Abstract:

During spring/summer over a three-year period in the Western Brook river system, Newfoundland, studies were conducted to gain general knowledge of the biology, ecology, and behaviour of juvenile anadromous Atlantic salmon for future use in management and research of this species in the system. More specifically, several sampling techniques, including mark-recapture experiments, were used to study fish size, age structure, population size, timing of migration, and migratory behaviour of juveniles in the system. Special attention was given to the effects of the fjord lake (Western Brook Pond) on migration and growth. The potential impacts of marking juveniles for recapture was also studied in the hatchery and in the field and found to be small. Atlantic salmon smolt production for the Western Brook system was estimated at 7 500 – 11 000 smolts per year, with the majority of emigrants being aged 3 years. Delayed migration in the lake was accompanied by increased growth and a lack of schooling behaviour. The contribution by the lake to the overall rearing and production of juveniles in the system is large (30 – 50%).
Acknowledgements:

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I wish like to extend my deepest gratitude to the people of the town of Cow Head, NF, for their incredible hospitality. You became a home away from home.
# Table of Contents

<table>
<thead>
<tr>
<th>Abstract</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>iii</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>ix</td>
</tr>
</tbody>
</table>

Chapter 1 – The juvenile Atlantic salmon (*Salmo salar* L.) of the Western Brook Pond system: Introduction and overview  

References  

Chapter 2 – The survival, healing, fin regeneration and recapture success of Carlin tagged, fin clipped and dye injected juvenile Atlantic salmon (*Salmo salar* L.)  

Abstract  

Introduction  

Methods  

Hatchery Study  

Statistical Analyses  

Field Study  

Study Site  

Upstream Marking Site – Stag Brook  

Downstream Recapture Site – Western Brook  

Statistical Analyses  

Results  

Hatchery Study  

Mortalities due to Tagging  

Fork-Length and Condition Factors  

Tag Condition  

Fin Regeneration  

Temperature Regime  

Field Study  

Survival of Marking Treatment Groups  

Panjet Tattooed VS. Carlin Tagged Recapture Success  

Discussion  

Conclusions  

References
Chapter 3 – Migratory behaviour of Atlantic salmon (Salmo salar L.) smolts in a Newfoundland fjord lake

Abstract 39
Introduction 40
Study Site 43
Methods

1998 (sampling year 1)
Stag Brook 45
Western Brook Pond 48
Western Brook 49

1999 (sampling year 2)
Stag Brook 49
Western Brook Pond 50
Western Brook 51

2000 (sampling year 3)
Stag Brook 51
Western Brook Pond 52
Western Brook 53

Temperature Regimes 54
Aging of Scale Samples 54
Statistical Analyses 55

Results
Fish Movement
1998 57
1999 60
2000 64
Fork-Lengths and Condition Factors 68
Scale Aging Analysis 70
Temperature Regimes During Smolt Movement 73
Mark-Recapture Results
1998 (sampling year 1) 75
1999 (sampling year 2) 76
2000 (sampling year 3) 78

Lacustrine Growth of Recaptured Emigrants (2000) 80
Discussion 84
Conclusions 92
References 93

Chapter 4 – Estimates of Atlantic smolt production by the Western Brook Pond river system, Newfoundland

Abstract 97
Introduction 98
## Methods

- Electrofishing 101
- Counting Fence Operations 103
- Mark – Recapture
  - Upstream Marking Site – Stag Brook 104
  - Downstream Recapture Site – Western Brook 105
- Statistical Analyses 105

## Results

a) Estimate of Stag Brook and Western Brook smolt production using parr densities calculated from electrofishing data 106
b) Estimate of Western Brook Pond smolt production using fyke trap efficiency data 109
c) Estimate of 1997 Western Brook system smolt production using the number of migrating adult salmon captured in 1998 110
d) Estimate of 1998 Western Brook Pond system smolt production using the number of migrating adult salmon captured in 1999 112
e) Estimate of total smolt production using the total count of smolts exiting the system in 1999 through the fish fence 112
f) Estimate of smolts produced in Western Brook Pond in 1999 using the total count of smolts exiting the system in 1999 and 1998 parr densities of Stag Brook and Western Brook 112
g) Petersen estimate using mark-recapture data for the 2000 field season 113

## Discussion 113

## Conclusions 119

## References 120

### Chapter 5 – Summary and Conclusions

References 127
List of Tables

Chapter 2:

Table 2.1: Mean fork-length (cm) at the initiation ($T_0$), termination ($T_4$) of the marking experiment and the specific growth rate ($\% \cdot \text{day}^{-1}$) calculated at the end of the experiment (146 days) for each treatment group.  

Table 2.2: Number of individuals showing partial fin regeneration for each treatment group ($n = 28$), for each time period.

Chapter 3:

Table 3.1: Table showing the start of sampling, the start, peak, and end of the smolt run, the termination date of sampling, and the number of smolts and parr captured at each site on the Western Brook system (1998 – 2000).

Table 3.2: Table showing the start of sampling, the first and last captured, peak, the termination date of sampling, and the total number of parr captured and $< \text{and} \geq 9 \text{ cm size categories where applicable at each site on the Western Brook system (1998 – 2000).}$

Table 3.3: Mean fork-lengths ($\pm 1 \text{ SD}$), mean condition factors ($\pm 1 \text{ SD}$), for Atlantic salmon smolts caught at each sampling site on the Western Brook system over 3 years (1998 – 2000).

Table 3.4: Average, minimum, and maximum daily mean temperatures for Stag Brook, Western Brook Pond and Western Brook from May 26 – July 27 (duration of Western Brook system smolt migration), 1998 – 2000.

Table 3.5: Number of smolts captured, marked and recaptured during migration in Stag Brook (STB), Western Brook Pond (WBP) and Western Brook (WB), 1998 – 2000.

