y^{-1}, which was 67% of total production; however, production in these latter habitats was only 0.07 g m^{-2} y^{-1} or 5% of the production per m^2 in riffle and outflow habitats.

Average year-class production was 980 kg y^{-1} for female smolts (Table 66). Total freshwater production for both sexes combined was 1960 kg y^{-1} (980 x 2). Except for the low value of the 1973 year-class, variation in year-class production was not great; the coefficient of variation was 25% (Table 66). Standing stock or available production of a year-class (A) was equal to about 40% of P, and it varied from 30% in the 1972 year-class to 46% in the 1977 year-class. The variation in A/P was primarily the result of differences in mortality rates, as growth rates were more constant.

Production in riffle and outflow habitats was not significantly different (Table 67). The combined estimate of 1.63 g m^{-2} y^{-1} was calculated without station 1. It was adjusted to 2.23 g m^{-2} y^{-1} for the 73% efficiency of electrofishing. The production at station 1 was more than twice the others; its adjusted value was 5.47 g m^{-2} y^{-1}. Standing stock was the main determinant of production, and the high values at station 1 could represent maximum production for the system. On average, production was about 60% of standing stock. On the other hand, production and mean biomass were almost equal

(Table 67), and the average ratio (P/B) was slightly less than unity. Almost 50% of production occurred between the 2+ and 3+ age groups. Production was proportionately less in the younger age groups. Again, this indicated the importance of standing stock and mean biomass in the calculation of production. Instantaneous growth rates were fairly similar between age groups.

Although production of salmon was greater in riffles and outflows these habitats accounted for only 33% of total stream production. Riffle and outflow habitats represented 288,000 m^2 or 1.4% of habitat accessible to salmon. Salmon production in these habitats was 643 kg y^{-1}, with 95% confidence limits of ± 137 kg. The area of lake and steady habitats was 20.17 x 10^6 m^2. Production in these latter habitats was 1317 kg y^{-1} or 0.07 g m^{-2} y^{-1}, which was 5% of production per m^2 in riffle and outflow habitats. Thus, by virtue of their large surface area, steady and lake habitats produced approximately 67% of the smolts in Western Arm Brook.

5. DISCUSSION

The discussion has two parts: first I examine results from each of the five sections; and the second part interrelates the above into a harvest model for Western Arm Brook. Smolt production in Western Arm Brook was influenced by a combination of year-class strength and biological characteristics including size, smolt age and sex. Fork length and weight of smolts had the lowest annual variation of all biological characteristics and any differences between years were largely due to an interaction with smolt age (Table 14). A similar situation was found with condition of smolts, but it did not vary significantly between smolt ages (Table 12). By constrast, there was considerable annual variation in smolt age (Table 11) and it could vary from 2+ to 7+. Although there were significant size differences between smolt ages (Table 13), the differences in growth rates were much greater. For example, 3+ smolts had annual growth rates almost double those of 5+ smolts (Table 24) which indicated that faster growing parr become smolts at younger ages. Variation in sex ratio was also important. During this study, 67% of males did not migrate to sea as smolts (Table 21). If these male smolts did go to sea, then salmon production would be increased by 50%. Thus variation in both smolt age and sex ratio could have a very important influence on the production of smolts.

Western Arm Brook was compared to seven other Atlantic salmon rivers in the world which also had continuous time series of smolt counts and biological characteristics. A similar degree of variation in abundance and biological characteristics of smolts was found on all rivers (Table 68). Means and coefficients of variation in smolt abundance were remarkably similar for Western Arm Brook, Little Codroy River and Burrishoole River which indicated that rivers of similar size were perhaps susceptible to similar sources of variation. The other five rivers were either larger or smaller than Western Arm Brook, but four had greater variation in annual smolt production. It appeared that the smallest rivers had the greatest variation. The lower variation on Sand Hill River was possibly due to incomplete counts of smolts (Pratt et al. 1974). Biological characteristics of smolts also had similar degrees of variation (Table 69). Sex ratio was the most variable characteristic on three of the four rivers but smolts were predominantly female on all rivers. Smolt age was the second most variable characteristic on four out of five rivers; on Ricklean River, it was the most variable characteristic. Fork length and condition were the least variable characteristics on all rivers. The similarity between these few studies suggested that explanations for the variation on Western Arm Brook might also be appropriate for other salmon rivers.

It has already been stated that smolt size is a relatively fixed characteristic. This suggests that smolt size is intrinsic to a particular river system and it is not related to growth rate. It also indicates that a single sample of smolts should generally reflect average smolt size within a given river, regardless of the year that the sample was taken. This latter point is useful for comparisons of smolt size between rivers which have only single samples of smolts.

It is conceivable that mean size of smolts has evolved in response to conditions in the marine environment during the time of smolt migration. A comparison with other rivers suggests that smolt size increases with latitude (Table 70), with more southerly rivers having smaller smolts. Northern rivers have a later spring, cooler sea temperatures and they are nearer to the oceanic feeding grounds. It is possible that smolts from more southern rivers go to sea at a smaller size, but they arrive at the oceanic feeding grounds at the same time and size as smolts from northern rivers.

Many other authors also have observed smolt age to increase with latitude (Dahl 1916, 1937; Sedgewick 1953; Shearer 1966; Symons 1979; Power 1982). These relationships between smolt age and latitude were based on single samples of smolts from a multitude of rivers. However, in this study, smolt age was found to be highly variable between years which indicates that mean smolt ages based on single samples must be viewed with caution. In spite of this short-coming, the above authors have speculated that smolt ages are greater in higher latitudes due to slower growth in cold and northern climates (Elson 1957b).

In this study, smolt age was very significantly correlated to temperature in the first year of life (Fig. 11). The relationship between smolt age and number of days greater than or equal to 7°C was also very significant (Table 29). This indicates that duration of growing season above 7°C, when salmon are active (Allen 1969), was an important factor in determining smolt age. In cold years, when growing season was shortest, smolt age was reduced.

Cold temperature could influence smolt age by increasing the growth rate in the first year of life. This is conceivable if cooler temperatures reduce energy requirements for routine metabolism during the short growing season. There was a slight, but insignificant trend ($r = 0.26$) for back-calculated ℓ_1 values to increase in cold years (Tables 26 and 29) which lends support to the influence of temperature on growth rate. Other authors have made similar observations. Lind (1980) and Prouzet et al. (1978) believed that cold temperatures reduced smolt age. Bisson and Davis (1976) found the growth rate of Oncorhynchus tshawytscha was reduced 25-50% in a heated stream; this was primarily due to increased growth efficiency at lower temperatures when exploiting a sparse food resource. Colbo and Porter (1981) also found the growth rate of Simuliidae was greatest when they were raised at cooler temperatures. Consequently, northern rivers may be conducive to better growth of salmon within the limits of food availability. Certainly, smolt age is an important biological characteristics that needs more research.

There also appeared to be a relationship between ovarian weight and smolt age. Ovarian weight was significantly greater in larger smolts (Table 17). The increase in ovarian weight was mostly due to a corresponding increase in somatic weight. It is possible that smolts with larger ovaries are in a more advanced state of maturity and they mature as grilse after only one year at sea. This question would be answered with a microscopic examination of ovaries which was not done in this study. However, many authors have found that older Atlantic salmon smolts return as 1SW adults whereas younger smolts return as 2SW and 3SW adults (Calderwood 1925; Hutton 1937; Saunders 1967; Ritter 1975; Bailey et al. 1980).

Similar relationships have been found for other salmonids, O. kisutch (Hager and Noble 1976; Bilton 1980) and O. nerka (Khaltruin 1972). Thus, ovarian weight of smolts could influence sea age.

This hypothesis was tested in samples of smolts taken in 1973 from 34 rivers around insular Newfoundland (Chadwick and Waldron, unpub. data). Mean ovarian weight was calculated for smolts from each river (Table 71 and Fig. 23). The index of large salmon abundance was the maximum percentage of large salmon angled in the river from 1953-77. The maximum, rather than mean percentage, was used due to intense selection of large salmon in the Newfoundland commercial fishery and the reduced catchability of large salmon in the recreational fishery (unpublished data). It appeared that rivers which had smolt with small ovaries also produced a greater percentage of large salmon. The relationship between mean ovarian weight and index of large salmon abundance was significant ($P < 0.02$; Fig. 24). Thus, greater ovarian weight in older and larger smolts could reduce sea age of adult salmon.

Biological characteristics of smolts sampled in the 34 rivers in 1973 (Table 71; Fig. 23) were compared to those sampled from Western Arm Brook. Sample sizes were small and probably biased but they provided a comparison for Western Arm Brook among Newfoundland rivers. The distribution of mean fork lengths indicated that most smolts were shorter than the mean of 17.3 cm found in Western Arm Brook (Fig. 25a). The distribution appeared to be bimodal with peaks around 14 cm and 17 cm, perhaps these two peaks were optimal sizes of smolts. Mean condition factors were normally distributed around a mode of 1.10 (Fig. 25b) and all rivers but one had populations with conditions that were greater than the 0.90 found for Western Arm Brook. The mean age of 3.8 y on Western Arm Brook was greater than the mean ages found on most of the other rivers (Fig. 25c). There was no statistical relationship between mean age and mean fork length, neither for rivers known to produce mainly grilse, nor those known as large salmon rivers (Fig. 26). There was an apparent inverse correlation between age and size for the five rivers of St. George's Bay (Fig. 26) which suggested that younger smolts were in fact larger than older smolts. It was also apparent in Fig. 26 that large salmon rivers had smaller smolts, but no similar distinction could be made for smolt age. Mean sex ratio was the only biological characteristic for which Western Arm Brook fitted the average (Fig. 25d). It appeared that most salmon rivers in Newfoundland had smolt migrations which were predominantly female. The two rivers with predominantly male sex ratios were probably based on sample sizes which were too small, as one of these rivers (Highlands) has since been found to have smolt migrations which were also predominantly female (unpub. data).

There was little direct evidence for density-dependent growth in Western Arm Brook. In two examples, density-dependence was not found. Smolt age was not directly correlated to year-class strength (Table 28). Similarly, back-calculated growth increments were not correlated to the estimated juvenile biomass present in the same year (Tables 26 and 27). However, density-dependence should not be manifest except at population densities near carrying capacity. At carrying capacity, growth rate is partially determined by the density of other individuals. Conversely, populations below carrying capacity are probably more susceptible to changes in the environment, as they are able to respond to favourable climatic factors (Skud 1982). Thus, it seems possible that smolt age on Western Arm Brook was correlated to temperature, at least partly because the population, or stock, was below carrying capacity. The multiple correlation between year-class strength, temperature and smolt age (Table 29) suggested that a density-dependent influence on smolt age might exist at higher stock densities.

Little Codroy River was examined for comparison. I reanalyzed the compilations of Murray (1968a,b; and unpubl. data) to obtain size of year-classes as smolts, mean smolt age and sex ratio. I found evidence for density-dependent factors influencing both sex ratio and smolt age. There was a nearly significant relationship ($P = 0.06$) between year-class strength of smolts and percentage males in the year-class (Tables 72). The largest year-classes had the most balanced sex ratios, but as they decreased in size, sex ratios became more skewed, with females predominating.

It also appeared that the older and slower-growing smolts had a more balanced sex ratio (Table 73). The sex ratio of age 4+ smolts was equally balanced between males and females, but as smolt age declined, sex ratio shifted in favour of females, until at age 2+, smolts were 78% female (Table 72). Unfortunately the small sample sizes of smolts on Western Arm Brook did not permit a similar analysis to corroborate these findings.

The most obvious mechanism for the skewed sex ratio of smolts was increased mortality of males which became sexually mature before the smolt migration. On Western Arm Brook and Little Codroy

River, averages of 20% and 50% of male smolts (Tables 21 and 73), respectively, were in a post-spawning condition, and therefore had been sexually mature. Yet there was evidence in Western Arm Brook that many of the mature male parr did not survive to migrate to sea as smolts. Males older than age 2+ sampled in the river during 1979 were mostly mature (Table 21) which suggested that males which had matured as parr had greater mortality rates. The increased mortality of mature male parr has been reviewed by Dalley (1978).

It is also noteworthy that male smolts which had spawned in Western Arm Brook were significantly larger than other smolts (Table 16). This suggested that faster growing males are more likely to become sexually mature as parr.

There is substantial evidence in the literature that early maturation of male salmon is due to increased growth rates. The evidence is chiefly from observations in hatcheries, where faster growing salmon parr became sexually mature (Evropeytseva 1960; Dalziel and Shillington 1961; Leyzerovich 1973; Glebe et al. 1978) but evidence is also available from field studies. Dalley (1978) compared the sizes of immature and mature males and found that at age 1+ the latter were always larger; Alm (1943) and Gibson (1978) also found that mature males had greater growth rates than immature males. Similar evidence was also found in other salmonids, namely, mature males were always larger than immature juveniles of the same age of *Oncorhynchus masou* (Utoh 1976), *O. gorbuscha* (MacKinnon and Donaldson 1976) and *Salmo gairdneri* (Schmidt and House 1979). There was recent evidence that maturation of male Atlantic salmon was due to density-dependent growth. Bailey et al. (1980) found that early maturity of males was significantly reduced when parr were raised at high tank densities. There seemed to be little doubt that the early maturation of male salmon parr was due to increased growth rate and this mechanism could be responsible for the shifting sex ratio of smolts.

There was further evidence for density-dependent growth in Little Codroy smolts. Smolt age of a year-class was significantly correlated to year-class strength of age 3+ smolts (Table 72). Age 3+ smolts were the largest age groups. The correlation between smolt age and the entire year-class with all age groups was not significant. This relationship suggested that growth of smolts was inhibited at higher stock densities. In contrast to Western Arm Brook, no environmental factors were found to influence smolt age in Little Codroy River.

One object of the section on salmon parr was to assess the influence of freshwater habitats on the biological characteristics of smolts. For example, faster growth in some habitats might result in younger smolt ages. It was found that parr from riffles were smaller and younger than parr from other habitats (Table 30); parr in outflows appeared to grow more during the summer season than parr from other habitats (Table 31); the fork length frequency distributions of riffle and outflow habitats were almost exactly out of phase by later summer (Fig. 12); and finally, the percentage of salmon was greater in riffles than in other habitats (Table 35). Presumably, if parr remained within particular habitats throughout their freshwater life history then habitat would likely influence biological characteristics of smolts.

The results of this study indicated that parr do not remain within particular habitats, instead there appeared to be a net downstream movement of parr. Evidence for downstream movement was as follows: only 4% of tagged fish were recaptured at the same stations one year later; tagged fish were never recaptured at upstream stations (Table 37); parr were found moving downstream at a stream trap (Table 38) and at the main counting fence (Table 8); and, standing stock of parr was greatest at downstream stations and declined significantly with distance from the river mouth (Table 44). There was evidence that parr redistributed themselves during the fall-to spring period. For example at the beginning of the season, the size of parr in riffles and outflows was not different (Table 31), but at the end of the season the size of parr in outflows was significantly greater (Fig. 12). This suggested that better growth occurred in outflows, but that parr redistributed themselves each year. There was also an example of redistribution of parr during the summer season. Station 3 was filled to almost its original density two months after depopulation (Table 39). It appeared that there was considerable movement of parr and it would not be valid to attribute biological characteristics of smolts to particular habitats.

The movement of parr is not well studied, but several authors feel that there is little movement after the first year of life. Saunders and Gee (1964) found this was the case in Ellerslie Brook, Prince Edward Island. Underwater observations also indicate that there is little movement of parr (R. J. Gibson, pers. comm.). However, the movement of parr could be related to density and it may increase when parr are numerous, while being negligible in less populated streams. In this study, there was a significant correlation between downstream movement of parr and size of smolt migrations (Fig. 7). In years when smolt migrations were large, a greater number of parr was counted moving through the fish trap. This suggests that stream movement could be influenced by density-dependent mechanisms.

There were other indications that density-dependent factors influenced the dynamics of parr. There was a significant inverse relationship between standing stock of parr and condition factor (Fig. 14). Condition was lowest at stations with highest standing stock. A second example was the correlation between standing stock of parr and trout. If standing stock of salmon was higher, then that of trout was generally lower (Fig. 13). Both examples depend largely on values found at station 1. Station 1 had the greatest standing stock and lowest condition of all stations. It also had the most constant standing stock between repeated sampling dates (Table 43). This latter point suggested that some upper threshold was being maintained and it could not be exceeded. The result was a density-dependent inhibition of growth rate and a reduction in condition factor.

The only feature of station 1 which made it different from the other riffle stations was that it was nearest to the river mouth; approximately 50 m below the lower end of this station was within the zone of tidal influence. Otherwise the station was free from any 'extra' nutrient inputs and its habitat appeared to be identical to station 3. I concluded that the greater biomass at station 1, and consequently the greater production, was due to the fact that it was the last stretch of freshwater habitat before the sea. It is possible that standing stock in the river fills from the mouth toward the source and all other riffle and outflow habitats could achieve a similar level of biomass (10.0 g m^{-2}) and production (5.5 g m^{-2} y^{-1}) as was found at station 1.

Average standing stock and production in riffle and outflow habitats combined were 3.5 g m^{-2} and 2.2 g m^{-2} y^{-1}, respectively (Tables 40 and 67). Other studies indicate that these estimates of standing stock and production are not unreasonable. Firstly, it was evident that production was linearly correlated to mean biomass (Table 67). In other words, greater production was achieved in habitats with greater biomass and not because the growth rate was greater. This was most apparent at station 1, which had the greatest production but also the lowest growth rate. Similar linear correlations between biomass and production have been found in populations of brook trout (Hunt 1966; Carline 1977). On average, the ratio between these two variables was around unity (0.91) and consequently, standing stock could be used for a quick and crude estimation of production. There are few values on the actual production of Atlantic salmon. Two examples are 6 g m^{-2} y^{-1} in Lake Hyttodammen, Sweden (Arnemo 1975) and 0.3-11.0 g m^{-2} y^{-1} in River Wye, U.K. (Gee et al. 1978). But there are numerous studies on standing stock of parr. Values ranged from 0.6 g m^{-2} in Pollett River, N.B., before control of fish eating birds (Elson 1962a) to a three year average of 8.0 g m^{-2} in Shelligan Burn, U.K. (Egglishaw 1967). The values on Western Arm Brook were within these limits.

Standing stock of salmon and trout adjusted for efficiency of electrofishing was 5.7 g m^{-2} in Western Arm Brook (Table 40). A comparison to salmonid biomass in other rivers and lakes indicated that values in Western Arm Brook were about average. In the literature, values from combined Atlantic salmon and brook trout ranged from 3.9 g m^{-2} in Indian River, Newfoundland (Sturge 1968) to 17.8 g m^{-2} in Matamek River, Que., (Gibson and Galbraith 1975). The average production of 42 studies on salmonids (unpublished data) is 6 g m^{-2} y^{-1} (Fig. 27). These studies cover six species of salmonids which range in distribution from New Zealand to Norway; they indicate that production of salmonids ranges up to 10 g m^{-2} y^{-1}; and the estimate of maximum production of 5.7 g m^{-2} y^{-1} at station 1 in Western Arm Brook would appear to be only average in comparison to these other studies.