Table 3.6: Fork-length, migration time, distance traveled, and trip speed of emigrant Atlantic salmon smolts from time of marking in Stag Brook until the time of recapture at the outflow of Western Brook Pond for 1999 and 2000.
Table 3.7: Differences in fork-length, number of plus growth circuli and ratio of plus growth circuli length to total scale length $L_+ : L_{\text{tot}}$, migration time, and growth per day, between the time of marking in Stag Brook and the time of recapture at the outflow of Western Brook Pond, 2000.

Table 3.8: Differences in number of circuli, radius length of plus growth circuli, and circulus width for Atlantic salmon smolts between the time of marking in Stag Brook until recapture at the discharge of Western Brook Pond, 2000.

Chapter 4:

Table 4.1: Estimated Atlantic salmon smolt production derived from parr densities estimated from electrofishing Stag Brook and Western Brook from 1998 – 2000.

Table 4.2: Estimates of yearly smolt production created by electrofishing, enumeration and mark-recapture data for Stag Brook, Western Brook Pond, Western Brook, and the system as a whole.
List of Figures

**Chapter 2:**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Map showing the marking sites and the recapture site set on the Western Brook Pond river system in 2000.</td>
<td>18</td>
</tr>
<tr>
<td>2.2</td>
<td>Mean condition factor (+ 1 SD) for each treatment group at the initiation ($T_0$) and termination ($T_4$) of the marking experiment.</td>
<td>22</td>
</tr>
<tr>
<td>2.3</td>
<td>Difference in mean condition factor (+ 1 SD) for each treatment group between the initiation ($T_0$) and the termination ($T_4$) of the marking experiment.</td>
<td>23</td>
</tr>
<tr>
<td>2.4</td>
<td>Percentage of juvenile Atlantic salmon individuals with partially healed, totally healed, and worse or irritated Carlin tag wounds for each time period.</td>
<td>24</td>
</tr>
<tr>
<td>2.5</td>
<td>Fluctuations in daily mean water temperature and the number of degree-days during each time period for the duration of the marking experiment (336.7 degree-days).</td>
<td>28</td>
</tr>
</tbody>
</table>

**Chapter 3:**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Map showing the location of the Western Brook system including Stag Brook, Western Brook Pond and Western Brook.</td>
<td>44</td>
</tr>
<tr>
<td>3.2</td>
<td>Maps showing location of sampling sites in Stag Brook, Western Brook Pond and Western Brook (1998 – 2000).</td>
<td>46</td>
</tr>
<tr>
<td>3.3</td>
<td>Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook, Western Brook Pond, and Western Brook with daily mean water temperatures, 1998.</td>
<td>58</td>
</tr>
<tr>
<td>3.4</td>
<td>Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook, Western Brook Pond, and Western Brook with daily mean water temperatures, 1999.</td>
<td>61</td>
</tr>
<tr>
<td>3.5</td>
<td>Daily counts of Atlantic salmon parr captured at the discharge of Western Brook Pond, and the mouth of Western Brook with daily mean water temperatures, 1999.</td>
<td>63</td>
</tr>
<tr>
<td>3.6</td>
<td>Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook, Western Brook Pond, and Western Brook with daily mean water temperatures, 2000.</td>
<td>65</td>
</tr>
</tbody>
</table>
Figure 3.7: Daily counts of Atlantic salmon parr captured at Stag Brook (for size classes < 9 cm and ≥ 9 cm) and at the discharge of Western Brook Pond (all size classes), with daily mean water temperatures, 2000.

Figure 3.8: Frequency of smolts captured by age class for Stag Brook, Western Brook Pond and Western Brook from 1998 – 2000.

Figure 3.9: Percent of Atlantic salmon smolts captured at each sampling site during both halves of the smolt run that showed plus growth (1998 – 2000).

Figure 3.10: Daily mean water temperature readings taken from May 26 to July 28, 2000 at Western Brook Pond near the inflow of Stag Brook (WBPS), Western Brook Pond near its drainage by Western Brook (WBPD), and Stag Brook and the start (S), peak (P) and end (E) of smolt migration from Stag Brook.

Figure 3.11: Relationship between lake residence time and the day of the smolt run which an individual was marked in Stag Brook in 2000 showing y-intercept (a), slope (b) and adjusted R² value.

Chapter 4:

Figure 4.1: Map showing the Western Brook Pond river system and the location of fyke trap sampling sites, fish-counting fence, and electrofishing sites for 1999 – 2000.

Figure 4.2: Yearly changes in the density (number of fish per 100 m² + 1 SD) of Atlantic salmon parr aged ≥ 2 + years at electrofished sites on Stag Brook and Western Brook.
Chapter 1 – The juvenile Atlantic salmon (Salmo salar L.) of the Western Brook system: Introduction and overview

The Atlantic salmon (Salmo salar L.) is one of the most sought after species of fish in the world. This beautiful animal is desired both for its food quality and for the experience it gives to anglers. Atlantic salmon stocks have been reduced and put under stress due to industrial encroachment on spawning, nursery and rearing habitat in tandem with stresses caused by commercial fisheries. Consequently, the conservation of this species has become paramount. Atlantic Region National Parks are likely among the few refugia left where Atlantic salmon exist with limited anthropogenic effects and where genetically pure populations may still occur (Anonymous 1990).

The juvenile life stages of the anadromous Atlantic salmon are extremely important to the overall survival of the stock. The smolt stage is the last stage in the life cycle that can be censused or surveyed prior to exploitation by fishing. Quantifying the changes in smolt abundance and understanding the behaviour of this life stage can aid in management of the stock as a whole (Power 1985).

In May of 1998 the M. Sc. research project detailed herein was initiated to gain an understanding of the production, behaviour, and general biological characteristics of juvenile Atlantic salmon, most especially smolts, in the Western Brook system, Gros Morne National Park, Newfoundland.

The Western Brook system located in the north end of the National Park has been closed to angling since 1984. The mandate of the National Park is for conservation and
protection of species (Anonymous 1990). Conversely, provision of a complete outdoor experience is strived for by the park. Such an experience has included angling in the past, and therefore calls for the promotion of angling as an acceptable activity (Anonymous 1990).

Stag Brook and Western Brook have supported important recreational fisheries to the communities in their vicinity, especially Sally’s Cove, St. Paul’s and Cow Head. Recent pressures to reassess the closure of this system to fishing have surfaced. The results of this project may be instrumental in the building of management guidelines for this river system in the future.

During spring and summer from 1998 – 2000, a research program was initiated to gather data pertaining to the production, general biological characteristics, and migration of the Atlantic salmon of the Western Brook system. The general objective of this thesis project was to quantify and describe the general biology and migratory patterns of Atlantic salmon smolts of the Western Brook system. The more specific objectives of this study were: (1) to gain an understanding of the general biological characteristics and timing of migration for the Atlantic salmon smolts of the Western Brook system; (2) to ascertain if Atlantic salmon smolts from the upper reaches of this system travel to the sea in one migratory season; (3) to study the effects of the fjord lake, Western Brook Pond, on the migratory behaviour of the salmon smolts; and (4) to estimate the annual smolt production of the Western Brook system and decipher the separate contributions of Stag Brook, Western Brook, and Western Brook Pond.

Because of the use of mark-recapture techniques in the study, it was necessary to further assess utility of fin clips and the rates of fin regeneration (Armstrong 1947, Coble
1967, Johnsen and Unegal 1988), as well as the retention, and effect, of Carlin tags (Hansen 1988, Coombs et al. 1990) and Panjet tattoos (Kelly 1967, Hart and Pitcher 1969, Coombs 1990, Herbinger et al. 1990) to juvenile Atlantic salmon. As a result, experiments were performed to investigate fin regeneration and tagging mortality in a hatchery setting. The Panjet tattoo was used as an alternative mark to Carlin tagging during the 2000 field season. The relative survival and recapture success of Carlin tagged versus dye injected wild Atlantic salmon smolts was tested in the field. Chapter 2 presents and discusses the results from both complementary experiments, conducted in the hatchery and in the field, to assess the use of Carlin tagging, fin clipping and Panjet tattooing on Atlantic salmon smolts during their migration.

Chapter 3 presents results and conclusions pertaining to a mark-recapture experiment in which Carlin tags were used to gain information pertaining to the behaviour of Atlantic salmon smolts as they migrate through a large fjord lake, Western Brook Pond. The rate of growth in relation to lower temperatures experienced by Atlantic salmon smolts in the pond is also presented and compared to rates of growth in both estuarine and riverine environments. This chapter also reports on the general biological characteristics of Atlantic salmon parr and smolts in the system, such as timing of movement, size distributions, and age classes.

The intent of Chapter 4 was to estimate the number of smolts within the Western Brook system. Using several methods for estimating population size, the smolt production for the Western Brook system was predicted. The contributions to smolt production of the two tributaries and the large fjord lake of the system were also estimated. Estimates of smolt production provided by this study are intended as a starting
point for discussion pertaining to the viability of a recreational fishery on this system and the proposed increase in anthropogenic activity on Western Brook Pond.

References:


Chapter 2 – The survival, healing, fin regeneration and recapture success
of Carlin tagged, fin clipped and dye injected juvenile
Atlantic salmon (Salmo salar L.)

Abstract:

To ascertain the potential impact of a mark-recapture technique on juvenile Atlantic salmon (Salmo salar L.) in the wild, survival, healing, and fin regeneration associated with Carlin tagging and fin clipping were assessed in the hatchery environment. Wild Carlin tagged and Panjet tattooed Atlantic salmon smolts of the Western Brook river system, NW Newfoundland, were also compared for survival and incidence of recapture. Hatchery reared juveniles ranging from 12.0 – 20.8 cm (mean = 17.4 ± 1.5 cm) were marked with Carlin tags and anal, pelvic or caudal fin-clips. No mortality or tag loss was found and there was no significant difference in condition factor between marked and unmarked salmon, or among fish of different mark groups. In general, Carlin tag wounds began healing soon after being inflicted (within 28 days). However, this was followed by a period where the majority of wounds became irritated or showed a slowing of the healing process. Following this was a period of increased healing, which continued until the end of the experiment. Fin regeneration increased as the study progressed: caudal fins showed the first signs of regeneration; pelvic fins showed the greatest amount of regeneration by the end of the experiment (approximately 340 degree-days). Atlantic salmon juveniles with anal fin clips showed significantly less fin regeneration than those with pelvic or caudal fin clips. 185 Panjet tattooed (mean
fork-length = 12.0 ± 1.20 cm) and 167 Carlin tagged smolts (mean fork-length = 12.7 ± 1.17 cm) were held for 24 hours in the field to assess initial mortality that may have been caused by marking. A comparison of mark retention and the percent of smolts recaptured, for each mark type, was assessed at downstream recapture sites. Survival after marking was 97 % overall. Retention was 100 % for smolts marked and held for 24 hrs; none of the smolts captured showed evidence of tag loss. Recapture success was 6.0 % for Panjet tattooed smolts and 5.9 % for Carlin tagged individuals. The high survival and mark retention of all individuals, both in the hatchery and in the wild, coupled with the observed rate of fin regeneration, indicated that these marking techniques could be used safely in the field. The insignificant difference in recapture success of Carlin tagged and Panjet tattooed Atlantic salmon smolts may indicate the comparability of these marking techniques when used in the wild.
Introduction:

The use of external marks and tags has been important for the study of movement, abundance, age, growth, mortality and behaviour of aquatic organisms (McFarlane et al. 1990). In fact, the mutilation of fins and other bony parts for these purposes has been practiced for well over a hundred years (McFarlane et al. 1990). Each type of tag or mark has its inherent limitations. Important considerations to be made when deciding on the use of a particular type of mark or tag are the following: (1) length of time the mark must remain on the organism, (2) availability and experience of personnel for tagging and recovery, (3) life history information about the species, (4) methods used to capture the organism and the handling techniques which minimize stress, and (5) whether it will be necessary to coordinate the marking program with other scientists or organizations (Wydowski et al. 1983).