Standing stock of the average smolt migration was 477 kg (Table 23). This represents about 24% of annual production and 22% of standing stock in Western Arm Brook. An estimate of the fork-length frequency distribution for the entire juvenile salmon stock, including smolts, is presented in Fig. 28. It can be seen that almost all parr greater than 150 mm become smolts.

The stock-recruitment relationships on Western Arm Brook (Table 63, Fig. 20) and Little Codroy River (Table 64) were the first developed for Atlantic salmon. They are important because they indicate that smolt production can be predicted from egg deposition and that it is possible to calculate optimal spawning requirements.

The poor survival rates of the 1972 year-class appeared to be caused by a combination of cold winter temperatures and low winter discharge (Fig. 21 and 22). Poor survival rates could be caused by egg mortality due to freezing of redds. This was suggested from the data on Indian River, where egg to fry survival was correlated to winter temperature and discharge (Table 65). A similar mechanism has been described by Power (1958) and Taylor (1973). For these reasons, it seemed reasonable to omit the 1972 year-class from the stock-recruitment relationship.

The ability to predict harvest several years in advance is also a significant breakthrough in Atlantic salmon management. For example, on Western Arm Brook, smolt counts were significantly correlated ($P < 0.05$) to grilse returning to the river in the following year (Table 74). They were also correlated to recreational harvests of grilse in River of Ponds, Castors River, St. Genevieve River (Fig. 4) and total commercial and recreational harvests in Statistical Area N (Table 74). These correlations were significant ($P < 0.05$) when values for 1975 and 1976 were excluded. Both of these years had unusually dry summers which probably accounted for increased catchability in the recreational fishery. The data also suggested that sea survival from smolts to returning adults was fairly constant among years. On Little Codroy River, only the first six years of data were used, but there were significant correlations ($P < 0.05$) between counts of smolts from Little Codroy River and adults (grilse plus large salmon) in Grand Codroy and Robinsons rivers (Fig. 4 and Table 75). The years 1960-63 were omitted as by this time the population on Little Codroy River was declining due to heavy tagging mortality of smolts (Murray 1968a). The correlations suggest that rivers with similar environmental conditions are synchronized in their annual production of smolts. It appears that this type of study may be a practical means of predicting available harvest for fisheries on a regional basis.

It is possible that optimal spawning requirements are much higher than previous estimates. The results of this study were not adequate to determine the point of inflection on the stock-recruitment curve, a longer time series would be required, but a brief comparison with current estimates of optimal spawning requirements might be instructive. Optimal spawning requirements for Atlantic salmon in Canadian rivers have been estimated from experiments on Pollett River, N.B. (Elson 1957a, 1975). Stock size was estimated from natural egg deposition and planted hatchery fry and recruits were measured as their smolt progeny. Elson (1975) concluded that an egg deposition of 2.4 egg m^{-2} of suitable rearing habitat gave optimal smolt production, and he also recommended levels for fry, small parr and large parr densities. These values are widely used throughout Atlantic Canada (Anon. 1978), but there are several reasons why they should be used with caution: salmon habitat is difficult to measure and may not be comparable between different rivers; Pollett River was manipulated and may not represent natural systems; and, an optimal egg deposition of 2.4 eggs m^{-2} may only be an arbitrary figure. I will elaborate on these points.

Salmon habitat is quite variable. In Newfoundland rivers, where there are no cyprinids or percids, Atlantic salmon are abundant in lentic as well as in riffle-pool habitats. For example, in this study about 67% of the smolt production occurred in 1960 ha of lakes and 44 ha of slow-flowing steadies and the conversion of egg deposition and smolt production to the 28.8 ha of standard rearing habitat leads to inflated values which are somewhat meaningless.

Pollett River may not be comparable to other rivers as fish-eating birds namely, mergansers and kingfishers, were actively removed during the experiment. The egg to smolt survival rates and annual variation in smolt production were quite different from Little Codroy River and Western Arm Brook. This was most clearly seen when the egg to smolt survival rates on all three rivers were adjusted to the same smolt age of 2.1 y. The survival rate on Pollett River was considerably lower (Table 76). This was somewhat surprising as the removal of major predators should have increased the survival. Possibly, other factors were involved or predation by birds is not the primary cause of mortality in Atlantic salmon. On Pollett River, the coefficient of variation in annual smolt production was twice that found on Little Codroy River and Western Arm Brook (Table 76); the values on the latter two rivers were almost equal. This greater variation on Pollett River could have been a consequence of the predator control and thus the results may not apply to other rivers.

There seems to be little evidence to support an optimal egg deposition of 2.4 eggs m^{-2}. The two relationships between eggs and smolts that are presented here (Tables 63, 64; Fig. 20) do not indicate an asymptote at this value. On the Pollett River, a linear fit ($r = 0.83$) had smaller residuals than Elson's (1975) curvillinear relationship ($r = 0.81$) suggesting that the asymptote had not been reached. The critical need for more research is therefore emphasized, and it is quite possible that optimal egg deposition could be considerably higher on many salmon rivers.

The final component in the dynamics of the Western Arm Brook Atlantic salmon was the influence of the commercial fishery. There was evidence that grilse harvested in the commercial fishery of St. Barbe Bay had different biological characteristics than grilse sampled in Western Arm Brook. Grilse from St. Barbe Bay were longer and heavier; they had higher condition factors; they were greater in mean smolt age; and they included a greater proportion of repeat spawners. Although the commercial fishery was concentrated on early migrants, there was evidence to suggest that biological characteristics of grilse did not change throughout the season, and therefore, samples from the commercial fishery were representative of the entire migration.

One question, however, is whether the commercial samples were biased by non-Western Arm Brook salmon. The tagging study in 1977 indicated that about 50% of the fish caught in St. Barbe Bay were destined for other rivers and it is conceivable that these fish were larger and older than grilse from Western Arm Brook. However, there was some evidence that the fishery was selecting older and larger grilse that were destined for Western Arm Brook. For example, the mean smolt age of grilse in the commercial fishery of St. Barbe Bay was always greater than for grilse in Western Arm Brook, yet the mean smolt age of the latter was usually less than the mean smolt age of smolts in the preceding year (Table 55). This suggests that the fishery was selecting grilse of greater smolt age.

There was some evidence that grilse with older smolt ages were slightly larger than younger grilse which accounts for their selection in the commercial fishery (Fig. 16). There were significant size differences between smolt ages of female grilse sampled in the commercial fishery, but not for grilse sampled in the river (Table 54). This suggested that the fishery was selecting the older and larger fish. The interaction between years and smolt ages was significant (Tables 49 and 51) and it indicated that variation between years was partly due to smolt age, with grilse of older smolt ages having greater condition.

The important influence of the fishery on Westerm Arm Brook stock was also reflected in variation of sea survival. Sea survival was not correlated to any intrinsic factors of the smolt migration (Table 46) nor to any of the environmental influences that were examined (Table 47). However, sea survival was correlated to the degree of selection for size and smolt age by the fishery (Table 62). In years when sea survival was high, there was less selection of size and smolt age by the fishery. In years when sea survival was low, selection appeared to be greatest. Thus natural mortality at sea is likely fairly constant.

The relatively constant sea survival of Atlantic salmon contrasts sharply with Pacific salmon and might be one reason for the difference in life history tactics between the two genera. Populations which have greatest fluctuations in the survival of immature fish tend to have iteroparity and spread reproduction over several years (Murphy 1968). Those populations which have greatest fluctuations in the survival of the sexually mature phase tend to have semelparity and reproduce at a younger age (Schaffer 1974). For salmons in general, the smolt stage provides a convenient division between the immature or freshwater phase, and the sexually mature or marine phase of life history. A comparison of the annual variation in freshwater survival (V_0) and marine survival (V_1) supports the above theory that Atlantic salmon should be iteroparous and pacific salmons should be semelparous. For example, Atlantic salmon of Western Arm Brook had almost equal annual variation in freshwater and marine survival rates and the ratio V_0/V_1 was slightly more than unity (Table 77). This also means that smolts would be a less likely predictor of adult escapment for the pacific salmons. Reasons for the lower and more variable marine survival rates on the Pacific coast could be related to the more complex oceanography of this region when compared to the Atlantic coast where the marine environment is more homogenous.

The commercial fishery in St. Barbe Bay was also selective towards 2SW salmon and repeat spawners. There were few 2SW salmon caught in the fishery, about 5% of total catch, but during the last five years of fence operation only two 2SW salmon were counted in the river. The selection of repeat spawners by the fishery was also significant. Nearly 9% of the total commercial catch consisted of repeat spawners, but only 1% of the river escapement in Western Arm Brook was this type of fish (Table 59). It appeared that larger fish were more vulnerable to gillnets. The overall effect of the fishery was to reduce both size of fish and the spread in spawning potential of a year-class. An example of the latter is presented in Table 78: a year-class of salmon captured in the commercial fishery had spawning potential spread over five years, which left only a two year spread for fish entering the river. The high over winter survival of kelt also suggested that without any commercial exploitation there would be considerable iteroparity in the spawning population. Nearly 60% of spawning adults survived to migrate down river the following spring (unpub. data) and presumably if these fish were not caught in gillnets, many would survive to spawn again. In spite of comments by some authors that Atlantic salmon are semelparous (Mann and Mills 1980), there was great potential for iteroparity in Western Arm Brook. Iteroparity has been found in other populations of Atlantic salmon. Barbour <u>et al</u>. (1979) found that 56% of an adult population of ouananiche were repeat spawners; Jarrams (1979) described a hatchery stock where 21% of the adults had spawned twice, 14% three times and 1% four times; and Ducharme (1969) mentioned escaping adults in Big Salmon River which were on their fifth and sixth spawning migrations. It appears that the commercial fishery has greatly reduced the iteroparity of Western Arm Brook stock.

Iteroparity and large body size would tend to stabilize a population of Atlantic salmon. The ability of a year-class to spread egg deposition over several years provides insurance against poor spawning conditions or poor egg survival in any particular year. Mechanisms such as interoparity are found in populations which are adapted to severe and unpredictable environments (Stearns 1976). Greater size of spawners may also tend to stabilize a salmon population. Large spawners can distribute their eggs throughout a greater variety of habitat and a larger part of the watershed than small spawners. This is because large salmon are capable of navigating higher stream obstructions (Stuart 1962), swimming against faster currents and spawning on larger substrates (Hartman 1969); they also produce larger eggs (Pope et al. 1961) which are known to contain more calories (Glebe et al. 1979).

The consequence of reduced size and age are yet more significant if these characteristics are very heritable. This is because a population would be less likely to regain its original phenotype if exploitation were stopped. However, there is also evidence that genetic factors explain only part of the great variation in phenotype of Atlantic salmon. Belding and Kitson (1934) pointed out that spring runs of many rivers had persisted inspite of very high exploitation. Similarly, large salmon and grilse are not as genetically distinct as some authors have suggested. For example, artificial propagation of large salmon parents does produce a greater proportion of large salmon offspring than grilse parents; however most of the offspring are grilse, regardless of parentage (Ritter 1972; Piggins 1974). There is also straying of salmon which would tend to reduce the influence of genetic fixation. On Little Codroy River, about 7% of tagged smolts were recaptured in other rivers (Murray 1968a), and on Western Arm Brook one tagged kelt was recaptured in Forteau River (unpub. data). Thus straying could be important in mixing gene pools but probably not enough to salvage a stock, as White (1936) noted that salmon would not stray into a river unless they detected the presence of juveniles. Finally, Wilder (1947) found no differences between morphological and meristic characteristics of landlocked and sea run Atlantic salmon. He concluded that any differences between these two types of fish were due to environmental factors. Thus, it may be fair to conclude that selective harvest in the fisheries may not result in an observable loss of phenotype.

In fact, there was evidence that the phenotype of Western Arm Brook stock was being maintained in spite of strong selection of spawners. Western Arm Brook has probably been exploited for hundreds of years. Communities at the river mouth have been settled since the 1600's and salmon were likely an important source of food. The current fishing berths are about ninety years old and mesh size and gear type probably have changed little in the past forty years. I have indicated that selection in these fisheries has allowed only small and young salmon to spawn. Yet, today smolt age still varies from age 3+ to 7+ and sea age varies from 1SW to 2SW virgin fish to a variety of repeat spawners. Thus, Western Arm Brook is maintaining some variation in phenotype inspite of strong selection in the commercial fishery.

One purpose of this study was to uncover factors which determine variation in smolt production and ultimately to develop a harvest model for the Western Arm Brook stock. This goal is not unlike the questions asked of other fish stocks; therefore, it might be valuable to list some of the more important assumptions of current fisheries models. In most fisheries models, recruitment is assumed to be density-independent (Beverton and Holt 1957). This is because fish eggs are small and their survival is believed to be influenced mostly by weather. The Ricker model assumes that recruitment increases exponentially with egg deposition until some fixed point where increased egg deposition inhibits survival (Ricker 1954). In the Schaefer model, yield is assumed to increase as biomass of the stock is reduced; this is due to a corresponding increase in growth rate (Schaefer 1957). Atlantic salmon are managed with the Elson model. Spawning requirements are assumed to be 2.4 eggs m^{-2} of rearing habitat and all remaining fish are available for harvest (Elson 1957b, 1962b, 1975). It is believed that egg densities greater than this value suppress the growth, survival and production of juveniles. Finally, all models assume stocks to be renewable and resilient, that is they can be exploited in perpetuity and parameters like growth rate will respond immediately to any change in biomass. Generally, it is thought that fishing is good for a population, much like pruning stimulates shrubs into a healthy state of continual growth. Thus the current harvest models tend not to take a conservative view of fishing.

The ideal harvest model should probably be based on observations which are specific to each stock. On Western Arm Brook, variation in smolt production was influenced by a combination of year-class strength, smolt age, and sex ratio. Year-class strength of smolts was correlated to egg deposition. Smolt age was correlated to temperature and there was some evidence that it was a function of density-dependent growth. This was because parr at lower densities appeared to grow faster. There was also some indirect evidence that density-dependent growth of juveniles could influence sex ratio. Thus a harvest model for Western Arm Brook should accommodate egg density, weather and density-dependent growth.

It was evident in Western Arm Brook that smolt age was determined by growth rate. This was because mean smolt size did not show annual changes and it was a relatively fixed characteristic. It seemed that faster growing fish became smolt at a younger age. The range of age at which smolt size was reached appeared to be bounded by extrinsic factors. At the lower end it was probably related to water temperature or productivity of the system. At the upper end it was probably limited by natural mortality. Presumably, mortality was related to the number of years spent in freshwater. In between these two limits it seemed reasonable that the age at which smolt size was attained was determined by density-dependent growth, and it is conceivable that smolt age could be manipulated by controlling the amount of egg deposition.

A simple model was developed to examine the stability of smolt production for different smolt ages. It was assumed that smolt production was affected indirectly by environmental factors through egg deposition success and fluctuations in mortality rates. The basic relationship for a single smolt age system was:

$$S = E \exp(-(Mt)) \tag{1}$$

where S = smolt production in numbers

E = number of eggs deposited

M = mortality rate

t = smolt age

Equation 1 was modified in two ways to make it more realistic: a) a distribution of smolt ages for each dominant age was used instead of a single smolt age; and, b) mortality from the egg stage to age three was considered separately from mortality between older ages. For example, with a dominant smolt age of four, assuming that 20% of the smolts were age three, 50% age four and 30% age five, equation 1 can be written as:

$$S_i = 0.2E_i\exp(-(M'_i)) + 0.5E_{i-1}\exp(-(M'_{i-1}+M_i)) + 0.3\,E_{i-2}\exp(-(M'_{i-2}+M_{i-1}+M_i))$$

where M' = mortality rate between egg stage and age 3
M = mortality rate between older ages
i = index for period i

A simulation model was constructed in which E, M' and M were allowed to be independently normally distributed random variables. To avoid negatives coefficients of variation were kept at less than 0.4 and absolute values were utilized. The average coefficient of variation for 40 years of smolt production was used as an indicator of stability.

The results indicated that stability of smolt production was related to a broad age distribution of smolts (Table 79). Stability of smolt production appeared to increase with dominant smolt age, but this was due to a broader spread in ages. For example, there was little difference between the stabilities of dominant smolt ages five and six, as both had identical spread in smolt ages (Table 79). Stability was only indirectly related to smolt age in that older smolt ages would have broader age distributions. It was apparent that narrow age distributions had considerably greater fluctuations in smolt production.

The ability of a year-class to spread its reproductive effect over several years is functionally similar to iteroparity. Organisms, such as Atlantic salmon, that are found in harsh or unpredictable environments, can insure themselves against calamity by spreading their reproductive effort over several years (Stearns 1976). In Western Arm Brook, this was achieved primarily by variation in smolt age, as spawners were almost always virgins which had spent only one winter at sea (grilse or 1SW salmon). It follows that a reduction in smolt age, could make a stock less resilient and preservation of smolt age should be considered in the management of Atlantic salmon.

According to the above model, to maintain a spread in smolt age would require high egg deposition. This is because more eggs would be needed to keep the density of parr at a level high enough to inhibit growth and, ultimately, to raise the smolt age. The cost in terms of eggs, was calculated for Western Arm Brook. The number of eggs required to produce the current smolt age distribution was calculated from the mean of observed values and it was compared to the number of eggs required for the hypothetical smolt age structure of an unexploited population. The hypothetical smolt age structure was assumed to be normally distributed around a dominant smolt age of five. The spread in smolt age was assumed to be bounded by ages three to seven. The number of eggs required to produce one smolt of age 7+ was 22 times the number of eggs required to produce one smolt of age 3+ (Table 80). The number of eggs required to produce 100 smolt of the hypothetical unexploited age structure was more than three times that required to produce the current age structure (Fig. 29). It was apparent that to maintain a spread in smolt age costs more eggs.

Maximum smolt production was calculated for Western Arm Brook. Several assumptions were made: the hypothetical smolt age structure was normally distributed around smolt age five; maximum freshwater production in riffles and outflows was equal to production observed at station 1; an increased production in riffle and outflow habitats would also occur to the same degree in other habitats; the sex ratio of smolts was 50% males; the standing stock of smolts was 32% of total freshwater production; and the mean weight of a smolt was 59.7 g (Table 80). The current estimate of average salmon production in riffle and outflow habitats was 2.23 g m^{-2} y^{-1}. The maximum observed value for production at station 1 (Table 67) was 2.45 times values observed in riffle and outflow habitats. Therefore maximum stream production of 1960 kg y^{-1} would be increased by 2.45 times to 4802 kg y^{-1}. Thus an approximate value for the maximum production of smolts was 1537 kg y^{-1} (4802 kg x 0.32) or 25,700 smolt y^{-1} at an average weight of 59.7 g (Table 80).