Carlin tags are typically classified as “dangling tags”, i.e., they dangle freely at the end of some form of attachment (McFarlane et al. 1990). Carlin tags have been used since the 1950’s for marking fish. The original tags were made out of steel and were fastened to the fish by passing steel wire through the body (Carlin 1955). Materials such as plastic and polyethylene monofilament have enabled this type of tag to become lighter and less invasive to the fish tagged. The unique number printed on each individual Carlin tag allows for the collection of life history data pertaining to each individual. The retention time of such tags has been shown to be as much as two years (Saunders et al. 1967, Hansen 1988). The relatively low loss rate (as low as 0 %, Hansen 1988, Kennedy et al. 1991) of these tags is offset by a large time commitment to mark
large numbers of fish. A second disadvantage is the risk of chronic wound problems associated with tags that protrude from the body (McFarlane et al. 1990).

Fin-clipping fish is a form of mutilation. Earlier studies indicated that little difference in growth and mortality were caused by fin mutilation (Armstrong 1947, Coble 1967). It does not appear to affect the sustained swimming ability of fish, but is not advisable to remove fins important in stabilization and propulsion, such as pectorals or caudals. The adipose fin is not known to regenerate whereas other fins do regenerate after mutilated. As a result, fin clipping is often used in short term (one field season) mark-recapture experiments (Wydowski et al. 1983). Coombs et al. (1990) clipped both adipose and pelvic fins of hatchery reared Atlantic salmon parr. The parr were held for three months (August – October) in outdoor holding tanks. Only 0.2 % of adipose fins showed signs of regeneration; conversely, 46.4 % of the individuals with left pelvic fin clips showed almost complete regeneration.

The fins of teleost fish (adipose fin excluded) are composed of structural units called rays. These rays are made segmented dermal bones called lepidotrichia. Rays are tapered distally by a group of actinotrichia, which are long rigid rods of a collagen-like protein called elasodin. Each lepidotrichial segment is made up of two hemisegments, which are joined by ligaments in a parenthesis-like structure. The whole structure is covered by a typical epidermis (Becerra et al. 1983). After clipping the fin, the stump of each ray regenerates by an epimorphic process. Restoration of the epidermis occurs first followed by blastema formation, cell proliferation and differentiation (Becerra et al. 1996).
There is evidence that the use of Carlin tags and fin clips on migrating smolts has a negative effect on survival for both wild and hatchery reared fish. Saunders et al. (1967) presented evidence that the percent of Atlantic salmon returning to the Miramichi River, New Brunswick, was lower for previously Carlin tagged or fin clipped smolts than non-marked individuals. The Carlin tags used in their study were tied with stainless steel wire and the fin clips used were adipose and left pelvic fin clips. The percentage of fin-clipped adults caught returning to the system was significantly higher than for tagged fish. In contrast, Hansen (1988) found that the rate of return of adults to the River Imsa, Norway, was similar for adipose fin clipped and Carlin tagged Atlantic salmon smolts. Some indication of a reduced growth rate between the smolt and grilse stages for tagged and fin-clipped was also presented. Hansen (1988) indicated that the higher mortality of Carlin tagged and fin-clipped individuals likely comes as a result of handling, anaesthesia and tagging. Kennedy et al. (1991) showed that wild migrating Atlantic salmon smolts fitted with modified Carlin tags were recaptured downstream with 83.6 % efficiency. The authors describe a river system that is sampled at 100 % efficiency at lower water levels (which was said to persist over the duration of their experiment). Therefore, the 16.4 % of smolts that were unaccounted for were assumed to have lost their tags, been misidentified, or died due to predation or handling stress.

Studies done in the hatchery environment have shown that tagging of smolts can increase mortality (Bergeron 1959). Furthermore, the size of smolts at the time of tagging has been positively correlated to survival (Isaksson and Bergman 1978). However, little difference in growth has been observed between Carlin tagged and non-
marked Atlantic salmon juveniles while in a hatchery environment (Bergeron 1959, Mills 1958).

A less intrusive method of marking fish is by injecting dyes into skin and fin rays. Kelly (1967) described the ideal dye marking technique as long lasting, permanent on every fish, non-toxic, non-irritating, and having no effect on normal growth. It should require little or no extra formulation, allow rapid marking, and be inexpensive. The ideal marking dye should also be non-encumbering (not interfere with normal swimming of feeding), easily observable to an untrained viewer, provide numerous combinations, and require a minimum of specialized equipment. Dyes are most often injected using a dental inoculator, which allows for a large number of fish to be marked in a relatively short period of time (Phinney et al. 1967), and often without anesthetizing the fish. The number of combinations possible using this type of marking technique is great. Many substances have been tested for Panjet tattoos, but Alcian Blue dye has been the most successful (Pitcher et al. 1977, Thedinga et al. 1995). This type of dye can persist for as long as 6 months in juvenile Atlantic salmon in hatchery conditions (Coombs et al. 1990). In the wild marks may be lost after as little as 2 months, yet retention can be as long as a year (Herbinger et al. 1990, Dussault et al. 1997). As with Carlin tags, jet-injected tattoos have been used extensively with salmonids (Coombs et al. 1990, Herbinger, 1990, Laufle et al. 1990, Thedinga et al. 1995, Dussault et al. 1997). The survival and recapture of Atlantic salmon smolts marked by Panjet tattoo has not been well discussed in the literature. However, parr of the same species have shown good survival and recapture rates (Dussault et al. 1997).
In 1999, a mark-recapture experiment was initiated on the Western Brook system of Gros Morne National Park. One of the goals of the project was to track and estimate the number of Atlantic salmon smolts in the different portions of the system. Taking into consideration the information outlined above, it was decided to evaluate modified Carlin tags and fin clips. Carlin tags were easy to use, available at a relatively low cost, and provided a means for uniquely identifying individual salmon smolts. Fin clips were used in tandem with the Carlin tags as a check for tag retention, because of the ease of application, and the short duration of the study (< 6 months). Panjet tattoos were administered in the field to assess if Carlin tagging was comparable to the technique of dye injection in the wild. Consequently, it was important that an experiment be initiated to assess the impact of Carlin tagging and fin clipping may have on the survival of Atlantic salmon smolts.