The required number of spawners to produce maximum smolt production was estimated as follows: the number of eggs (Fig. 29) was calculated assuming egg requirements outlined in Table 80; the average fecundity of Atlantic salmon in Newfoundland was estimated to be 1540 eggs kg^{-1} from several previous studies on Noel Paul's Brook and Indian River (Sturge 1968; Anon. 1978; and, unpub. data); the average weight of a 1SW salmon before exploitation in the commercial fishery was estimated to be 1.8 kg; and the sex ratio was assumed to be 50% female. Egg requirements were estimated to be 3.95×10^6 eggs or 2850 1SW adults. To achieve this number of fish, at least 11.1% of the smolt migration ((2852 ÷ 25739) x 100) must return to the river to spawn.

Currently, natural sea survival of 1SW salmon in Newfoundland waters is assumed to be 15% of smolt production (Anon. 1978). This value is based on the difference between estimates of smolt production and harvests in both recreational and commercial fisheries. There are other estimates of sea survival which are lower than 15%. These are based on studies of tagged smolts and they range from 3.9% on Miramichi River (Saunders and Allen 1967), 9.4% on Little Codroy River (Murray 1968a), to 11.5% on Sand Hill River (Pratt et al. 1974). Thus it appears that for Western Arm Brook stock to maintain itself in the hypothetical unexploited state, it would require almost all of its smolt production (11%) for spawning requirements. Even with the highest estimate of natural sea survival, only a small surplus of fish (<4% of smolt production) would be available for harvest when the stock is in its hypothetical unexploited state.

It is possible that there could be a wide range of egg depositions which give similar yields to the fisheries. This is because increased egg depositions may shift the smolt age distribution with a corresponding reduction in the output of smolts. For example, on Western Arm Brook I estimated current egg deposition and I speculated on egg requirements for a hypothetical, unexploited population. Currently, about 10200 smolts are produced annually (Table 8), of these 10% will be harvested (Anon. 1978) and 5% will return to the river. Thus, a current estimate of harvest is about 1000 fish. The unexploited population would require an estimated 2850 spawners which would be 11% of maximum production of 25700 smolts, leaving 1287 virgin fish for exploitation. Repeat spawners could be harvested which would equal 260 fish (2850 virgin x 60% post spawning survival x 15% sea survival). Thus in the unexploited state, about 1550 fish would be available for harvest. It appears that yield to the fisheries could be increased by only 50% with a cost of a 300% increase in egg deposition.

The maximum smolt age distribution would occur when freshwater production of parr is at carrying capacity. The minimum smolt age distribution would occur when growth rate of juveniles is completely density-independent, with the density of juveniles having no influence on smolt age. Elson (1957a) found that density-dependent effects were noticeable at a density of 0.17 alevins m^{-2}, 0.05 small parr m^{-2} and 0.02 large parr m^{-2} which would be an approximate production of 1.0 g m^{-2} y^{-1}. In Western Arm Brook, this production would result in a dominant smolt age distribution of 3.5 y (Fig. 30). Other rivers with a riffle production below 1.0 g m^{-2} y^{-1} might possibly be at their minimum smolt age distribution. The current smolt age distribution in Western Arm Brook could be approaching this minimum value because of its significant correlation to temperature.

The relationship for spawners, recruits and available harvests between this range in smolt age is more easily seen on a graph. In Fig. 31a, as the number of spawners increase, recruits also increase in a nearly linear fashion. At 2850 spawners, carrying capacity is reached and there is no further increase in recruits. This graph emphasizes the gradual relationship between the two variables.

The mean harvest that would be available to the fisheries is indicated in Fig. 31b. Mean harvest would increase slightly between the minimum and the most stable smolt age distribution and graphically this appears as a flat dome shape. An important difference between the two extreme smolt age distributions would be variation around mean harvest (Fig. 31b). At the minimum smolt age there would be considerable variation in available harvest as the population would be governed entirely by density-independent factors. However, at the maximum smolt age there would be virtually no variation about mean harvest because of complete density-dependence in the juvenile population.

The above model might be suitably called the biomass model, because it operates on biomass. At low biomass, there is a high ratio of yield to stream production, but the system is not stable. To increase biomass requires an ever increasing egg deposition, but yield remains constant and the system gains stability. The biomass model predicts a slowly-ascending, linear stock-recruitment relationship which is markedly different from the dome-shaped Ricker models with their regions of sensitive compensatory and depensatory mortality. The biomass model also predicts that exploitation can erode away the biomass of a virgin system for a long time under the guise of a healthy fishery, until, fairly suddenly, catches become erratic and the fishery declines. To re-establish stability, a large investment of energy must be diverted into biomass. This concept is not new. Margalef (1968) viewed biomass as the keeper of information and in mature communities the ratio of production to biomass is minimized. Community stability is not strictly analogous to the single species system of this study; however, recently Johnson (1981) has emphasized the role of high biomass in maintaining stability in Arctic charr lakes. It is possible that for Atlantic salmon, high biomass is something to be managed towards.

There is another attribute of high biomass which is often not appreciated. A salmon population at carrying capacity or at high biomass is able to utilize more of the available secondary production than populations below carrying capacity. This is because invertebrate production occurs in large pulses during the late spring and early fall, and otherwise, remains at low levels throughout the remainder of the season (unpublished data). An efficient feeding strategy is to maintain a large parr biomass which can fully utilize these pulses and then to remain in a resting phase for the balance of the year. Such a situation has been documented for insect populations of Arctic lakes where the ratio of carnivores to herbivores was ten to one (Odum 1971). There was also an indication that the resting phase was important, as growth rate of juveniles was greatest in cold years, when the cost of routine metabolism would be lowest. This ability to utilize more secondary production at higher biomass suggests that yield would also be greater at carrying capacity. But, as no measurements were available, this aspect was not included in the biomass model.

It is possible that a high and constant fishing mortality would create a regular cycle in stock abundance. For example in the hypothetical unexploited state of Western Arm Brook stock, a fishing mortality greater than 4% of smolt production would cause egg deposition, smolt production and smolt age to decline. The decline would continue with each generation until spawning escapements became constant. Eventually, egg requirements per smolt would be reduced such that smolt production would increase. Smolt age would also increase and the cycle would repeat itself.

It is unlikely that fishing mortality would be entirely constant. There is evidence from this study that selection in the commercial fishery would reinforce the proposed cycle of stock abundance. This is because at high stock densities, grilse would have older smolt ages. Older grilse are slightly larger, and as a result, they are more vulnerable to commercial nets. At low stock densities grilse would have lower smolt ages and they would be less vulnerable to gillnets. Consequently, at low stock densities, fishing mortality would be less which might allow for increased egg depositions.

To end this paper, I examine trends in abundance and biological characteristics of Atlantic salmon stocks in general for evidence of the proposed biomass model. As I have stated before, there are two fisheries for Atlantic salmon in Newfoundland and Labrador. Landings in the commercial fishery have been recorded annually since 1910 (Murray 1966; Lear and May 1972; Reddin and Waldron 1976; Moores, unpub.) but records extend back to 1736 (V.R. Taylor, Fisheries and Oceans, St. John's, pers. comm.). The recreational fishery is at least 100 years old and landings have been recorded by river since

1953 (Moores <u>et al</u>. 1978; Moores and Tucker 1980). A feature of the commercial landings was a trend in the shape of a sine curve. This curve was most easily seen when total Canadian and West Greenland harvests were included and treated with an eight year moving average (Fig. 32). There was a similar trend in the recreational fishery, with a steady increase from the 1950's to a leveling off in the mid 1970's. Both fisheries had the same degree of variation: coefficients of variation for annual catch were equal to 30%, similar to the variation of smolt production found on Western Arm Brook and Little Codroy River (Table 68). This suggested that freshwater production of smolts explained a large part of the variation in commercial and recreational landings.

The curve of landings was fairly regular except for what appears to be a declining trend in catch. The curve had two maxima (1930, 1970), two ascending slopes, one descending slope, two minima (1920 and 1960) and a period of 40 years (Fig. 32). The maxima and ascending slopes were quite similar, the difference between maxima could be partly explained by the advent of the salmon fishery at West Greenland; and the slopes or rates of increase in catch were 6% y^{-1} from 1922 to 1934 and 5% y^{-1} from 1962 to 1974. It is possible that the regularity of the curve is caused by the same biological mechanisms that were proposed for the Western Arm Brook stock.

It is unlikely that trends found in the commercial fisheries were due to changes in fishing effort. There were several reasons for believing that fishing effort has remained relatively constant. First, the salmon fishery is 300 years old and fishing is done with passive gear at traditional family berths. Effort had changed little since about 40 years ago when a move was made from trap nets to synthetic gillnets but this possible increase in efficiency was partly offset by a post-war decline in fishing activity. Second, fluctuations in salmon landings for Maritimes, Quebec and Newfoundland were synchronous in degree and timing. There was also a close correspondence between the commercial and recreational fisheries. Third, the two ascending slopes in Fig. 32 were very similar which suggested effort had remained constant during these periods. The yearly increments along these slopes were almost equal ($r = 0.99$) which indicated a constant effort. Finally, other studies have found a relatively constant sea and fishery survival of 6% (unpubl. data). Undoubtedly, there were some annual fluctuations in catchability but these would be due to weather patterns and they were probably independent of stock abundance. It seemed reasonable to conclude that landings were a fair indicator of stock abundance and that changes in effort had little to do with the shape of the sine curve.

Concurrent with the sine curve of abundance, there have been trends in the biological characteristics of Atlantic salmon captured in the Newfoundland fisheries. There have been at least ten studies on the biological characteristics of Atlantic salmon taken in the commercial fisheries (Table 81). Trends in the characteristics were determined from 1931 to present, but there were several potential sources of error which should be mentioned. For example, in the 1930's there was a tendency to underestimate the number of grilse landed, especially in years of bountiful harvest, like 1931 (Lindsay and Thompson 1932). However, the most serious problem was to obtain unbiased, random samples from the fishery. There are at least 200 unique salmon stocks which are exploited in the mixed stock fisheries of Newfoundland and as a result it is probably impossible to obtain a meaningful sample of them. This is because stock composition can change markedly over a season and probably change from one year to the next for any particular area. In spite of the above constraints, these studies were probably indicative of trends for Atlantic salmon stocks in general.

The studies indicate that there have been declines in smolt age, sea age and the proportion of repeat spawners in the commercial landings. Smolt age dropped significantly ($P < 0.01$) from the 1930's to the early 1970's (Table 82). The grilse component increased from 2% in 1931 to 69% in 1973 (Table 83). This increase was at least partly due to a corresponding decline in the proportion of large salmon. In 1931, repeat spawners comprised 15% of the commercial catch and they declined to 2% in 1972-73 (Table 84). This decline was the most consistent change in stock characteristics but also indicated a tremendous loss of variation in the life history of Atlantic salmon. Lindsay and Thompson (1932) counted 33 different types of spawners from a sample of 5000 adults distributed around the island in 1931. The most current sample of similar magnitude had only 16 different types of spawners (Lear and May 1972) and it indicated that the potential spread in reproductive age for a year-class had been reduced (Fig. 33). The decline in both age and spread in age could be caused by the same mechanisms that were discussed for Western Arm Brook.

Evidence for the biomass model was suggested by a feedback mechanism between stock abundance and smolt age. There was a significant relationship (P F 0.01, r = 0.97) between smolt age and stock abundance (Fig. 34). Stock abundance was estimated from values on the sine curve of commercial landings (Fig. 32). Smolt age appeared to be influenced by density-dependent growth; greatest smolt age occurred at highest stock densities; and smolt age decreased at low stock densities. The mechanism could be as follows: at low stock densities, smolt age was reduced which, in turn, increased the reproductive rate and caused the stock to increase, conversely, at high stock densities, growth rate was suppressed, which increased smolt age and reduced the reproductive rate with the result that stocks declined. The 40 year period of the sine curve could be determined by these shifts in smolt age. Thus, the biomass model developed on Western Arm Brook has provided a framework for examining the interrelationship between harvest and production for all Atlantic salmon stocks.

In summary, this study has been a significant contribution because it has described the dynamics of a single Atlantic salmon stock. The stock was found to have predictable responses to changes in egg deposition, climate and the fishery. A number of correlations were described for the first time including: a stock-recruitment relationship between egg deposition and smolt offspring; a relationship between smolt age and temperature; a relationship between stock density and downstream movements of juveniles; a relationship between the size and smolt age of spawning adults and selection in the commercial fishery; and a relationship between the size of smolt migrations in Western Arm Brook and harvest in the local fisheries in the following year. However, the most important aspect of this paper is that it indicates the value of integrated, time series research on small systems as a rational basis for Atlantic salmon management.

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Table 1. St. Anthony mean monthly and mean annual air temperatures (°C) 1968-80.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean	S.D.
1968	-9.4	-7.7	-6.7	-0.8	3.2	6.7	12.4	10.7	10.1	5.8	-1.5	-4.6	1.52	7.68
1969	-4.4	-4.8	-3.5	-3.7	3.2	9.3	13.4	13.7	8.6	1.8	1.8	-0.9	2.87	6.34
1970	-9.8	-8.0	-4.1	-1.5	3.4	7.8	13.6	13.8	8.1	4.2	-0.2	-8.4	1.58	8.26
1971	-9.8	-11.2	-3.4	-0.3	4.8	8.2	13.2	13.5	8.7	3.5	0.0	-9.4	1.48	8.69
1972	-13.4	-14.1	-9.6	-4.1	0.2	6.8	12.4	11.5	7.7	1.8	-2.7	-15.5	-1.58	9.99
1973	-13.1	-10.9	-6.8	-2.1	2.3	7.3	14.8	11.5	9.1	3.2	-1.2	-3.1	9.2	8.76
1974	-17.5	-10.5	-9.0	-3.8	0.6	7.7	11.2	12.0	8.7	2.6	-1.7	-5.3	-0.42	9.30
1975	-13.8	-15.1	-5.3	-2.0	2.4	7.5	15.8	12.2	9.9	3.3	-1.7	-7.1	0.51	9.86
1976	-9.9	-12.8	-9.6	-1.1	4.2	7.9	12.3	13.2	9.1	2.9	-2.7	-8.9	0.38	9.23
1977	-7.6	-9.1	-4.2	-1.6	1.8	8.5	12.8	12.8	6.4	3.7	1.3	-5.6	1.60	7.51
1978	-10.4	-5.6	-9.4	2.2	2.2	8.1	12.7	12.6	6.3	2.8	-4.8	-6.7	0.47	8.18
1979	-7.6	-11.8	-3.5	-0.4	5.5	11.7	12.5	11.8	7.7	3.9	-1.1*	-7.1	1.80	8.31
1980	-9.4	-10.3	-5.6	-1.7	2.2	7.4	11.4	10.1	7.7	3.2	0.4	-7.8	0.63	7.66
Mean	-10.47	-10.15	-6.21	-1.95	2.77	8.07	12.96	12.26	8.32	3.28	-1.08	-6.95		
SD	3.33	3.06	2.48	1.25	1.52	1.29	1.26	1.15	1.16	1.04	1.78	3.50		
CV	32	30	40	64	55	16	10	10	14	32	165	50		

*Estimated from mean of other years.

Table 2. Mean monthly discharge ($m^3 sec^{-1}$) from St. Genevieve River 1970-80.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1970	7.1	6.7	5.7	7.3	20.2	17.4	11.4	8.1	5.8	6.7	6.9	10.0	9.5
1971	7.6	5.5	4.6	12.0	31.4	20.8	11.2	8.6	9.6	7.5	6.3	5.4	10.9
1972	4.1	1.8	2.7	11.7	10.3	30.0	18.2	11.2	7.3	6.2	6.2	6.7	9.7
1973	4.0	5.2	4.2	6.1	18.4	18.5	12.7	6.9	4.8	3.7	3.5	5.2	8.0
1974	4.6	2.9	2.2	3.5	15.6	21.2	13.9	8.5	5.3	7.4	7.6	7.9	8.4
1975	4.9	3.4	2.9	5.3	16.7	16.5	8.9	4.9	3.1	4.1	7.4	9.5	7.3
1976	6.9	6.5	5.7	21.9	20.0	12.3	5.9	4.0	3.8	6.2	11.7	11.2	9.7
1977	10.5	5.9	4.9	13.1	23.0	32.3	11.9	8.1	8.0	16.5	10.4	6.6	12.6
1978	8.3	4.6	3.6	4.3	21.6	20.7	12.3	7.9	6.0	4.9	5.4	5.6	8.8
1979	11.0	9.1	18.7	11.0	17.5	10.1	6.3	7.7	11.7	9.6	12.1	8.7	11.1
1980	8.5	5.9	4.0	6.1	16.9	18.2	12.0	9.1	8.0	10.1	13.9	10.6	10.3
Mean	7.05	5.23	5.38	9.30	19.24	19.82	11.34	7.73	6.67	7.54	8.31	7.95	9.66
SD	2.45	2.02	4.56	5.37	5.27	6.60	3.44	1.95	2.56	3.59	3.24	2.18	1.53
CV	35	39	85	58	27	33	30	25	38	48	39	27	16

Table 3. Summary of water chemistry collected at selected stations on Western Arm Brook, July 1980.

Station	pH	Conduct. μ mhos	Colour	Nitrate (mgl^{-1} N)	Phosphate (mgl^{-1} PO_4)	Sulphate (mgl^{-1})	Total hardness	Turbidity (JTU)	Total alkalinity	Calcium	Chloride
1	7.44	94	-	0.008	<0.005	<5	50.0	0.80	42.0	7.1	8.0
3	7.33	122	35	0.014	<0.005	<5	32.0	1.00	40.0	7.0	8.0
4	7.73	91	35	0.009	<0.005	<5	82.0	2.00	74.0	10.9	8.5
10	7.22	89	25	0.003	<0.005	<5	42.0	1.50	34.0	6.4	8.0
22	7.11	82	40	0.010	<0.005	<5	22.0	1.20	32.0	4.4	9.0
21	7.31	95	25	0.006	<0.005	<5	46.0	1.50	40.0	6.9	5.5
Mean	7.36	96	32	0.008	<0.005	<5	45.7	1.33	43.7	7.1	7.8
SD	0.21	13.8	6.7	0.004	-	-	20.5	0.43	15.4	2.1	1.2

Table 4. Summary of commercial and recreational salmon harvest statistics in Area N and Western Arm Brook (WAB), 1952-80.

Year	Area N Commercial (t)	Area N Recreational (No.)	Area N Percent grilse	WAB Recreational catch (No.)	St. Barbe Bay Commercial catch (t)
1952	32.2	-	96	-	
1953	25.0	105	98	-	
1954	14.5	50	85	-	
1955	20.0	100	82	-	
1956	26.3	109	87	-	
1957	17.3	222	92	-	
1958	27.3	217	92	-	
1959	21.8	173	98	-	
1960	19.1	171	96	-	
1961	24.1	208	98	1	
1962	4.5	615	92	38	
1963	8.6	991	91	86	
1964	10.9	1586	97	130	
1965	9.5	1831	96	123	
1966	10.9	2049	94	219	
1967	7.3	2150	95	192	
1968	2.7	2333	97	176	
1969	6.4	2830	97	336	
1970	9.5	3018	94	336	1.0
1971	5.0	2141	98	205	1.1
1972	5.9	1366	95	97	4.5
1973	20.0	2796	99	243	7.0
1974	8.2	1804	99	124	5.2
1975	10.9	2732	99	8	4.9
1976	9.1	3048	99	32	2.7
1977	13.7	2431	99	11	1.3
1978	5.2	1363	99	18	0.3
1979	14.0	3294	99	0	3.0
1980	19.8	1683	98	32	6.2
1981	19.7	2542	99	41	4.4

Table 5. Habitat accessible to Atlantic salmon in Western Arm Brook, by stream order in ha.

Habitat	Stream order 2°	3°	4°	Total
Riffle	2.4	2.1	21.3	25.8
Steady	0.8	11.6	32.9	45.3
Outflow	0.4	0.1	2.5	3.0
Lake	130.0	818.0	1024.0	1972.0
Total	133.6	831.8	1080.7	2046.1

Table 6. Sampling stations in Western Arm Brook, 1977-1979.

Habitat	Stream order 2°	3°	4°
Riffle	2	17	1
	23	24	3
	27	25	5
	28		6
	29		7
			8
			9
Steady	16	18	6a
	22	19	11
		20	
Outflow	4	21	10
		26	14
Lake	30		12
			13

Table 7. Dates when smolt counting fence was in operation and when the first and last smolts were counted in Western Arm Brook, 1971-1980.

Year	Fence operation Start	Finish	smolt run in days	Smolt count First	Last
1971	28 May	11 July	46	28 May	11 July
1972	5 June	19 Aug.	65	5 June	9 Aug.
1973	28 May	17 Sept.	58	28 May	24 July
1974	1 June	30 July	57	3 June	30 July
1975	23 May	11 July	46	23 May	7 July
1976	20 May	30 June	42	20 May	30 June
1977	29 May	6 July	33	3 June	6 July
1978	28 May	14 July	48	28 May	14 July
1979	26 May	3 July	39*	26 May	3 July
1980	27 May	12 Oct.	67	27 May	8 Oct.

* 1979 was not a complete count.

Table 8. Downstream migrating fish at Western Arm Brook, 1971-80.

Year	Salmon Kelt	Salmon Smolt	Salmon Parr	Trout	Eel	Other Smelt	Other Shad	Other Stickleback
Summer								
1971	185	5734	434	135	91	108	3	-
1972	210	11906	431	220	197	181	52	11
1973	95	8484	250	429	97	365	5	44
1974	302	12055	267	809	574	539	3	338
1975	201	9733	122	851	92	607	0	112
1976	208	6359	148	408	30	926	0	16
1977	198	9640	358	373	65	354	12	26
1978	210	13071	899	1000	69	527	2	21
1979	1	9400*	235	109	1	53	0	21
1980	969	15675	1292	850	131	338	0	19
Fall (included above)								
1977	-	13	13	59	53	13	-	2
1978	-	29	164	38	32	19	-	2
Mean	258	10206	444	518	135	400	8	68
S.D.	262.3	3043.8	370.8	330.3	163.3	261.6	16.0	106.0
C.V.	102	30	84	64	125	65	200	156
Correlation with smolt migration								
r	0.671[a]		0.735[b]	0.638[a]	0.345	0.077	0.161	0.122

*Estimated (see text).
S.D. = standard deviation
C.V. = coefficient of variation

[a] = $P < 0.05$

[b] = $P < 0.02$

Table 9. Average annual biomass of smolts, eels, trout and smelt exported from Western Arm Brook.

	Mean weight (g)	Mean numbers	Biomass exported (kg)
Smolts	47	10,206	480
Eels	198	135	27
Trout	40	464	19
Smelt	30	400	12
Total			538

Mean weights of eels, trout and smelt were estimated.

Table 10. Percentage of smolts in each age group for smolt migrations sampled in Western Arm Brook 1971-1980.

Year	Smolt count	Percent in each age group 2	3	4	5	6	Sample size
1971	5734	-	18.2	52.7	25.5	3.6	55
1972	11906	-	11.7	78.4	9.0	0.9	231
1973	8484	-	15.1	77.9	7.0	-	86
1974	12055	-	12.0	62.5	23.5	2.0	200
1975	9733	0.9	35.3	60.4	3.4	-	235
1976	6359	-	15.2	71.2	12.8	0.8	125
1977	9640	-	56.4	41.9	1.7	-	172
1978	13071	-	36.9	55.6	7.5	-	160
1979	9400*	-	24.6	68.9	6.5	-	183
1980	15675	-	39.7	56.7	3.6	-	252
Mean		0.1	26.5	62.6	10.0	0.7	
SD		0.28	14.96	11.61	8.23	1.21	
CV		285	56	19	82	172	

*1979 was not a complete count and it was estimated (see text).

Table 11. Mean smolt age of smolts in Western Arm Brook compared between years.

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	All years
Mean	4.15	3.99	3.92	4.16	3.66	3.99	3.45	3.71	3.82	3.64	3.82
SD	0.756	0.493	0.466	0.643	0.556	0.561	0.533	0.600	0.530	0.551	0.600
n	55	231	86	200	235	125	172	160	183	252	1699

ANOVA

Source	df	SS	MS	F	P
Between years	9	78.71	8.75	27.77	0.001
Within years	1689	531.88	0.31		
Total	1698	610.59			

Table 12. Results of three-way analysis of variance (for each of fork length, weight and condition) between year, smolt age and sex of smolts in Western Arm Brook.

Source	F-value: Fork length F	df	Weight F	df	Condition F	df
A (year)	2.78[b]	8	2.99[b]	6	4.89[b]	6
B (smolt age)	37.94[b]	3	7.71[b]	3	0.49	3
C (sex)	3.20[a]	2	3.84[a]	2	0.70	2
AB	4.85[b]	16	3.19[b]	11	1.18	11
AC	0.90	9	0.79	7	0.71	7
BC	0.42	4	0.82	4	1.60	4
ABC	1.74	12	1.28	10	1.45	10
Model	7.27[b]	55	4.43[b]	43	2.34[b]	43
Error		958		922		921
Total		1013		965		964
R^2	0.29		0.17		0.10	

[a]Significant $P < 0.05$.

[b]Very significant $P < 0.01$.

Table 13. Biological characteristics of smolts in Western Arm Brook compared between smolt ages.

Smolt age	Fork length (cm)	Weight (g)	Condition
3	16.7	42.5	0.90
4	17.4	48.2	0.90
5	18.8	58.2	0.90

Table 14. Main effects and significant interactions and their percentage contribution to the total explained source of variation in the three-way ANOVAS for fork length, weight and condition of smolts in Western Arm Brook.

Source	Fork length	Weight	Condition
Year	5	14	51
Smolt age	73	37	4
Sex	6	19	6
Year x smolt age	9	15	10
Total	93	84	71

Table 15. Biological characteristics of smolts in Western Arm Brook compared between years of sampling.

Year	Fork length (cm)	Weight (g)	Condition
1971	18.8	-	-
1972	17.3	49.5	0.94
1973	17.1	46.2	0.90
1974	17.3	-	-
1975	17.1	-	-
1976	17.6	-	-
1977	17.2	46.9	0.90
1978	17.1	46.1	0.91
1979	17.8	50.4	0.87
1980	16.9	43.8	0.89
All years	17.3	46.8	0.90

Table 16. Biological characteristics of smolts in Western Arm Brook compared between sexes.

Sex	Fork length (cm)	Weight (g)	Condition
Male	17.3	47.2	0.89
Female	17.3	46.5	0.90
Matured males	18.5	56.5	0.90

Table 17. Ovarian weight (a) and ovarian index (b) of smolts in Western Arm Brook compared between smolt ages for all years combined.

a) Ovarian weight (g)

	3	4	5	All ages
Mean	0.012	0.018	0.031	0.016
SD	0.013	0.019	0.024	0.018
N	122	178	16	316

ANOVA

Source	df	SS	MS	F	P
Between ages	2	0.0063	0.0032	10.63	<0.0001
Within ages	313	0.0934	0.0003		
Total	315	0.0998			

b) Ovarian index

	3	4	5	All ages
Mean	3.147	4.043	4.882	3.760
SD	3.356	3.702	3.009	3.559
N	59	92	9	160

ANOVA

Source	df	SS	MS	F	P
Between ages	2	40.82	20.41	1.62	0.200
Within ages	157	1972.99	12.57		
Total	159	2013.82			

Table 18. Comparison of vertebral counts for smolts of ages 3+ 4+ and 5+ sampled in Western Arm Brook, 1977.

	Number vertebrae	3+	4+	5+
	56	1		
	57	1	1	
	58	8	2	
	59	10	12	2
	60	8	13	
	61	3	2	
	62		1	
Mean		59.0	59.5	59.0
SD		1.17	0.96	
n		31	31	2

No significant difference ($P > 0.1$) between 3+ and 4+ smolt.

Table 19. Comparison of change in mean smolt size (mm) throughout the duration of the 1979 smolt migration in Western Arm Brook.

	Time period* in groups of five days							
	1	2	3	4	5	6	7	8
Mean	173	178	180	174	178	179	179	180
SD	14.7	19.7	16.4	17.3	17.3	17.2	14.4	13.8
n	20	25	25	25	25	25	25	25

* For example, time period 1 contains samples from the smolt run in days 1 to 5.
F-test: P = 0.79 that there was no size difference between time periods.

Table 20. Fork length (cm) of age 4+ smolts in Western Arm Brook compared between years.

	1972	1973	1974	1975	1976	1977	1978	1979	1980	All years
Mean	17.5	17.3	17.4	17.4	17.7	17.4	17.4	17.9	17.1	17.4
SD	1.69	1.79	1.74	1.41	1.62	1.66	1.31	1.57	1.81	1.64
N	181	67	124	141	88	72	89	126	143	1031

ANOVA

Source	df	SS	MS	F	P
Between years	8	44.14	5.52	2.07	0.04
Within years	1022	2726.32	2.67		
Total	1030	2770.46			

Table 21. The percentage males for smolts of ages 3+, 4+ and 5+ in Western Arm Brook, 1971-80; abundance of matured males is also indicated 1977-80.

Year	Smolt age 3+	4+	5+	All ages	Number sexed	Matured males as a percent of total males
1971	25	32	18	25.6	43	-
1972	18	27	38	26.9	108	-
1973	54	30	0	31.8	85	-
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-
1976	-	-	-	-	-	-
1977	30	18	0	24.4	172	30
1978	22	16	25	18.8	160	20
1979	27	27	17	26.2	183	14
1980	23	25	22	24.1	249	11
Overall Mean	26.1	24.4	19.7	24.7	1000	

Table 22. A summary of coefficients of annual variation (C.V.) for biological characteristics of smolts in Western Arm Brook (1971-80).

Characteristic	Units	Mean	C.V.
Smolt run	fish	10206	30
Year-class	fish	9796	25
Smolt age	year	3.8	6
Smolt fork length	mm	173	1
Smolt condition	-	0.90	2
Smolt sex	% male	25	16
Smolt standing stock	kg	477	28
Grilse escapement*	fish	577	37
Grilse harvest Area N	lbs	26025	12

*Excluding 1979.

Table 23. Mean weight and standing stock of smolt migrations in Western Arm Brook 1971-79.

Year	Mean weight (g)	Number	Standing stock (kg)
1971	-	5734	268*
1972	49.5	11906	589
1973	46.2	8484	392
1974	-	12055	564*
1975	-	9636	451*
1976	-	6259	293*
1977	46.9	9640	452
1978	46.1	13071	603
1979	50.4	9400	474
1980	43.8	15675	687
Mean	46.8		477
SD	2.04		135.9

*Standing stock estimated using mean weight of 47.9 g.

Table 24. Annual instantaneous growth rates of smolts sampled in Western Arm Brook compared between smolt ages for all years combined.

	Smolt age 3	4	5	6	All ages
Mean	2.006	1.536	1.279	1.182	1.663
SD	0.089	0.069	0.060	0	0.245
N	165	353	30	1	549

ANOVA

Source	df	SS	MS	F	P
Between ages	3	29.80	9.93	1762.28	<0.001
Within ages	545	3.07	0.0056		
Total	548	32.87			

Table 25. Back-calculated fork lengths (mm) for ages 3+, 4+ and 5+ smolts sampled in Western Arm Brook, 1971-77.

Year-class	Year of capture	Smolt age	Sample size	Fork length	Back-calculated fork length ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	Total
1974	1977	3+	54	170	75	119	163			170
1973	1976	3+	18	169	72	116	149			158
	1977	4+	91	176	67	105	138	169		176
1972	1975	3+	83	166	67	112	153			165
	1976	4+	88	177	66	105	142	169		173
	1977	5+	5	181	59	95	128	164	183	187
1971	1974	3+	18	164	60	107	143			166
	1975	4+	141	174	65	102	135	164		174
	1976	5+	15	189	61	94	131	159	183	202
1970	1973	3+	12	170	69	107	142			168
	1974	4+	26	174	64	105	140	164		179
	1975	5+	3	184	59	81	105	142	156	188
1969	1972	3+	12	166	73	114	155			166
	1973	4+	50	173	61	94	124	152		169
	1974	5+	10	173	57	85	113	142	161	183
1968	1971	3+	7	170	66	121	171			168
	1972	4+	50	175	67	103	147	181		225
	1973	5+	5	157	54	85	109	135	156	159
1967	1971	4+	29	172	60	89	122	155		169
	1972	5+	25	197	59	93	131	168	196	246
1966	1971	5+	15	190	57	85	113	147	173	201

Table 26. Comparison of back-calculated growth increments (mm) of smolts sampled in Western Arm Brook, 1968-74.

Growth year	Smolt age	Age group					Mean*	SD
		0-1	1-2	2-3	3-4	4-5		
1968	3+	38	-	-				
	4+	39	29	-	-		33.8	4.97
	5+	36	34	38	-	-		
1969	3+	45	55	-				
	4+	33	36	33	-		38.9	9.08
	5+	29	31	38	34	-		
1970	3+	41	41	50				
	4+	36	33	44	33		36.4	8.29
	5+	31	28	24	37	26		
1971	3+	32	38	41				
	4+	37	41	30	34		33.6	6.35
	5+	33	22	28	26	28		
1972	3+	39	47	35				
	4+	38	37	35	28		35.4	6.25
	5+	31	33	24	29	21		
1973	3+	44	45	36				
	4+	39	39	33	24		38.4	3.90
	5+	-	36	37	37	19		
1974	3+	47	44	41				
	4+	-	38	37	29		38.2	5.02
	5+	-	-	33	28	14		
Overall mean	3+	41	45	41				
	4+	37	36	35	30			
	5+	30	31	30	32	22		

*Mean is weighted equally for each smolt age and includes only age groups 0-1, 1-2 and 2-3.

Table 27. Standing stock of age 0+, 1+, 2+, 3+ and 4+ salmon present in Western Arm Brook during the years 1969-74.

Year	Standing stock (kg) in age group					Total standing stock (kg)
	0	1	2	3	4	
1969	593	645	504	666	123	2531
1970	376	805	796	388	146	2511
1971	352	510	994	748	114	2718
1972	616	478	630	927	63	2714
1973	239	680	591	576	307	2393
1974	439	337	683	537	31	2027

Table 28. Abundance and biological characteristics of year-classes of smolt from Western Arm Brook, 1967-77.

Year-class	Abundance	Mean smolt age	Fork length (cm)		Weight (g)		Condition	
			$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
1967	6932	-	-	-	-	-	-	-
1968	11213	4.02	17.4	1.86	49.5	13.26	0.91	0.084
1969	10835	4.14	17.1	1.92	47.8	15.63	0.91	0.080
1970	9198	3.98	17.4	1.68	-	-	-	-
1971	8164	3.96	17.4	1.61	-	-	-	-
1972	8141	3.54	17.2	1.58	-	-	-	-
1973	6074	3.89	17.5	1.84	52.6	16.28	0.91	0.109
1974	13316	3.57	17.3	1.48	48.1	15.93	0.89	0.073
1975	11864	3.74	17.3	1.81	47.7	13.83	0.89	0.078
1976	12646	3.93	17.2	1.74	43.9	10.98	0.88	0.077
1977	16932	-	-	-	-	-	-	-

Table 29. Correlation of mean smolt age of year-classes of smolts in Western Arm Brook to environmental variables.

	X					Y
	Daily temp °C		Monthly temp °C			Mean
Year-class	Annual mean 1.	S.D. 2.	Annual mean 3.	S.D. 4.	No. days ≥ 7°C 5.	smolt age
1968	5.46	2.15	1.50	1.93	163	4.02
1969	6.77	2.06	2.89	1.72	164	4.14
1970	5.73	2.41	1.61	2.09	164	3.98
1971	5.23	2.45	1.50	2.18	152	3.96
1972	2.56	2.72	-1.56	2.52	130	3.54
1973	4.64	2.43	0.94	2.21	145	3.89
1974	3.37	2.56	-0.44	2.34	130	3.57
1975	4.27	2.70	0.50	2.49	151	3.74
1976	4.32	2.54	0.39	2.32	150	3.93

Simple correlations

1. Daily temp. (X): $Y = 0.153X + 3.143$, $r = 0.949$, df = 7, $P < 0.01$
2. SD of daily temp. (X): $Y = -0.762X + 5.728$, $r = 0.832$, df = 7, $P < 0.01$
3. Monthly temp. (X): $Y = 0.149X + 3.743$, $r = 0.940$, df = 7, $P < 0.01$
4. SD of monthly temp. (X): $Y = -0.675X + 5.348$, $r = 0.854$, df = 7, $P < 0.01$
5. Days ≥ 7°C (X): $Y = 0.014X + 1.724$, $r = 0.923$, df = 7, $P < 0.01$

Multiple correlation

X_1 = monthly temperature X_2 = size of year-class (Table 28)

$Y = 3.784 + 0.148X_1 - 4.105 \times 10^{-6} X_2$, $r = 0.941$, df = 6, $P < 0.01$

Table 30. Fork length, whole weight, condition and mean age of parr older than age 0+ compared between habitats in Western Arm Brook (1977-79).