Specifically the purposes of the study were to:

1) Quantify mortality of salmon smolts due to tagging in the hatchery.

2) Quantify differences in growth between tagged and untagged individuals.

3) Record the rate of fin regeneration for the four different types of fin clips: anal, pelvic, and upper and lower caudal fin.

4) Quantify differences in growth among groups with different fin clips, and determine which fin clip would be the most recognizable in the field for the longest period of time.

5) Compare and assess short-term (24 h) mortality due to marking for the techniques of Carlin tagging and Panjet tattooing in the field.
6) Compare the recapture success of migrating smolts marked by either Carlin tag or Panjet tattoo over 3 months in the field.

7) Determine if Carlin tags were an acceptable mark for work in the wild.

Methods:

Hatchery Study:

The initial portion of the experiment was conducted at the Maqtaquac fish culture station, approximately 20 km north of Fredericton, New Brunswick. Atlantic salmon pre-smolts used in the study were 1 year old and supplied by the hatchery.

A tank with a volume of 5.4 m³ was prepared for holding the pre-smolts for the experiment. River water was fed into the tank from the Saint John River with enough pressure to create a counter-clockwise current in the tank. The depth of water in the tank was approximately 1.05 m. Pebbles and rocks of a variety of sizes were collected from the nearby riverbank and put into the holding tank to simulate riverbed conditions. A thermograph suspended in the tank logged temperatures every hour for the duration of the experiment.

On November 23, 1999, 140 Atlantic salmon parr ranging from 12.0 – 20.8 cm (mean = 17.4 ± 1.5 cm) were randomly picked out of a large rearing tank (approximately 25 at a time) and placed into a temporary holding tub (volume = 0.12 m³). They were then anesthetized in a 40 parts per million clove oil bath. Each individual was measured for fork-length (cm) and weight (g), and 112 individuals were fitted with an individually numbered (7 mm) Carlin tag. This was accomplished by passing two syringe needles
through the dorsal musculature of the fish just ventral to the dorsal fin so as to pass between the internal fin rays. Monofilament line was then threaded through the needles and out the other side of the body of the fish. The line was then tied with surgical knots and excess line was clipped off with scissors. Each of the 112 Carlin tagged fish was also given a fin clip with scissors. The remaining 28 parr were not marked for later comparison to marked individuals. The type of fin clip that was administered produced five treatment groups, each with 28 salmon parr, as follows:

1) **Control group** – no marks were given to these fish, however they were anesthetized and measured.

2) **Tag + AFC** – each fish was Carlin tagged and given an anal fin clip (AFC).

3) **Tag + LPFC** – each fish was Carlin tagged and given a left pelvic fin clip (LPFC).

4) **Tag + UCFC** – these fish were Carlin tagged and given upper caudal fin clips (UCFC)

5) **Tag + LCFC** – these fish were Carlin tagged and given a lower caudal fin clip (LCFC).

All individuals were placed into a recovery tank (volume = 1.8 m$^3$) directly after marking. Once recovered (after 5 – 7 minutes), parr were transferred to the empty holding tank with river substrate. After all 140 fish were in the holding tank, it was covered with wood and steel grating to prevent fish from jumping out. This date (Nov. 23 / 99) was recorded as the starting time ($T_o$). The salmon were then left in
their new environment. They were manually fed standard pellet food four times daily at an amount of 5 % of their body weight per day.

Twenty-one days later on December 22 ($T_1$) fish were sampled to observe occurrences of mortality and determine the condition of the marked salmon. The experimental fish were transferred from their holding tank to a temporary holding tub (volume = 0.12 m$^3$). Each tagging wound and fin clip was examined for healing and regeneration, respectively. All fish were then placed into a recovery tank (volume = 1.8 m$^3$) until the experimental holding tank (with substrate) was cleaned, after which fish were returned to the larger cleaned tank.

An index system was used to quantify the state of the tagging wound and the percent of regeneration associated with the fins, as follows:

**Tag Condition (relative to initial tagging):**

0 = no visible change to the wound
1 = tag intact and the wound partially healed
2 = tag intact and the wound totally healed
3 = tag intact, but the wound is worse or irritated
4 = tag missing, and the wound is partially healed
5 = tag missing, and the wound is totally healed
Fin Regeneration:

0 = none
1 = ≤ 10 % of total fin regenerated
2 = > 10 % and ≤ 25 % of total fin regenerated
3 = > 25 % regeneration

This same protocol was followed to assess tag condition and percent fin regeneration at T₁ (21 days post tagging), T₂ (day 54), T₃ (day 90), and T₄ (day 146).

At day 146, all individuals were again measured for fork-length and weight as well as observed for tag and fin condition. Once this information was recorded the Atlantic salmon, now fully developed smolts, were freed into the Saint John River system. The thermograph was recovered and the daily mean water temperatures were used to calculate degree-days.

Statistical Analyses:

A comparison of initial mean fork-length for each treatment group was done by one-way analysis of variance (ANOVA) and followed by Duncan’s multiple range test. The same type of statistical test was used to compare the relative change in length of the juvenile Atlantic salmon from the start to the end of the experiment for each fin clip group. The specific growth rate of each individual was calculated after 146 days. The mean specific growth rate (% • d⁻¹) was compared for each treatment group by one-way ANOVA. Initial (T₀) condition factors as well as condition factors after 146 days (T₄)
were calculated for each individual using the formula: $C_f = \left[ \frac{\text{Weight}}{(\text{Length})^3} \right] \cdot 100$ (Lundqvist et al. 1988). A one-way ANOVA was also used to compare the mean condition factors of each treatment group at the start and the end of the study, and also the difference in mean condition factor between $T_0$ and $T_4$ for each group.