Biological characteristic	Habitat				ANOVA
	Riffle	Steady	Outflow	Lake	
Fork length (mm)					
Mean	97	115	108	87	F = 21.78
SD	26.3	38.4	31.4	14.9	P < 0.001
n	1033	63	298	49	
Weight (g)					
Mean	12.4	32.9	22.5	8.3	F = 40.57
SD	10.74	16.96	21.54	4.31	P < 0.001
n	382	35	92	49	
Condition					
Mean	1.30	1.17	1.29	1.17	F = 7.03
SD	0.173	0.224	0.414	0.089	P < 0.001
n	291	34	61	49	
Mean age (y)					
Mean	1.80	2.10	1.90	1.53	F = 5.90
SD	0.792	0.756	0.861	0.649	P < 0.001
n	1033	63	298	49	

Table 31. Fork length (mm) of salmon parr sampled in Western Arm Brook compared between habitats in early and late summer, 1978-1979.

Season	Age	Habitat			ANOVA		
		Riffle	Steady	Outflow	F	df	P
Early summer							
	1	70	56	68	3.14	2,81	0.05
	2	98	93	99	1.66	2,166	>0.05
	3	137	118	133	1.31	2,81	>0.05
Late summer							
	1	75	75	84	20.88	2,301	<0.001
	2	103	112	116	12.76	2,250	<0.001
	3	136	-	152	15.23	1,96	<0.001

Table 32. Fork length (mm) of salmon parr sampled in Western Arm Brook in late summer at ages 1+, 2+, and 3+ compared between stations within a) riffle habitats and b) outflow habitats.

a) Riffle

Age	Station								ANOVA		
	1	3	5	6	7	8	9	17	F	df	P
1	81	73	76	80	71	76	74	74	2.49	7,196	0.02
2	104	97	105	104	107	108	104	117	6.11	7,215	0.001
3	136	145	123	132	132	142	122	138	1.09	7,62	0.38

b) Outflow

Age	Station				ANOVA		
	4	10	14	21	F	df	P
1	82	80	87	82	2.20	3,77	0.09
2	102	118	120	118	1.25	3,22	0.32
3	165	151	155	135	2.03	3,23	0.14

Table 33. Sex ratio of salmon parr sampled at four habitats in Western Arm Brook, 1977-1979.

Habitat	n	% Males
Riffle	392	50
Steady	100	49
Outflow	27	59
Lake	43	58

Table 34. Sex ratio of salmon parr sampled in Western Arm Brook at stations in 1977, 1978, 1979 and all years combined. The percentages of males which were sexually mature is also indicated.

Age	1977		1978		1979		Total		Mature
	Sample size	Percent males	Sample size	Percent males	Sample size	Percent males	Sample size	Percent males	males as % of males
0	12	35	16	31	9	22	37	30	0
1	130	44	58	60	26	50	214	49	0
2	86	49	43	42	69	46	198	46	31
3	42	60	22	50	43	65	107	60	61
4	5	100	1	0	10	70	16	81	71
Total	275	48	140	49	157	52	572	50	39

Table 35. Percentage salmon parr of salmonids captured by electrofishng in four habitats in Western Arm Brook.

Habitat	River order 2°	3°	4°
Riffle	29	56	92
Steady	15	48	78
Outflow	8	66	61
Lake	-	-	-

Table 36. Percentage salmon of salmonids captured at sampling stations in Western Arm Brook, 1977-79.

Station	Year				
	1977	1978		1979	
1	100	99	95	96	96
2		35	24	15	
3		94	99	95	99
4		17	12	1	0
5			91		87
6			98		89
6a				77	79
7			95		100
8		84	97		76
8a				94	
9			82	92	72
10	46	68	57	64	69
11	100				
12	100				
13	100				
14		52	94	44	48
15		47			
16		11	42	0	
17		89	88	18	94
18		81		15	
19	100*				
20	100*				
21	100*	81	84	61	81
22		22		0	
23		0		0	
24		81			
25	100*				
26	100*				
27		19			
28	100*				
29	2				
30				0	

*Sample obtained by angling.

Table 37. A summary of juvenile salmon tagged and recaptured at stations 1 and 3 in Western Arm Brook, 1978-79.

	Station 1								Station 3							
	17/07/78				19/09/78				26/07/78				20/09/78			
	1	2	≥3	T	1	2	≥3	T	1	2	≥3	T	1	2	≥3	T
Released	34	51	36	121	21	68	36	125	9	24	4	37	61	76	14	151
Recaptured																
a	2	7	1	10	-	-	-	-	2	13	0	15	-	-	-	-
b		4		4		1		1	1			1	7	11	1	19
c	1			1		1		1		2		2	2	7	0	9
Total (b+c)	1	4		5		2		2	1	2		3*	9	18	1	28
Percent	3	8	0	4	0	3	0	2	11	8	0	8	15	24	7	19

a - Recaptured in September of same year and released again.
b - Recaptured on 04.07.79 for station 1, and 31.05.79 for station 3.
c - Recaptured on 29.08.79 for station 1, and 24.07.79 for station 3
* - Two fish were recaptured twice.

Table 38. Summary of downstream trap counts at station 2 on Western Arm Brook.

	1978					1979				
Date	Smolt	Parr	Trout	Eels	3-spine stickle-backs	Smolt	Parr	Trout	Eels	3-spine stickle-backs
May 26										
27										
28										
29							1			2
30										
31	2	4	10	1	17		1			
June 1										
2										
3										4
4		3	1		6					
5										
6		2	1		3					
7										
8										
9			1		8					
10										
11								1		3
12										
13										
14			1		13					
15										
16										
17										
18										
19										
20										
21			3		3					
22										
23										
24										
25										
26										
27										
28										
29			2							
30										
Total	2	9	19	1	47		2	1		9

Table 39. Comparison of biological characteristics of salmon parr at station 3 on 29 May 1979, before it was depopulated, and on 27 July 1979, two months afterwards.

Parameter	Before $\bar{x}$	Before SD	Before n	After $\bar{x}$	After SD	After n	t-test
Fork length age 0+ (mm)	-	-	-	42	1.7	11	
Fork length age 1+ (mm)	55	5.6	27	73	5.6	17	$P < 0.05$
Fork length age 2+ (mm)	85	8.9	67	98	7.1	37	$P < 0.05$
Fork length age 3+ (mm)	128	30.6	21	126	8.5	14	NS
Average fork length (mm)	84	24.2	115	90	26.6	79	NS
Average condition (w/ℓ^3)	1.25	0.19	115	1.27	0.20	69	NS
Average age (y)	1.95			1.96			
Biomass (gm^{2})	1.95			1.51			

Table 40. Density and standing stock of salmon (S) and brook trout (T) at riffle and outflow stations in Western Arm Brook.

	Density (No. m^{-2}) S	Density (No. m^{-2}) S+T	Standing stock (g m^{-2}) S	Standing stock (g m^{-2}) S+T
a) Riffle n = 7				
$\bar{X}$	0.34	0.55	2.41	3.14
SD	0.16	0.30	0.91	1.03
b) Outflow n = 7				
$\bar{X}$	0.17	0.55	2.67	5.24
SD	0.07	0.48	0.51	0.82
c) Average n = 14				
$\bar{X}$	0.26	0.55	2.54	4.19
SD	0.15	0.39	0.72	1.41

Table 41. Density and standing stock of salmon (S) and brook trout (T) in steady habitat in Western Arm Brook.

	Density (No. m^{-2})		Standing stock (g m^{-2})	
	S	S+T	S	S+T
$\bar{X}$	0.01	0.08	0.06	0.29
SD	0.01	0.07	0.07	0.33
n	4	4	4	4

Table 42. Percentage of standing stock of salmon at each age in three types of habitat in Western Arm Brook.

Habitat	Age 0	1	2	≥3
Riffle	5	20	37	38
Outflow	0	15	21	64
Steady	2	75	23	0

Table 43. Standing stock ($g\ m^{-2}$) of salmon at station 1, Western Arm Brook, from 1977-79.

Date	Age 0	1	2	>3	T
Sept. 1977	0.08	2.02	1.26	2.99	6.35
July 1978	0.01	0.45	2.62	5.13	8.21
Sept. 1978	0.01	0.61	4.04	3.36	8.02
July 1979	0	0.97	1.80	3.86	6.63
$\bar{x}$	0.03	1.01	2.43	3.84	7.30
SD	0.04	0.71	1.21	0.93	0.95
CV	123%	70%	50%	24%	13%

Table 44. Mean size, age and standing stock at riffle stations in Western Arm Brook proceeding upstream at approximately 2 km intervals. The correlation coefficient with the distance upstream is indicated; the levels of significance are * P<0.05 and ** P<0.01.

Variable	Station upstream → 1	3	5	6	7	8	9	17	r
					1978				
Size (mm)	109	88	96	90	94	94	80	83	0.73*
Age (y)	1.94	1.65	1.69	1.66	1.82	1.88	1.40	1.27	0.66
Standing stock (gm^{-2})	8.02	3.34	-	-	3.99	-	2.27	0.86	0.91*
					1979				
Size (mm)	109	98	101	95	87	90	85	86	0.92**
Age (y)	2.18	1.96	2.00	1.56	1.57	1.62	1.57	1.57	0.85**
Standing stock (gm^{-2})	6.63	1.95	-	-	2.02	-	0.62	0.75	0.84

Table 45. Results of ANOVAS comparing biological characteristics of grilse in Western Arm Brook between years and smolt ages (1971-1980).

Variation		Biological characteristic			
		Fork length	Whole weight	Condition	Smolt age
Between years	F	5.95	5.35	1.71	4.14
	df	9,821	8,694	8,341	9,763
	P	<0.001	<0.001	0.10	<0.001
Between smolt ages	F	1.72	3.11	1.43	
	df	3,820	3,775	3,385	
	P	0.16	0.03	0.23	

Table 46. Correlations between sea survival rates (smolt to escaping 1SW salmon) and biological characteristics of smolts and returning grilse in Western Arm Brook, 1971-1980.

Year	Sea survival	Smolt FL (cm)	Smolt W (g)	Smolt CF	Smolt No.	Smolt Smolt age	Grilse FL (cm)	Grilse W (g)	Grilse CF	Grilse No.	Grilse Smolt age
1971	7.08	18.6	-	-	5,734	4.15	52.4	1691	1.16	406	3.79
1972	6.67	17.5	50.6	0.92	11,906	3.99	53.1	1590	1.06	798	3.90
1973	6.16	17.1	46.2	0.90	8484	3.92	53.1	1620	1.08	523	4.12
1974	5.30	17.3	-	-	12,055	4.16	53.5	1638	1.07	639	3.72
1975	5.67	17.1	-	-	9,733	3.66	53.5	1551	1.05	552	-
1976	5.87	17.7	-	-	6,359	3.99	52.7	1515	1.04	373	3.72
1977	3.27	17.2	46.9	0.90	9,640	3.45	52.1	1589	1.14	315	3.61
1978	12.06	17.1	46.1	0.91	13,071	3.71	51.1	1508	1.13	1576	3.88
1979	5.00	17.8	50.3	0.87	9,400	3.82	54.2	1792	1.10	470	3.77
1980	3.10	16.9	43.8	0.89	15,675	3.64	52.4	1562	1.07	492	3.59
Correlation		0.110	0.071	0.471	-0.011	0.217	-0.488	-0.266	0.265	0.863**	0.531

**$P<0.01$

Table 47. Correlations between sea survival rates (smolts to escaping 1SW salmon) in Western Arm Brook and selected environmental conditions.

		Air temperature			Water discharge			Sea environment		
1980-81	% Sea survival	June	July	Mean annual	St. Lawrence Jun-Aug mean	Total annual St. Genevieve ac ft	% during smolt run (20 day peak)	Ice conditions during peak	Stn 27 - May-Aug Salinity	Stn 27 - May-Aug Temperature
1971-72	7.08	4.8	8.2	1.48	7480	279,000	13.42	4	-1.101	9.648
1972-73	6.67	0.2	6.8	-1.58	8683	-	-	6	-0.202	3.122
1973-74	6.16	2.3	7.3	0.92	9660	205,000	12.43	2	-2.335	2.125
1974-75	5.30	0.6	7.7	0.42	9377	215,000	12.80	8	-0.810	-2.411
1975-76	5.67	2.4	7.5	0.51	8317	187,000	12.74	7	0.304	0.960
1976-77	5.87	4.2	7.9	0.38	9667	248,000	7.15	4	0.665	4.109
1977-78	3.27	1.8	8.5	1.60	7283	323,000	12.35	3	-0.822	3.048
1978-79	12.06	2.2	8.1	0.47	8277	225,000	11.65	2	-0.451	8.357
1979-80	5.00	5.5	11.7	1.80	8027	286,882	5.12	5	0.000	6.317
1980-81	3.10	2.2	7.4	0.63	8230	263,478	6.32	3	0.009	0.884
Correlation		-.001	-0.100	-0.239	0.077	-0.385	0.305	-0.224	-0.089	0.567

Table 48. Comparison of sea survival rates (smolts to escaping 1SW salmon) for three smolt ages on Western Arm Brook, 1971-80.

Year	Smolt age 3+	4+	5+
1971	13.7	6.8	3.9
1972	8.4	6.7	4.4
1973	6.1	4.8	19.5
1974	12.3	6.1	0
1975	6.8	6.1	5.5
1976	13.9	4.8	1.7
1977	2.5	4.0	9.1
1978	7.2	14.8	15.8
1979	5.4	4.5	3.6
1980	3.2	2.7	2.5
Mean	7.5	5.8	5.2

ANOVA

MS Between years 19.04

Within years 30.15

F value = 0.63, P>0.75

Table 49. Results of four-way analysis of variance (for each of fork length, whole weight, and condition) between year, smolt age, sex, and location of virgin 1SW salmon sampled in St. Barbe Bay and Western Arm Brook, 1977-1980.

Source	df	F-value: Fork length	F-value: Whole weight	F-value: Condition
A (year)	4	4.41[b]	4.39[b]	6.45[b]
B (smolt age)	4	1.38	0.61	1.99
C (sex)	1	7.74[b]	5.49[a]	0.15
D (location)	1	25.44[b]	36.90[b]	7.98[b]
AB	10	1.29	1.33	2.26[a]
AC	4	1.11	1.44	0.90
AD	4	2.59[a]	1.97	0.88
CD	1	0.14	1.38	0.46
BD	3	0.18	0.36	0.21
BC	4	0.64	0.63	0.10
ABC	8	0.73	0.58	1.72
ACD	4	0.65	0.88	0.74
BCD	2	0.15	0.22	0.11
ABD	8	0.64	0.65	0.81
ABCD	4	0.18	0.19	0.84
Model	62	5.45[b]	5.77[b]	3.13[b]
Error	1413	-	-	-
Total	1475	-	-	-
R^2		0.19	0.20	0.12

[a]Significant $P < 0.05$.

[b]Very significant $P < 0.01$.

Table 50. Biological characteristics of virgin 1SW salmon sampled in Western Arm Brook and St. Barbe Bay, 1977-1981.

Location	Fork length (cm)	Length weight (gm)	Condition	Sample size
Western Arm Brook	52.3	1590	1.11	376
St. Barbe Bay	54.9	1920	1.14	1100

Table 51. Main effects and significant interactions and their percentage contribution to the total explained source of variation in the four-way anovas for fork length, whole weight, and condition of virgin 1SW salmon in St. Barbe Bay and Western Arm Brook, 1977-1981.

Source	Fork length	Percent whole weight	Condition
Year	9	8	25
Smolt age	3	1	8
Sex	16	10	1
Location	54	65	31
Year x smolt age	3	2	9
Year x location	5	3	3
Total	90	89	77

Table 52: Biological characteristics of virgin 1SW salmon in Western Arm Brook and St. Barbe Bay compared between years of sampling, 1977-1981.

	Fork length (cm)	Whole weight (gm)	Condition	Sample size
1977	53.6	1660	1.07	383
1978	54.6	1910	1.17	109
1979	52.7	1720	1.18	384
1980	55.8	2010	1.15	286
1981	55.5	2010	1.15	314

Table 53. Biological characteristics of virgin 1SW salmon sample in Western Arm Brook and St. Barbe Bay compared between sexes.

Sex	Fork length (cm)	Whole weight (gm)	Condition	Sample size
Male	54.8	1900	1.13	446
Female	54.0	1810	1.13	1030

Table 54. Fork length of virgin female 1SW salmon compared between years and smolt ages for fish sampled in St. Barbe Bay and in Western Arm Brook, 1977-1981.

Location	Smolt age	Year 77	78	79	80	81	ANOVA Source	F	P
Bay	3	51.9	55.0	52.7	55.6	55.5	Year	14.56	<0.01
	4	54.1	53.6	53.9	55.8	55.1	Smolt age	3.42	<0.01
	5	53.8	56.9	53.6	57.6	55.1	Year x smolt age	1.93	<0.05
River	3	51.5	53.2	52.1	54.0	52.1	Year	2.02	0.03
	4	52.6	51.3	51.1	54.4	52.9	Smolt age	0.80	0.50
	5	-	50.0	51.3	53.4	50.2	Year x smolt age	0.86	0.61

Table 55. A comparison of mean smolt age between smolts and virgin 1SW salmon in Western Arm Brook and virgin 1SW salmon.

	A			B			C			Tests of significance		
Year i	Smolts in year i-1			Grilse in Western Arm Brook year i			Grilse in St. Barbe Bay year i			AB	AC	BC
	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n			
1972	4.15	0.756	55	3.79	0.674	71	-	-	-	b	-	-
1973	3.99	0.493	231	3.90	0.476	136	-	-	-	c	-	-
1974	3.92	0.466	86	4.12	0.678	81	-	-	-	a	-	-
1975	4.16	0.643	200	3.72	0.461	18	-	-	-	b	-	-
1976	3.66	0.556	235	-	-	-	-	-	-	-	-	-
1977	3.99	0.561	125	3.72	0.632	53	4.14	1.029	358	b	c	b
1978	3.45	0.533	172	3.61	0.583	62	3.96	0.732	94	c	b	b
1979	3.71	0.600	160	3.88	0.551	205	3.91	0.568	198	b	b	c
1980	3.82	0.530	183	3.77	0.533	60	3.93	0.608	228	c	c	c
1981	3.64	0.551	252	3.59	0.554	66	3.90	0.605	256	c	b	b

a - $P < 0.05$.
b - $P < 0.01$.
c - N.S.

Table 56. Sex ratio of smolts and virgin 1SW salmon in Western Arm Brook and virgin 1SW salmon in St. Barbe Bay compared between years (1977-81).

	A Smolts in year i-1		B Grilse in Western Arm Brook in year i		C Grilse in St. Barbe Bay in year i	
Year i	% Male	n	% Male	n	% Male	n
1977	-	-	34.5	58	32.3	338
1978	24.4	172	9.5	21	42.4[a]	92
1979	18.8	160	42.1[a]	221	34.2	196
1980	26.2	183	11.6[a]	69	21.2[a]	226
1981	21.7	249	19.7	61	27.7	256
Total or expected	23.6	764	31.4	430	30.1	1108

[a]Significant difference ($P < 0.05$) between observed and expected sex ratios.

Table 57. Sex ratio of smolts and virgin 1SW salmon in Western Arm Brook and virgin 1SW salmon in St. Barbe Bay compared between smolt ages (1977-81).

	A Smolts in Western Arm Brook		B Grilse in Western Arm Brook		C Grilse in St. Barbe Bay	
Smolt age	% Male	n	% Male	n	% Male	n
3	26.3	301	26.0	104	28.7	216
4	22.5	427	31.5	241	28.2	652
5	19.4	36	40.0	30	36.2	213
Total or expected[a]	23.6	764	30.7	375	29.9	1081

[a]No significant difference $P > 0.05$ between expected sex ratios and observed sex ratios at smolt age in all three analyses.

Table 58. Biological characteristics of virgin 1SW salmon throughout the 1979 season compared between weeks, for Western Arm Brook and St. Barbe Bay.

Week	Western Arm Brook			St. Barbe Bay		
	Fork length (cm)	Whole weight (g)	Smolt age	Fork length (cm)	Whole weight (g)	Smolt age
1	49.2	1480	4.0	54.9	2040	4.0
2	51.1	1810	4.4	53.1	1860	3.9
3	50.7	1610	4.0	52.7	1840	3.8
4	51.2	1500	3.8	53.5	1800	4.0
5	52.2	1360	4.0	-	-	-
6	51.1	1320	3.9	-	-	-
7	51.9	1480	3.7	-	-	-
8	51.3	1300	3.8	-	-	-
ANOVA						
df between	7	7	7	3	3	3
within	129	129	114	126	126	125
F	1.37	4.38	1.93	2.61	2.11	2.19
P	NS	<0.01	NS	NS	NS	NS

Table 59. Number of repeat spawner 1SW salmon sampled in the commercial fishery of St. Barbe Bay and Western Arm Brook and their percentage of the total 1SW salmon (virgins and repeat spawners).

Year	Commercial fishery of St. Barbe Bay		Western Arm Brook	
	No. of repeat spawners	% of total 1SW salmon	No. of repeat spawners	% of total 1SW salmon
1977	36	9.8	0	0
1978	4	4.2	0	0
1979	4	2.0	0	0
1980	3	1.3	2	3.2
1981	56	18.0	3	4.9
Total	103	8.6	5	1.3

Table 60. Sex ratio of virgin and repeat spawner 1SW salmon sampled in the commercial fishery of St. Barbe Bay and in Western Arm Brook (1977-81).

Sex ratio	Virgin 1SW salmon	Repeat spawner 1SW salmon
% Male[a]	30.2	42.6
Sample size	1476	108

[a]Significantly different $P < 0.05$.

Table 61. Percentage at each smolt age of virgin and repeat spawner 1SW salmon sampled in the commercial fishery of St. Barbe and in Western Arm Brook (1977-81).

Smolt age	Virgin 1SW salmon %	Repeat spawner 1SW salmon %
2	<1	1
3	22	25
4	61	55
5	16	17
6	1	2
Mena smolt age	3.96	3.94
Sample size	1476	108

[a]No significant difference.

Table 62. Correlations between biological characteristics of virgin 1SW salmon sampled in St. Barbe Bay and Western Arm Brook and their sea survival.

Biological characteristics		Year 77	78	79	80	81
Fork length (cm)						
Bay		53.7	55.1	53.8	56.1	56.2
River		52.7	51.9	51.5	54.3	52.6
Difference	X_1	1.0	3.2	2.3	1.8	3.6
Whole weight (g)						
Bay		1680	1970	1910	2060	2090
River		1520	1600	1530	1790	1640
Difference	X_2	160	370	380	270	450
Smolt age (y)						
Bay		4.14	3.96	3.91	3.93	3.90
River		3.72	3.61	3.88	3.77	3.59
Difference	Y	0.42	0.35	0.03	0.16	0.31
Sea survival (%)	Z	5.87	3.27	12.06	5.00	3.10

Correlations

Z on X_1Y	$r = 0.830$	df = 2
Z on X_2Y	$r = 0.803$	df = 2

Table 63. Prediction of year-classes of smolts from egg deposition on Western Arm Brook.

Year-class	X Number of eggs x 10^{-3}	Y Year-class as smolts	95% confidence limits
1973	428	6,074	
1974	787	13,316	
1975	667	11,864	
1976	827	12,646	
1977	870	16,932	
1978	737	(12,456)	(10,883-14,257)
1979	572	(8,991)	(7,631-10,594)
1980	3,024	(77,188)	(36,098-165,049)

$\ln Y = 1.29 \ln X - 8.014$

$r = 0.971$ $P<0.01$

$F = 49.55$

Table 64. Regression of smolt year-class strength (Y) and egg deposition (X) on Little Codroy River. Egg deposition was calculated using kelt as an index of spawners.

Year-class	X Number eggs (thousands)	Y Smolt year-class size
1954	1360	12,490
1955	455	8,911
1956	542	11,533
1957	370	8,945
1958	82	5,354
1959	352	8,164
1960	185	7,799

$\ln Y = 0.302 \ln X - 5.223$

$r = 0.954 \quad P < 0.01 \quad df = 5$

Table 65. Indian River spawning channel: relationship between winter temperature, change in water level and egg to fry survival.

Year	X Lowest winter mean mo. temp (°C)	Y Difference between Nov. and lowest winter mean mo. discharge (ls^{-1})	Z Egg to fry survival arc sin $\sqrt{P}$ *
1963-64	-9.1	3,824	32.6
1964-65	-8.1	4,306	39.2
1965-66	-6.4	1,360	53.7
1966-67	-10.9	1,133	38.1
1967-68	-7.9	5,212	35.1
1968-69	-4.3	2,351	39.2
1969-70	-9.4	4,334	22.0
1970-71	-9.1	453	54.9
1971-72	-12.0	4,561	20.3

$Z = 68.07 + 1.89X - 0.005Y$

$r = 0.844 \quad df = 6 \quad P < 0.01$

* P = egg to fry survival as a proportion

Table 66. Calculation of net production (P) and available production (A) of female smolt year-classes in Western Arm Brook, 1972-77.

Year-class	No. eggs x 10^3	No. smolt	Mean weight of smolt	Production (kg) P	A	(A/P)x100
1972	745	6187	46.8*	974	290	30
1973	214	4616	52.6	571	243	43
1974	394	10120	48.1	1099	487	44
1975	334	9017	47.7	958	430	45
1976	414	9229	43.9	970	405	42
1977	435	12868	46.8*	1307	602	46
$\bar{x}$				980	410	
SD				240.1	130.8	

*Estimated from mean weight of smolts in all years.

Table 67. Calculation of production ($g\ m^{-2}\ y^{-1}$), mean biomass ($g\ m^{-2}\ y^{-1}$), and growth at selected riffle and outflow stations on Western Arm Brook from 1978-79. Turnover ratios for production (P) to mean biomass (B) are also given.

Stat.	Growth			Mean biomass				Production				
	0-1	1-2	2-3	0-1	1-2	2-3	Total	0-1	1-2	2-3	Total	P/B
1	1.40[a]	0.72	0.77	0.49	1.13	3.24	4.86	0.69	0.81	2.49	3.99	0.82
3	1.40[a]	1.23	0.85	0.12	0.78	1.16	2.06	0.17	0.96	0.99	2.12	1.03
7	1.40	0.99	0.76	0.39	0.65	0.91	1.95	0.55	0.64	0.69	1.88	0.96
9	1.52	0.99	0.75	0.17	0.43	0.64	1.24	0.26	0.43	0.48	1.17	0.94
10	1.29[a]	1.07	0.85	0.15	0.24	1.56	1.95	0.19	0.26	1.33	1.78	0.91
14	1.29	0.63	0.78	0.09	0.41	1.19	1.69	0.12	0.26	0.93	1.31	0.77
21	1.29[a]	0.85	0.53	0.42	0.73	0.68	1.83	0.54	0.62	0.36	1.52	0.83
Mean[b]				-	-	-	-	0.31	0.53	0.80	1.63	
SD				-	-	-	-	0.19	0.27	0.36	0.36	

[a]Value estimated from mean of other stations in the same habitat.

[b]Mean excludes station 1.

Table 68. Rivers with counts of wild Atlantic salmon smolts.

River	Location	Reference	Smolt migrations: No. years counted	Smolt migrations: Mean count	Smolt migrations: Coefficient of variation
Western Arm Brook	Newfoundland	This study	10	10,206	30
Little Codroy	Newfoundland	Murray 1968b	10	9,998	25
North Harbour	Newfoundland	Lear and Day 1977	12	1,169	67
Sand Hill	Labrador	Pratt et al. 1974	5	48,548	14
Big Salmon	New Brunswick	Jessop 1975	6	20,085	36
N.W. Miramichi	New Brunswick	Paloheimo and Elson 1974	16[a]	24,460	40
Burrishoole	Ireland	(Anon. 1975-79)	10	11,918	27
Ricklean	Sweden	(Osterdahl 1969)	4	1,980	44

[a]5 years of imcomplete counts were omitted.

Table 69. Biological characteristics of smolts on selected rivers and their relative annual variation.

River	Age (yr) Mean	Age (yr) CV	Fork length (cm) Mean	Fork length (cm) CV	Condition Mean	Condition CV	Percent male Mean	Percent male CV
Western Arm Brook	3.84	6%	17.3	1%	0.90	2%	26	15%
Little Codroy	2.64	5%	14.9	3%	0.92	3%	31	12%
North Harbour	2.99	9%	15.3	5%	-	-	-	-
Sand Hill	4.33	5%	15.9	2%	-	-	38	16%
Big Salmon	2.49	7%	14.3	5%	0.97	4%	-	-
Ricklean	2.49	14%	-	-	-	-	37	10%

CV = Coefficient of variation.

Table 70. Comparison of fork length and age for smolts sampled in several Canadian rivers; latitude of the river mouth is also included.

River	Mean fork length (mm)	Mean smolt age (yr)	Latitude	Reference
Newfoundland				
Western Arm Brook	174	3.8	51°	This report
Little Codroy River	149	2.6	48°	Murray 1968
North Harbour River	153	3.0	48°	Lear and Day 1977
Bay du Nord River	167	-	48°	Unpublished
Labrador				
George River	215	5.9	58°	Power 1969
Whale River	206	5.2	57°	Power 1969
Koksoak River	206	5.0	57°	Power 1969
Sand Hill River	160	4.4	53°	Pratt et al. 1974
Quebec				
Matamek River	149	-	50°	Naiman 1980
Maritimes				
NW Miramichi River	147	2.9	47°	Forsythe 1967
Pollett River	159	-	46°	Elson 1962a
Big Salmon River	143	2.5	46°	Jessop 1975

Table 71. Biological characteristics of smolts sampled in 34 rivers around insular Newfoundland in 1973. An index of large salmon abundance is also given for each river.

River	Map No.	Sample size	Fork length (cm)	Condition	Mean age	Percent male	Weight (g) ovaries	Weight (g) body	Index of large salmon abundance
Beaver Bk.	1	75	13.8	1.17	4.0	25	0.30	31	6
Sops Arm R.	2	24	13.0	1.14	4.1	29	0.25	25	9
Burlington R.	3	28	15.1	0.95	3.6	21	0.31	34	7
Riverhead Bk.	4	75	16.0	0.97	3.4	28	0.46	44	4
Pt. Leamington R.	5	7	15.6	1.12	3.4	43	0.37	46	16
Cambellton R.	6	100	16.1	1.09	3.2	29	0.44	46	13
Gander R.	7	24	14.4	1.05	3.8	8	0.32	32	36
Ragged Harbour R.	8	63	17.4	0.96	3.2	24	0.59	60	21
Indian Bay Bk.	9	76	16.7	1.06	3.0	37	0.38	51	8
Gambo R.	10	49	16.7	1.16	3.0	24	0.55	55	18
Terra Nova R.	11	41	14.9	1.10	3.5	37	0.33	37	15
Northwest R.	12	47	17.2	1.00	4.0	34	0.56	55	12
Champney's R.	13	34	15.5	1.06	3.4	15	0.33	40	6
Trouty Bk.	14	53	16.7	1.11	3.2	11	0.69	53	0
Renews R.	15	22	17.8	1.06	2.7	41	1.06	65	26
Salmonier R.	16	54	16.0	1.03	3.1	24	0.49	45	1
Branch R.	17	97	15.8	1.03	3.1	7	0.40	41	33
Northeast R.	18	32	13.9	1.35	3.2	69	0.52	37	22
Pipers Hole R.	19	37	16.4	1.16	3.4	32	0.46	52	40
Red Harbour R.	20	99	14.7	1.18	3.2	4	0.41	38	17
Taylor Bay Bk.	21	80	17.5	1.83	3.3	15	0.75	92	1
Terrenceville R.	22	112	13.9	1.12	3.3	9	0.27	31	32
Grandy's R.	23	9	17.7	0.96	3.8	-	-	-	-
Farmers R.	24	103	16.6	0.89	3.1	-	-	-	-
Garia R.	25	19	15.7	1.13	2.9	26	0.37	45	33
Highlands R.	26	56	13.7	0.94	2.7	64	0.15	25	95
Robinsons R.	27	44	13.5	1.06	3.0	34	0.21	26	45
Fischells R.	28	35	14.0	1.04	2.6	26	0.22	29	58
Southwest Bk.	29	40	13.4	1.07	3.0	50	0.25	26	61
Harry's R.	30	10	12.7	1.21	3.4	20	0.20	24	34
River of Ponds	31	86	16.2	1.09	3.2	29	0.42	47	13
Little Brook Ponds	32	29	17.4	1.16	3.1	48	0.57	61	1
East R.	33	104	13.6	1.01	4.0	34	-	-	-
St. Genevieve R.	34	99	17.0	0.84	4.2	34	-	-	-
Mean			15.5	1.10	3.3	29	0.42	43	
SD			1.52	0.161	0.41	15.2	0.190	14.9	
CV			10%	15%	13%	52%	45%	35%	

Table 72. Correlations between year-class strength of smolts, smolt age and sex ratios on Little Codroy River.

Year-class	1. No. smolts	2. No. smolts age 3+	3. Smolt age	4. Percent males
1951	11704	7570	2.71	-
1952	11269	6411	2.63	-
1953	13433	8863	2.68	-
1954	12490	6603	2.57	37
1955	8911	6323	2.79	27
1956	11533	8771	2.78	34
1957	8945	4683	2.70	26
1958	5354	3190	2.62	29
1959	8164	3523	2.45	26
1960	7799	3004	2.43	28

Correlations

1. and 3.	$r = 0.344$	$df = 8$	N.S.
2. and 3.	$r = 0.688$	$df = 8$	$P < 0.05$
1. and 4.	$r = 0.730$	$df = 5$	$P = 0.06$

Table 73. Sex-ratio as percentage male for three smolt ages on Little Codroy River (1956-63).

Year	Smolt age 2	3	4	n	Matured males as a percentage of total males
1956	34	27	70	367	-
1957	4	39	0	281	-
1958	29	34	40	470	56
1959	24	35	57	631	59
1960	19	31	50	831	46
1961	20	34	50	637	44
1962	27	33	75	626	43
1963	22	29	60	366	57
Mean	22	33	50		51

Table 74. Correlations between smolts counted in Western Arm Brook and grilse (1SW salmon) the following year taken in the recreational fishery of nearby rivers and total harvest in Area N.

Year	No. smolts in Western Arm Brook in year i	Recreational harvest of grilse in year i+1 from rivers near Western Arm Brook							
		Little River of Ponds	Brook Ponds	Big East	Castors	St. Genevieve	Forteau	Pinware	Area N
1971	5,734	435	91	136	329	758	178	245	1,332
1972	11,906	1,378	255	172	403	1,777	472	957	2,648
1973	8,484	406	34	78	351	1,165	258	482	1,789
1974	12,055	935	244	70	866	1,718	284	785	2,716
1975	9,733	1,838	374	134	590	2,376	818	1,680	3,014
1976	6,359	1,279	110	223	670	1,548	612	1,050	2,413
1977	9,640	870	65	144	274	931	164	409	1,350
1978	13,071	1,772	120	410	1,023	2,130	394	507	3,281
1979	9,400	714	136	141	341	1,129	339	599	1,651
Correlations									
All years		0.52	0.40	0.46	0.52	0.60	0.06	0.13	0.64
Excluding 1976		0.68	0.37	0.58	0.72[a]	0.71[a]	0.31	0.31	0.78[a]
Excluding 1975 and 1976		0.87[a]	0.60	0.58	0.72	0.92[b]	0.70	0.71	0.88[b]

[a] $p < 0.05$.

[b] $p < 0.01$.

Table 75. Correlations between smolts counted in year i on Little Codroy River and recreational harvest of grilse (1SW salmon) in year i+1 and large salmon (2SW salmon) in year i+2 in rivers of St. Georges Bay.

Year (i)	No. of smolts on Little Codroy	Recreational harvest in rivers of St. Georges Bay									
		Grand Codroy	Highlands	Crabbes	Barachois	Robinsons	Fishells	Flat Bay	Southwest	Harry's	Area K
1954	12,210	741	65	295	97	562	101	460	151	705	3,292
1955	11,248	780	83	491	296	766	225	585	248	1,161	4,808
1956	14,771	894	133	605	254	1,094	281	757	301	1,636	6,131
1957	8,900	651	83	318	125	458	187	638	417	1,079	4,100
1958	9,341	584	80	286	74	605	182	399	266	695	3,267
1959	12,099	703	35	259	111	926	167	1,045	747	722	4,902
r		0.90[a]	0.37	0.62	0.48	0.84[a]	0.37	0.41	0.01	0.53	0.71

[a] $p < 0.05$.

Table 76. Summary of mean smolt ages and egg to smolt survival rates on three Atlantic salmon rivers.

Parameter	Pollett River	Little Codroy River	Western Arm Brook
Smolt age (yr)	2.1	2.6	3.9
% survival (egg to smolt)	1.1	2.9	1.7[a]
% survival adjusted to smolt age 2.1 yr	1.1	3.6	3.2
Coefficient of variation in annual smolt production	64%	27%	30%

[a]Excluding 1972 year-class.

Table 77. Comparison of annual variation in freshwater (V_0) and marine (V_1) survival for Atlantic salmon and sockeye salmon.

Variable	Atlantic salmon	Sockeye salmon
V_0	13%	19%
V_1	12%	27%
V_0/V_1	1.1	0.7
Reference	This study	Parker 1974

Table 78. Comparison of the number of years after birth before spawning for salmon sampled in 1978 commercial fishery of St. Barbe Bay and in Western Arm Brook.