A Chi-square test was used to test for differences between treatment groups in respect to the amount of fin regeneration, for each time period. Differences in tag wound condition were analyzed with a Chi-square test. The frequency of fish showing a particular degree of tag wound healing versus time period was analyzed.

Field Study:

Study Site:

The Western Brook system ($49^\circ 44'\ N, 57^\circ 46'\ W$) has a catchment area of 171.2 km$^2$. Western Brook Pond is an ultraoligotrophic fjord lake that has a mean depth of 72.5 m and a maximum depth of 165 m (Kerekes 1994). Stag Brook, located at the southwestern end of the lake, is the largest tributary entering the lake and is the only tributary accessible to anadromous salmon upstream of the lake. Western Brook Pond is drained by Western Brook at its northwestern end. Western Brook flows for approximately 9 km before emptying into the Gulf of St. Lawrence (Figure 2.1).
Figure 2.1: Map showing the marking sites and the recapture site set on the Western Brook Pond river system in 2000.

**Upstream Marking Site – Stag Brook:**

Two fyke traps with 18 mm mesh size were set in Stag brook approximately 2 km upstream of where the brook empties into Western Brook Pond on May 26, 2000 (Figure 2.1). The traps were fitted with wooden boxes at their cod ends. The smolt-boxes were constructed of plywood and were 60 cm X 120 cm X 30 cm. A square funnel (15 cm X 15 cm X 90 cm) was fitted through the front of the rectangular box and created a passage from the fyke trap’s cod end into the box. The boxes were submerged by the flow so that the top, which bore a door, was at the surface. Boxes reduced mortality by creating an area less penetrable by outside predators, and more especially by acting as a sanctuary from high velocities that can lead to fatigue and death for smolts crowded into the cod end of a fyke trap. Smolts caught in the traps were anesthetized using a 40 ppm
clove oil bath (Anderson et al. 1997, Keene et al. 1998) and measured for fork-length and weight.

Using a Panjet dental inoculator, a number of smolts were given 2 % Alcian Blue tattoos (Hart & Pitcher 1969). The tattoos were applied to the ventral surface, just anterior to the pelvic girdle. This location was picked due to its lack of pigmentation so that the mark was easily discernible. The marks appeared as a blue dot on the white belly.

The alternate mark was an individually numbered Carlin tag. The green plastic, 7 mm tags were attached just anterior of the dorsal fin with double polyethylene monofilament thread.

All individuals were marked with an anal fin clip (AFC) to create a check on tag or tattoo loss. Individuals that were marked were put in a 85 cm X 110 cm rectangular wood and plastic screen live trap that was sunk and anchored close to the centre of a flat/pool about 50 m downstream of the Stag Brook capture site. The trap was covered with plywood for cover from predators and exposure to the sun. The marked smolts were held for 24 hours to observe mortalities due to marking.

**Downstream Recapture Site – Western Brook:**

Four fyke traps were placed in the river on June 14, 2000. On June 21 a fifth fyke trap was added to increase the volume of flow sampled. The fyke traps were positioned approximately 440 m downstream from Western Brook Pond at a widening of the river. Approximately 5 km were traveled by smolts marked in Stag Brook and recaptured at the drainage of Western Brook Pond (Figure 2.1). Water velocities were
taken at this site on July 15 to ascertain the percent discharge sampled by the fyke trap
sampling regime at this site. A 6th fyke trap was set approximately 300 m upstream from
the main recapture site on Western Brook. Smolts were captured and marked there for the
assessment of trap efficiency at the recapture site 300 m downstream (Figure 2.1).
Efficiency trap recaptures were anesthetized with 40 ppm clove oil (Anderson et al. 1997,
Keene et al. 1998) and re-measured for length and weight.

**Statistical Analyses:**

The mean fork-length (cm) of Panjet tattooed and Carlin tagged smolts that were
held for 24 hrs was compared by student t-test. The same test was used to analyze
differences in fork-length (cm) of tattooed versus tagged smolts that were recaptured at
Western Brook. Chi-square analysis was used to compare the frequency of individuals
that were recaptured at Western Brook for each of the two mark types administered in
Stag Brook.
Results:

Hatchery Study:

Mortalities due to Tagging:

All fish that were anesthetized, handled, and tagged (n = 112) recovered and survived for the duration of the experiment (146 days).

Fork-Length and Condition Factors:

The Duncan’s multiple-range test indicated that the mean fork-length of salmon pre-smolts at the beginning of the experiment (T₀) was significantly different among treatment groups. The mean fork-length of the lower caudal fin clip (LCFC) and control (CONT) treatment groups were significantly greater than for the anal fin clip (AFC) treatment group \( P < 0.05 \) (Table 2.1).

Table 2.1: Mean fork-length (cm) at the initiation (T₀), termination (T₄) of the marking experiment and the specific growth rate (\% • day⁻¹) calculated at the end of the experiment (146 days) for each treatment group.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Length at T₀ (cm)</th>
<th>Length at T₄ (cm)</th>
<th>Specific Growth Rate (% • day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT</td>
<td>28</td>
<td>17.6 ± 1.3</td>
<td>19.4 ± 1.3</td>
<td>0.67 ± 0.02</td>
</tr>
<tr>
<td>LCFC</td>
<td>28</td>
<td>17.9 ± 1.3</td>
<td>19.6 ± 1.3</td>
<td>0.69 ± 0.02</td>
</tr>
<tr>
<td>LPFC</td>
<td>28</td>
<td>16.9 ± 1.9</td>
<td>18.5 ± 2.1</td>
<td>0.68 ± 0.02</td>
</tr>
<tr>
<td>AFC</td>
<td>28</td>
<td>17.3 ± 1.2</td>
<td>18.9 ± 1.2</td>
<td>0.69 ± 0.02</td>
</tr>
<tr>
<td>UCFC</td>
<td>28</td>
<td>17.5 ± 1.2</td>
<td>19.1 ± 1.0</td>
<td>0.69 ± 0.02</td>
</tr>
</tbody>
</table>
The specific growth rate was not significantly different between treatment groups ($P > 0.05$). All treatment groups showed a similar percent increase in length (approximately 0.7 % • day$^{-1}$) during the experiment (Table 2.1).

Figure 2.2 shows the mean condition factors by treatment group at the start ($T_0$) and end ($T_4$) of the experiment. Although slight differences were observed among treatment groups within one period, there was no statistical significance at either $T_0$ or $T_4$ ($P > 0.05$). Furthermore, the mean difference in condition factor between the initiation and termination of the experiment ($C_f$ at $T_0$ – $C_f$ at $T_4$) was not significant among treatment groups ($P > 0.05$)(Figure 2.3).

![Figure 2.2: Mean condition factor (+ 1 SD) for each treatment group at the initiation ($T_0$) and termination ($T_4$) of the marking experiment.](image-url)
Although the treatment groups did not show a statistically significant difference in the mean difference in condition factor ($C_f$ at $T_0$ – $C_f$ at $T_4$), Figure 2.2 shows an overall decrease in condition factor for all groups from the start of the experiment ($T_0$) to the termination ($T_4$). The mean condition factor at $T_0$ for all fish was $1.24 \pm 0.10$, which was significantly greater than the mean condition factor at $T_4$ of $1.08 \pm 0.06$ ($P < 0.001$).
**Tag Condition:**

Chi-square analysis showed a significant difference in the frequency of juvenile Atlantic salmon with a particular degree of tag wound healing over time.

After 21 days ($T_1$), the majority (61.6 %) of juvenile Atlantic salmon showed partial healing of their Carlin tag wounds. A smaller percentage (24 %) of individuals showed almost total healing of their tag wounds. A small percentage (13.4 %) had wounds that appeared more irritated than when initially caused through tagging (Figure 2.4). These fish most often displayed wounds that were chaffed by rubbing of the monofilament line on the body, or inflammation of the needle puncture wounds.

![Figure 2.4: Percentage of juvenile Atlantic salmon individuals with partially healed, totally healed, and worse or irritated Carlin tag wounds for each time period.](image)

Figure 2.4: Percentage of juvenile Atlantic salmon individuals with partially healed, totally healed, and worse or irritated Carlin tag wounds for each time period.
After 54 days ($T_2$), many of the individuals that had showed partial to full healing of tagging wounds at $T_1$ now had wounds that were worse or irritated. Fish with worse or irritated wounds accounted for 45.5 % of all tagged individuals. The percentage of tagged juvenile Atlantic salmon showing full healing increased slightly from $T_1$ to $T_2$ (24 % to 28.6 %). The percentage of individuals with partial healing of tagging wound decreased to 25.9 % after 54 days, down 35.7 % from $T_1$ (Figure 2.4).

After 90 days ($T_3$), 50 % of the Carlin tagged salmon had wounds that were worse or irritated compared to when initially tagged. This number increased from $T_2$ as the number of juveniles showing total healing decreased by 5.4 % from $T_2$ (28.6 % to 23.2 %). The number of salmon pre-smolts with partially healed tag wounds increased slightly (from 25.9 % in $T_2$ to 26.8 % in $T_3$)(Figure 2.4).

After 146 days ($T_4$) the majority (45.5 %) of Atlantic salmon juveniles had totally healed tag wounds. The percentage of fish with worse or irritated wounds dropped by 11.6 % (from 50 % in $T_3$ to 38.4 % in $T_4$) and the percent of fish with partially healed wounds dropped by 10.7 % (from 26.8 % in $T_3$ to 16.1 % in $T_4$) (Figure 2.4). These fish with irritated or partially healed wounds in $T_3$ experienced an increase in tag healing during the 56 days between their inspection at $T_3$ and the termination of the experiment.
Fin Regeneration:

Virtually no fin regeneration had occurred by day 54 ($T_2$). Only two individuals in the upper caudal fin clip group and two individuals in the lower caudal fin clip group showed fin regeneration after 54 days. Fin regeneration was evident by day 90 ($T_3$) in all treatment groups (Table 2.2).

Table 2.2: Number of individuals showing partial fin regeneration for each treatment group (n = 28 per group), for each time period.

<table>
<thead>
<tr>
<th>Group</th>
<th>% Regeneration</th>
<th>$T_1$ (day 21)</th>
<th>$T_2$ (day 54)</th>
<th>$T_3$ (day 90)</th>
<th>$T_4$ (day 146)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCFC</td>
<td>0</td>
<td>28</td>
<td>26</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>≤ 10</td>
<td>0</td>
<td>2</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>&gt; 10 and ≤ 25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>UCFC</td>
<td>0</td>
<td>28</td>
<td>26</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>≤ 10</td>
<td>0</td>
<td>2</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>&gt; 10 and ≤ 25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>LPFC</td>
<td>0</td>
<td>28</td>
<td>28</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>≤ 10</td>
<td>0</td>
<td>0</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>&gt; 10 and ≤ 25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>AFC</td>
<td>0</td>
<td>28</td>
<td>28</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>≤ 10</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>&gt; 10 and ≤ 25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

The number of individuals showing ≤ 10 % fin regeneration was significantly lower for the anal fin clipped group than all other groups ($P < 0.001$). Approximately two-thirds of the anal fin clipped individuals continue to show no fin regeneration (Table 2.2).
By the end of the experiment (146 days), the anal fin clip group showed a statistically significant difference in the number of individuals with a more advanced degree of fin regeneration ($P < 0.001$). Only 2 individuals (7%) show $> 10$ and $\leq 25\%$ regeneration and 50% (14 individuals) show $\leq 10\%$ regeneration. However, a large proportion (43%) of individuals in the anal fin clip treatment group showed no fin regeneration (Table 2.2), more so than any other group.

The upper and lower caudal fin clip groups showed approximately 45% of individuals with $> 10$ and $\leq 25\%$ fin regeneration. The group with the greatest degree of fin regeneration was the left pelvic fin clip group. 17 of 28 juvenile salmon showed close to 25% fin regeneration by the end of the experiment (Table 2.2).