	No. of years after birth before spawning				
	4	5	6	7	8
Fishery (%)	17	51	22	9	1
River (%)	51	49			

Table 79. Smolt age distribution used in simulation for Western Arm Brook and average coefficient of variation for each dominant smolt age. The coefficient of variation was used as an indicator of stability.

Dominant smolt age	Proportion of smolt at age 3	4	5	6	7	Average C.V.
3	0.9	0.1				1.20
4	0.3	0.5	0.2			0.82
5	0.1	0.2	0.5	0.2		0.71
6		0.1	0.2	0.5	0.2	0.74

Table 80. Variables used to calculate production (P) available production (A) and egg deposition at smolt ages 3-7, Western Arm Brook.

Variable	Smolt age 3	4	5	6	7	Mean[a]
Smolt weight (g)	42.5	48.2	58.2	70.0	85.0	59.7
Instantaneous growth rate	6.052	6.178	6.366	6.551	6.745	
Instantaneous mortality rate	3.120	3.900	4.680	5.460	6.240	
A/P	0.51	0.41	0.33	0.25	0.19	0.32
Eggs required to produce one smolt	23	49	108	235	513	

[a]Mean values are weighted for hypothetical unexploited smolt age structure (see text).

Table 81. A summary of historical information on biological characteristics of Atlantic salmon in insular Newfoundland.

Year	Reference
1931	Lindsay and Thompson 1932
1937	Belding and Préfontaine 1938
1938	Belding and Préfontaine 1961
1939	Blair 1943
1942	Blair 1965
1943	Blair 1943
1969	Lear and May 1972
1970	Lear and May 1972
1971	Lear 1973
1972	Lear, Burfitt and Batten 1974
1973	Lear, Batten and Burfitt 1976
1973	Chadwick and Waldron, unpublished

Table 82. Comparison of smolt ages of salmon found in biological samples of the Newfoundland commercial fishery and in the combined samples of smolt migrations in 43 rivers.

Year	Area								Total	
	A	AB	C	D	E	F	DEF	J	n	x
1931		3.82	3.26				3.33		3515	3.77
1939	4.30		3.83	3.49	4.09	3.21			1676	3.78
1969	3.73		2.80			2.80		2.80	1026	3.03
1970	4.05		2.99		2.90			3.17	2397	3.28
1971	3.91					3.50		3.62	1261	3.29
1973[a]									2038	3.30

n - total number fish sampled.
x - weighted mean smolt age.

a - 43 rivers sampled throughout insular Newfoundland. (Chadwick and Waldron, unpublished)

Table 83. Summary of percentage 1SW salmon (grilse) found in biological samples of the Newfoundland commercial fishery.

Year	Area														Total		
	A	B	AB	C	D	E	F	DEF	H	I	J	K	L	O	1	2	3
1931			2	6				5						0	69	3708	2
1937											0					587	0
1938	4														17	380	4
1939	7	75		54	32	36	1							17	1099	3643	30
1942													57		546	955	57
1943												14			102	752	14
1969	38			28			11				2			0	256	1488	17
1970	39			49		0					1			0	506	2666	19
1971	27			37							1			17	569	3069	19
1972				52	93										924	1359	68
1973	87					14			24	94					880	1274	69

1 - Total number of grilse.
2 - Total number of fish sampled in commercial fishery.
3 - Proportion grilse.

Table 84. Summary of percentage repeat spawners found in biological samples of the Newfoundland commercial fishery.

Year	Area														Total		
	A	B	AB	C	D	E	F	DEF	H	I	J	K	L	O	1	2	3
1931			16	7				14						12	562	3708	15
1937											7				40	587	7
1938	12														46	380	12
1939	20	4		4	10	12	11							14	420	3643	12
1942													10		91	955	10
1943												16			122	752	16
1969	4			4			6				10			11	106	1488	7
1970	3			2							3			8	86	2628	3
1971	4			2							4			5	111	3017	4
1972				3	1										30	1339	2
1973	1					3			3	4					18	955	2

1 - Total number of repeat spawners.
2 - Total number of fish sampled in commercial fishery.
3 - Proportion repeat spawners.

Figure 1. Location of Western Arm Brook, Newfoundland.

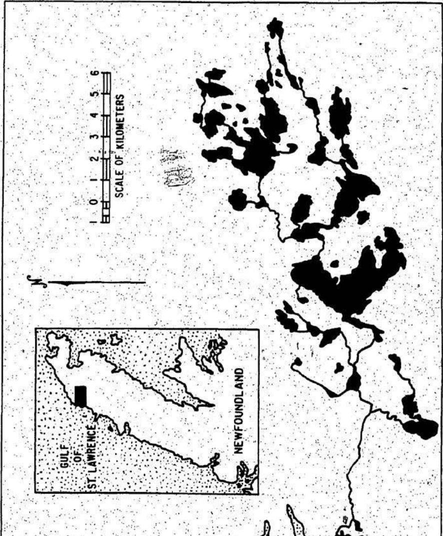

1 0 1 2 3 4 5 6
SCALE OF KILOMETERS
N
GULF
OF
ST. LAWRENCE
NEWFOUNDLAND
GULF OF ST. LAWRENCE

Figure 2. Basin relief and stream habitat which is available to Atlantic salmon in Western Arm Brook.

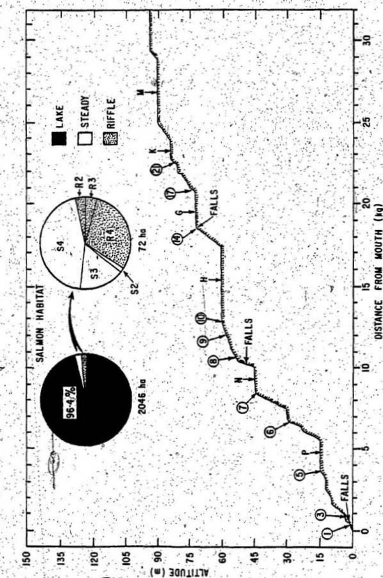

SALMON HABITAT
96.4%
2046 ha
S4
S3
S2
R2
R3
R4
72 ha
LAKE
STEADY
RIFFLE
ALTITUDE (m)
150
135
120
105
90
75
60
45
30
15
0
0
5
10
15
20
25
30
DISTANCE FROM MOUTH
FALLS
FALLS
FALLS
1
3
5
6
7
8
9
10
14
17
21
P
N
H
G
K
M

Figure 3. Mean annual precipitation and annual surface runoff in insular Newfoundland, after (Murray and Harmon 1969).

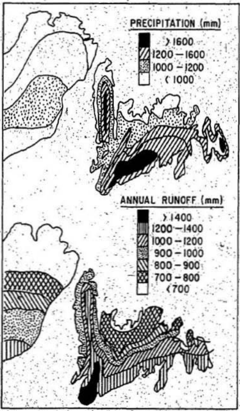
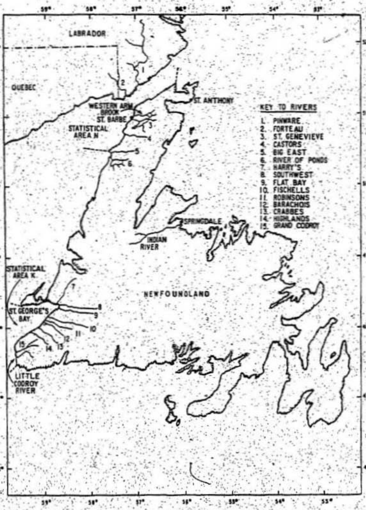

PRECIPITATION (mm)
> 1600
1200 – 1600
1000 – 1200
< 1000
ANNUAL RUNOFF (mm)
> 1400
1200 – 1400
1000 – 1200
900 – 1000
800 – 900
700 – 800
< 700

Figure 4. Location of rivers and places in insular Newfoundland and southern Labrador that are mentioned in the text.



LABRADOR
QUEBEC
WESTERN ARM BROOK
ST. BARBE
STATISTICAL AREA N
ST. ANTHONY
SPRINGDALE
INDIAN RIVER
NEWFOUNDLAND
STATISTICAL AREA K
ST. GEORGE'S BAY
LITTLE CODROY RIVER
KEY TO RIVERS
1. PINWARE
2. FORTEAU
3. ST. GENEVIEVE
4. CASTORS
5. BIG EAST
6. RIVER OF PONDS
7. HARRY'S
8. SOUTHWEST
9. FLAT BAY
10. FISCHELLS
11. ROBINSONS
12. BARACHOIS
13. CRABBES
14. HIGHLANDS
15. GRAND CODROY

Figure 5. Location of Western Arm Brook and St. Barbe Bay.

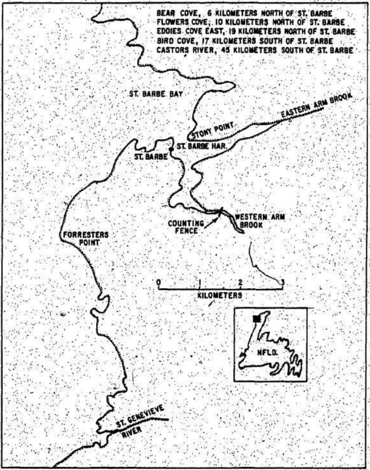

BEAR COVE, 6 KILOMETERS NORTH OF ST. BARBE
FLOWERS COVE, 10 KILOMETERS NORTH OF ST. BARBE
EDDIES COVE EAST, 19 KILOMETERS NORTH OF ST. BARBE
BIRD COVE, 17 KILOMETERS SOUTH OF ST. BARBE
CASTORS RIVER, 45 KILOMETERS SOUTH OF ST. BARBE
ST. BARBE BAY
EASTERN ARM BROOK
STONY POINT
ST. BARBE HAR.
ST. BARBE
COUNTING FENCE
WESTERN ARM BROOK
FORRESTERS POINT
0
1
2
3
KILOMETERS
NFLD.
ST. GENEVIEVE RIVER

Figure 6. Daily counts of smolt migration and daily temperature (0800 h) at Western Arm Brook 1971-1979. Temperatures above 13°C are shown as a horizontal line.

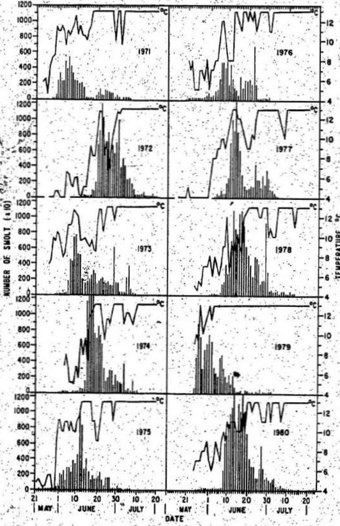

1971
1976
1972
1977
1973
1978
1974
1979
1975
1980
NUMBER OF SMOLT (x10)
TEMPERATURE °C
°C
MAY
JUNE
JULY
DATE

Figure 7. Counts of Alantic salmon smolts and parr at the fish counting fence on Western Arm Brook, 1971-1980.

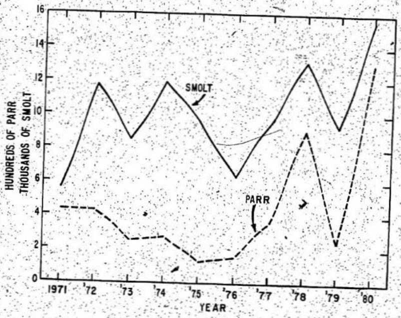

HUNDREDS OF PARR
THOUSANDS OF SMOLT
YEAR
SMOLT
PARR
0
2
4
6
8
10
12
14
16
1971
'72
'73
'74
'75
'76
'77
'78
'79
'80

Figure 8. Daily counts of Atlantic salmon smolts and parr at the fish counting fence on Western Arm Brook, 1977-1979.

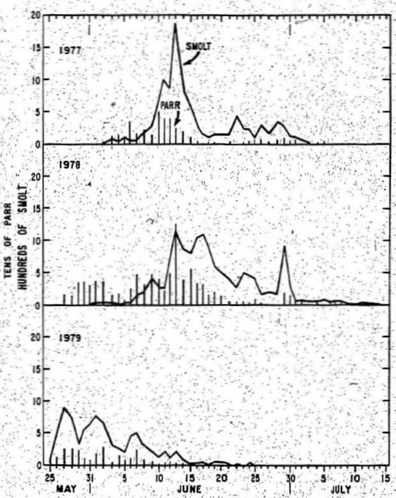

1977
SMOLT
PARR
1978
1979
TENS OF PARR
HUNDREDS OF SMOLT
0
5
10
15
20
25
31
5
10
15
20
25
30
5
10
15
MAY
JUNE
JULY

Figure 9. Frequency distributions of fork length, weight, condition and annual instantaneous growth rates for smolts at the three dominant smolt ages, for all years combined (1971-1980), Western Arm Brook.

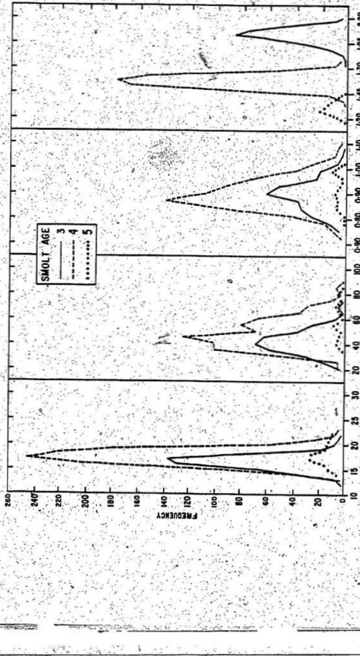

SMOLT AGE
3
4
5
FREQUENCY
FORK LENGTH (cm)
WEIGHT (g)
CONDITION FACTOR
ANNUAL GROWTH

Figure 10. Frequency distributions of fork length, weight and condition between years (1971-1980) for Atlantic salmon smolts sampled in Western Arm Brook.

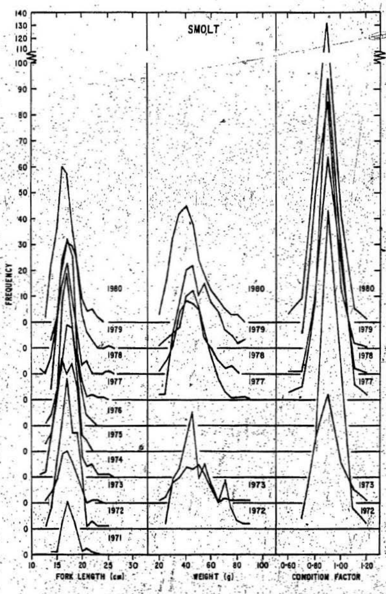
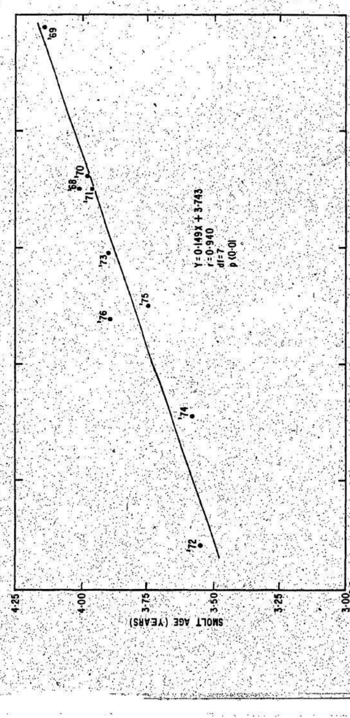

SMOLT
FREQUENCY
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1980
1979
1978
1977
1976
1975
1974
1973
1972
1971
10
15
20
25
30
40
60
80
100
0·60
0·80
1·00
1·20
FORK LENGTH (cm)
WEIGHT (g)
CONDITION FACTOR

Figure 11. Relationship between mean smolt age of a year-class of smolts in Western Arm Brook and mean annual air temperature in St. Anthony during the first year of life history of the year-class.



Y=0·149X + 3·743
r=0·940
df=7
p<0·01
SMOLT AGE (YEARS)
ANNUAL MEAN MONTHLY TEMPERATURE (°C)
'68
'69
'70
'71
'72
'73
'74
'75
'76

Figure 12. Fork length frequency distributions of Atlantic salmon parr sampled in riffle and outflow habitats in the late summer of 1978 and 1979 in Western Arm Brook.

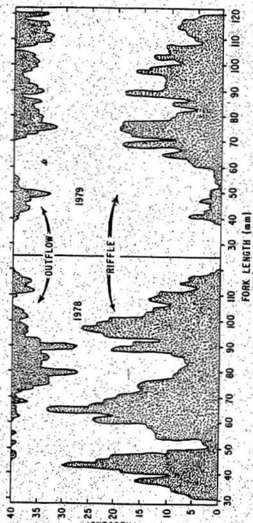

FREQUENCY
FORK LENGTH (mm)
OUTFLOW
RIFFLE
1978
1979
0
5
10
15
20
25
30
35
40
30
40
50
60
70
80
90
100
110
120

Figure 13. Relationship between Atlantic salmon parr biomass and salmonid (salmon and brook trout) biomass for stations sampled in Western Arm Brook, 1978-1979.

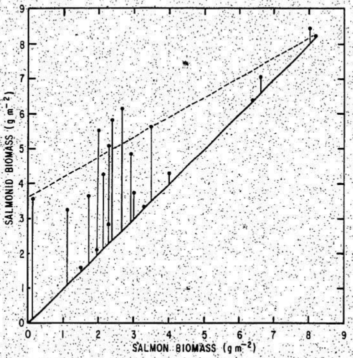
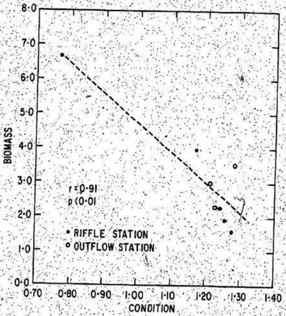

SALMONID BIOMASS (g m^{-2})
SALMON BIOMASS (g m^{-2})
0
1
2
3
4
5
6
7
8
9

Figure 14. Relationship between condition factor and biomass of Atlantic salmon parr sampled at riffle and outflow stations during late summer, 1979 in Western Arm Brook.



8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0·0
BIOMASS
r = 0·91
p (0·01
• RIFFLE STATION
o OUTFLOW STATION
0·70
0·80
0·90
1·00
1·10
1·20
1·30
1·40
CONDITION

Figure 15. Frequency distributions of fork length, whole weight and condition between years (1971-1980) for Atlantic salmon grilse sampled in Western Arm Brook.

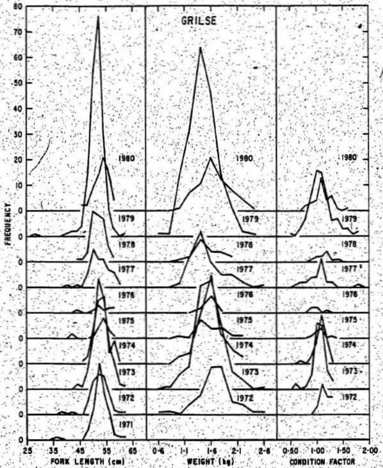
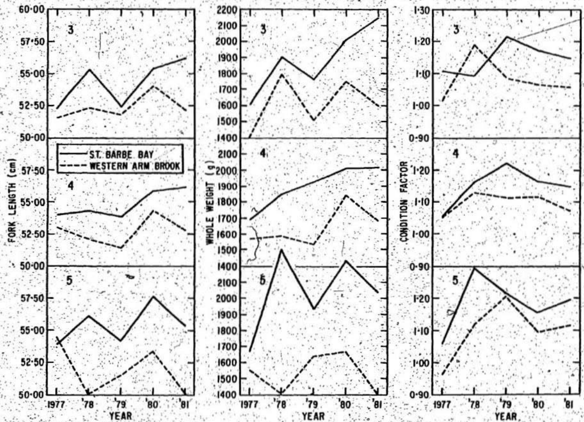

GRILSE
FREQUENCY
1980
1979
1978
1977
1976
1975
1974
1973
1972
1971
FORK LENGTH (cm)
WEIGHT (kg)
CONDITION FACTOR

Figure 16. Fork length, whole weight, and condition of 1SW salmon compared between the commercial fishery in St. Barbe Bay and Western Arm Brook for smolt ages 3+, 4+, and 5+ and years (1977-1981).



ST. BARBE BAY
WESTERN ARM BROOK
FORK LENGTH (cm)
WHOLE WEIGHT (g)
CONDITION FACTOR
YEAR
3
4
5

Figure 17. Fork length, whole weight, and condition of 1SW salmon compared between sexes for years (1977-1981) and locations (St. Barbe Bay and Western Arm Brook).

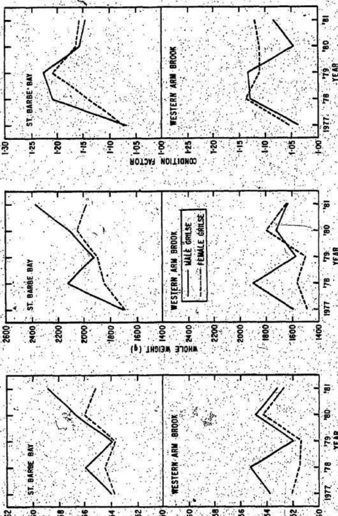

ST. BARBE BAY
WESTERN ARM BROOK
CONDITION FACTOR
1·30
1·25
1·20
1·15
1·10
1·05
1·00
WHOLE WEIGHT (g)
2600
2400
2200
2000
1800
1600
1400
MALE GRILSE
FEMALE GRILSE
FORK LENGTH (cm)
62
60
58
56
54
52
50
1977
'78
'79
'80
'81
YEAR

Figure 18. Mean smolt age and sex ratio compared between years for 1SW salmon sampled in St. Barbe Bay and Western Arm Brook and smolts sampled in Western Arm Brook in the previous years.

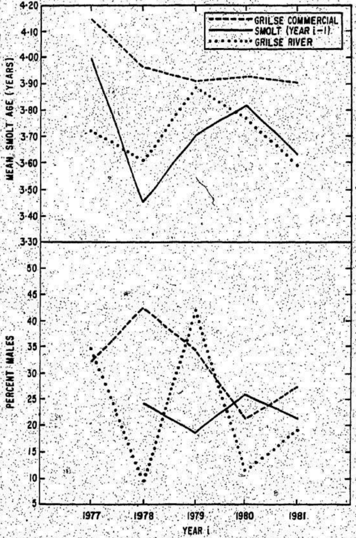

GRILSE COMMERCIAL
SMOLT (YEAR i-1)
GRILSE RIVER
MEAN SMOLT AGE (YEARS)
4·20
4·10
4·00
3·90
3·80
3·70
3·60
3·50
3·40
3·30
PERCENT MALES
50
45
40
35
30
25
20
15
10
5
1977
1978
1979
1980
1981
YEAR i

Figure 19. Numbers of 1SW salmon counted in Western Arm Brook (stipple) and 1SW salmon caught in the commercial fishery of St. Barbe Bay (bar graph) 1981.

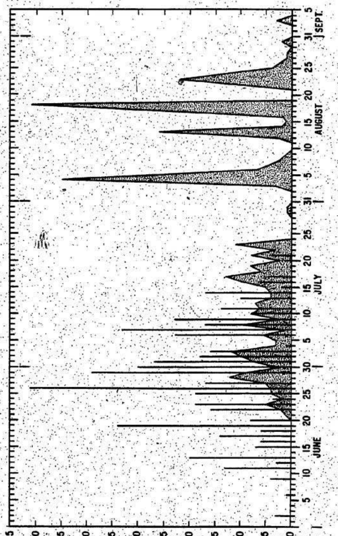
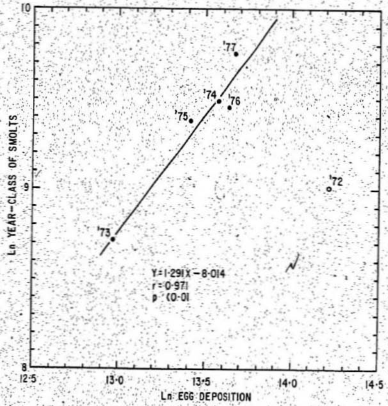

NUMBERS OF GRILSE
0
5
10
15
20
25
30
35
40
45
50
55
JUNE
JULY
AUGUST
SEPT.

Figure 20. Relationship between egg deposition and year-class strength as smolts in Western Arm Brook. Year-classes are indicated.



'77
'74
'76
'75
'72
'73
Y=1·291X − 8·014
r=0·971
p <0·01
10
9
8
12·5
13·0
13·5
14·0
14·5
Ln YEAR-CLASS OF SMOLTS
Ln EGG DEPOSITION

Figure 21. Egg to smolt survival for year-classes of Atlantic salmon in Western Arm Brook (1972-1977); discharge ratio on St. Genevieve River (1971-1980); and winter air temperature at St. Anthony (1971-1980).

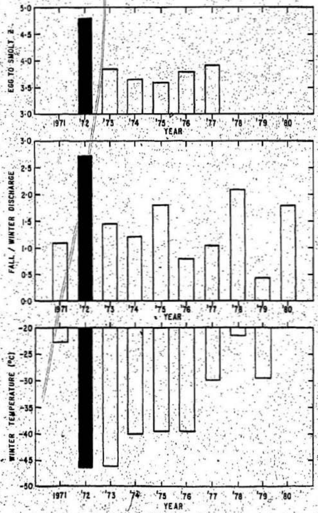

EGG TO SMOLT %
5·0
4·5
4·0
3·5
3·0
1971 '72 '73 '74 '75 '76 '77 '78 '79 '80
YEAR
FALL / WINTER DISCHARGE
3·0
2·5
2·0
1·5
1·0
0·5
0·0
1971 '72 '73 '74 '75 '76 '77 '78 '79 '80
YEAR
WINTER TEMPERATURE (°C)
-20
-25
-30
-35
-40
-45
-50
1971 '72 '73 '74 '75 '76 '77 '78 '79 '80
YEAR

Figure 22. Mean monthly discharge on St. Genevieve River (1970-1979) and mean monthly air temperature (January-May) for St. Anthony.

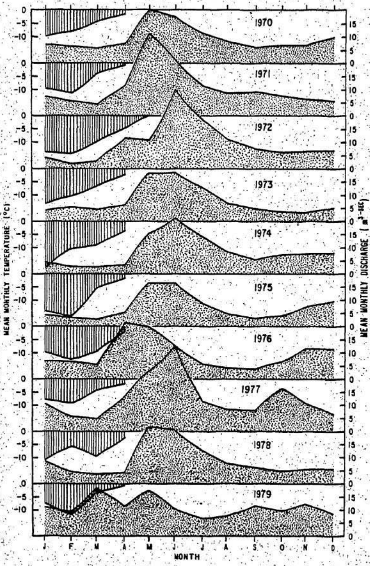

1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
MEAN MONTHLY TEMPERATURE (°C)
MEAN MONTHLY DISCHARGE (m³·sec⁻¹)
0
-5
-10
15
10
5
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

Figure 23. Location of 34 river systems in insular Newfoundland where samples of Atlantic salmon smolts were taken in 1973. The numbers refer to river names in Table 71.


1
2
3
4
5
6
7
8
9
10
11
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

Figure 24. Relationships between ovarian weight and an index of large salmon abundance for 34 rivers sampled in insular Newfoundland in 1973.

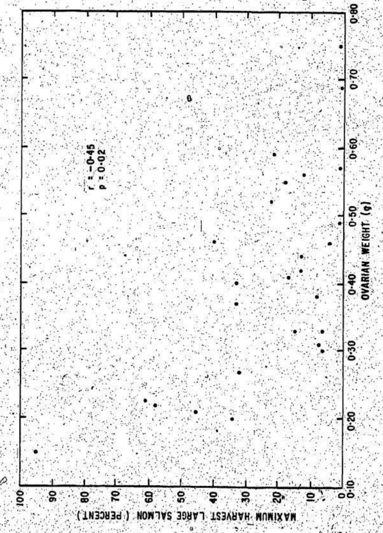

r = -0·45
p = 0·02
MAXIMUM HARVEST LARGE SALMON (PERCENT)
OVARIAN WEIGHT (g)
0·10
0·20
0·30
0·40
0·50
0·60
0·70
0·80
0
10
20
30
40
50
60
70
80
90
100

Figure 25. Frequency distributions of (a) mean fork length, (b) mean condition factor, (c) mean smolt age, and (d) percentage males for smolts sampled in 34 rivers of insular Newfoundland in 1973.

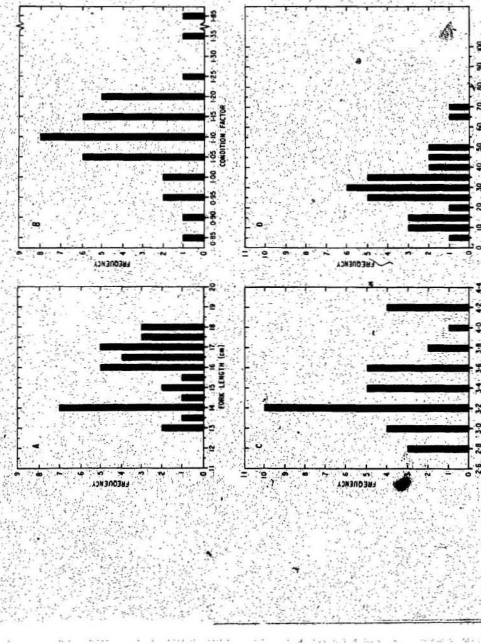
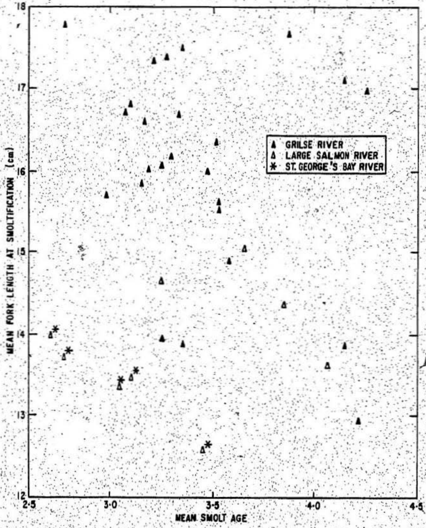
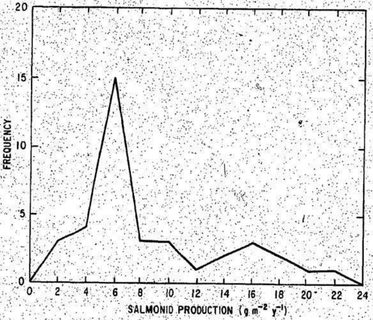

A
FREQUENCY
FORK LENGTH (cm)
B
FREQUENCY
CONDITION FACTOR
C
FREQUENCY
AGE (YEARS)
D
FREQUENCY
PERCENT MALE

Figure 26. Relationship between mean smolt age and mean fork length of smolts sampled in 34 rivers in insular Newfoundland in 1973. Rivers are identified as having large salmon or grilse stocks. Rivers in St. George's Bay are also indicated.



MEAN FORK LENGTH AT SMOLTIFICATION (cm)
MEAN SMOLT AGE
GRILSE RIVER
LARGE SALMON RIVER
ST. GEORGE'S BAY RIVER
18
17
16
15
14
13
12
2·5
3·0
3·5
4·0
4·5

Figure 27. Frequency distribution of salmonid production in 108 studies (unpub. data).



20
15
10
5
0
FREQUENCY
0
2
4
6
8
10
12
14
16
18
20
22
24
SALMONID PRODUCTION ($g\ m^{-2}\ y^{-1}$)

Figure 28. Fork length frequency distribution for Atlantic salmon parr and smolts in Western Arm Brook, 1979; smolts are indicated with dotted lines.

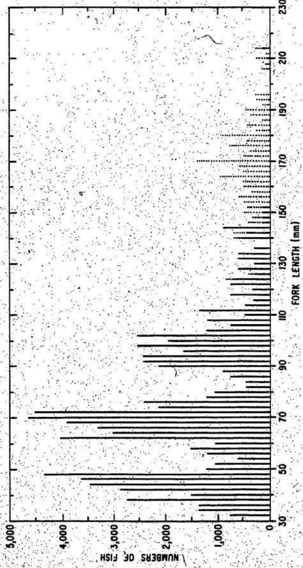

NUMBERS OF FISH
5,000
4,000
3,000
2,000
1,000
0
FORK LENGTH (mm)
30
50
70
90
110
130
150
170
190
210
230

Figure 29. Smolt age distribution and egg deposition requirements in the present Atlantic salmon stock in Western Arm Brook and the stock in a hypothetical unexploited state.

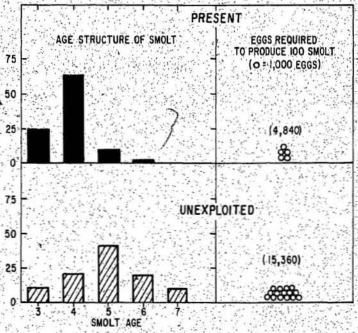

PRESENT
AGE STRUCTURE OF SMOLT
EGGS REQUIRED TO PRODUCE 100 SMOLT (o = 1,000 EGGS)
(4,840)
UNEXPLOITED
(15,360)
PERCENT
75
50
25
0
3
4
5
6
7
SMOLT AGE

Figure 30. A proposed relationship between freshwater production of Atlantic salmon and smolt age distribution of smolts in Western Arm Brook: A = current values, B = maximum values, and C = minimum smolt age structure.

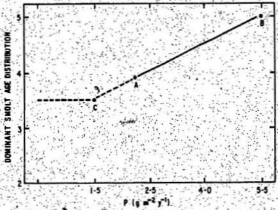

DOMINANT SMOLT AGE DISTRIBUTION
5
4
3
2
1·5
2·5
4·0
5·5
P (g m^{-2} y^{-1})
A
B
C

Figure 31. a) A proposed stock-recruitment relationship for Atlantic salmon in Western Arm Brook. b) A proposed yield to the fisheries assuming the above stock-recruitment relatationship: A = current values, B = maximum smolt age distribution, and C = minimum smolt age distribution.

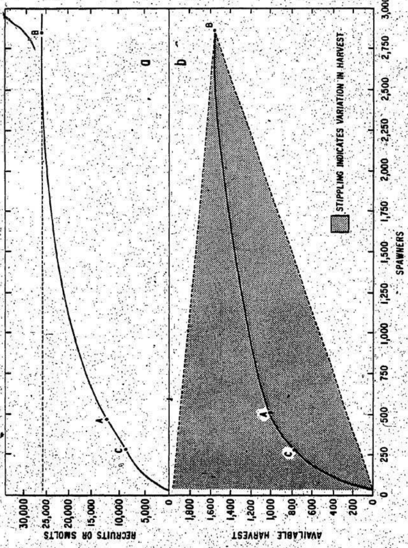

a
b
A
B
C
RECRUITS OR SMOLTS
0
5,000
10,000
15,000
20,000
25,000
30,000
AVAILABLE HARVEST
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
SPAWNERS
0
250
500
750
1,000
1,250
1,500
1,750
2,000
2,250
2,500
2,750
3,000
STIPPLING INDICATES VARIATION IN HARVEST

Figure 32. Commercial landings of Atlantic salmon for Atlantic Canada and West Greenland, 1910-1981; an eight-year moving average is also indicated.

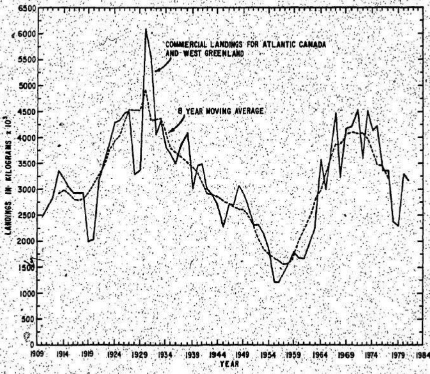

6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
LANDINGS IN KILOGRAMS x 10^3
COMMERCIAL LANDINGS FOR ATLANTIC CANADA AND WEST GREENLAND
8 YEAR MOVING AVERAGE
1909
1914
1919
1924
1929
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
YEAR

Figure 33. Percentage distribution of age at spawning for Atlantic salmon sampled in the commercial fisheries of insular Newfoundland in 1931 (Lindsay and Thompson 1932) and 1970 (Lear and May 1972).

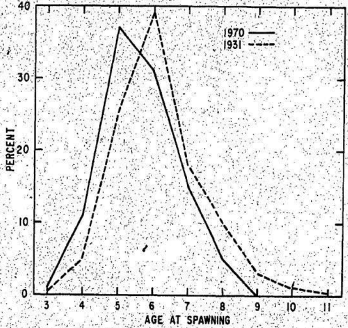
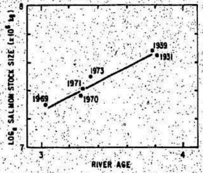

1970
1931
PERCENT
0
10
20
30
40
3
4
5
6
7
8
9
10
11
AGE AT SPAWNING

Figure 34. Relationship between smolt age and stock abundance for Atlantic salmon sampled in the commercial fisheries of insular Newfoundland, 1931-1973.


LOG$_e$ SALMON STOCK SIZE ($\times 10^6$ kg)
8
7
3
4
RIVER AGE
1969
1970
1971
1973
1939
1931