**Temperature Regime:**

The daily mean water temperature in the holding tank decreased from $T_1$ to the end of $T_3$. The daily mean temperature reached its low ($0.6\, ^\circ C$) during $T_4$ (March 2 – 8), after which it increased at a relatively rapid rate for the remainder of this time period (Figure 2.5).
Figure 2.5: Fluctuations in daily mean water temperature and the number of degree-days during each time period for the duration of the marking experiment (336.7 degree-days).

As the daily mean temperature, and therefore degree-days, increased during T\(_3\) and T\(_4\) the number of juvenile Atlantic salmon with >10 % fin regeneration also increased. The greatest number of individuals with >10 % fin regeneration was observed at T\(_4\) during which temperatures significantly increased compared to the previous time periods.

As the daily mean temperature decreased during T\(_1\), the partial healing of tag wounds was high. However, as lower water temperatures persisted over T\(_2\) and T\(_3\) an increase in individuals with wounds that were worse or irritated, and a reduction in the number of partially or totally healed wounds occurred. As the temperature increased during T\(_4\), the number of fish with irritated wounds decreased and those with totally healed wound increased (Figures 2.4, 2.5).
Field Study:

Survival of Marking Treatment Groups:

352 Atlantic salmon smolts were marked with Panjet or Carlin tag at Stag Brook and held for 24 hr. As stated earlier, the type of tag applied at the main marking site in Stag Brook was random. The size of fish was not a deciding factor on the type of mark used. The mean fork-length of smolts marked with Carlin tags and held for 24 hrs was 12.7 ± 1.4 cm, while the mean fork-length of tattooed smolts was significantly smaller ($P < 0.05$) at 12.0 ± 1.2 cm. The total number of mortalities after handling and marking was 9 smolts (2.6 %). The number of smolts that were marked with Carlin tags was 167; 6 (3.6 %) of these died, all before being placed in the live trap. The number of smolts marked with Panjet tattoo was 185; 3 (1.6 %) of these died, all after spending some time in the live trap.

Panjet tattooed VS. Carlin Tagged Recapture Success:

Before describing the mark-recapture data, it would be prudent to discuss the efficiency of recapture at the trap site. Velocity measurements were taken at the Western Brook Pond recapture site on July 15. The total instantaneous discharge calculated from these measurements was 7.48 m$^3$/s. The five traps in the brook at this site sampled 4.31 m$^3$/s for 57.6 % of the discharge sampled by the nets. Of the 33 smolts marked at the efficiency fyke trap, only 4 were recaptured 300 m downstream at the Western Brook capture site (12 %).
In total, 469 migrating Atlantic salmon smolts were caught and marked in Stag Brook. The total number of recaptures was 28, giving an overall recapture rate of 6.0 %. Of the 182 smolts given Panjet tattoos, 11 were recaptured at the Western Brook Pond recapture site for a recapture percentage of 6.0 %. 17 of the 287 individuals given Carlin tags were recovered for a recapture percentage of 5.9 %.

Discussion:

All of the juvenile Atlantic salmon that were tagged in the hatchery survived the tagging procedure and went on to survive and retain their tags for the duration of the experiment, indicating that the technique of Carlin tagging can be successful in terms of tag retention and the survival of those marked in hatchery conditions. The lack of a significant difference between treatment groups in terms of increased fork-length in this study corroborated previous evidence that indicated that Carling tagging and fin-clipping have a small effect on growth (Mills 1958, Armstrong 1947, and Cobble 1967).

The rate of survival for the first 24 hrs after marking was high (96.4 %) for wild Atlantic salmon smolts of the Western Brook system. Such a survival rate indicates that Carlin tagging, if executed by experienced markers, can be as successful on the short-term in the field as in the hatchery environment.

The reduction in mean condition factor observed from the start of the hatchery experiment to the end was likely due to the smoltification of the juveniles and not an effect of marking. Initially, the salmon tagged were classified as parr. However, as the experiment progressed the fish assumed smolt characteristics such as darkening of fins
and body silvering (Wedemeyer et al. 1980). Condition factors ranging from 1.20 to 1.40 are expected for hatchery-reared parr/pre-smolts (Saunders et al. 1998, Handeland et al. 2001). The mean condition factor of the parr used in this study was 1.24 ± 0.10 which is well within the range described by previous studies. Atlantic salmon smolts may have condition factors < 1.00 and as great as 1.25. The reduction in condition factor in Atlantic salmon juveniles is accompanied by an increase in Na\(^+\)-K\(^+\) ATPase activity, and as a result is considered a good indication of smoltification (Saunders et al. 1998, Specker et al. 2000, Handeland et al. 2001).

The fin regeneration data suggest that fin regeneration is slow in cold water, which was expected. Regeneration was directed towards fins that were used for propulsion and stability in swimming. Both the upper and lower caudal fin clip groups showed the earliest signs of regeneration, and the left pelvic fin clip treatment group showed the greatest percent of individuals (60.7 %) with >10 and ≤25 % fin regeneration at T\(_4\). The anal fin clip treatment group showed significantly less fin regeneration. This fin is of less functional importance as it does not supply stability or propulsive force (Webb 1975). Therefore, the anal fin appears to be most suitable for clipping purposes. This does not agree with findings by Johnsen & Ugedal (1988) who concluded that anal fin clips were not good for long-term studies with brown trout (Salmo trutta L.) due to faster regeneration of anal fins compared to various other clipped fins. The adipose fin of salmonids has been shown to regenerate slower than other fins and therefore provides a desirable method of marking (Johnsen & Ugedal 1988, Stuart 1958). Adipose clips were not used in the field during this study in an effort to reduce the
probability of misidentifying marked individuals. The hatchery experiment did not include an adipose fin clipped treatment group since this mark was not used in the field.

The duration of the hatchery experiment was 146 days and a total of 336.7 degree-days. The low temperatures in the hatchery over the winter likely created a slow growth period. On the Western Brook Pond river system smolts were marked at Stag Brook between May 23 and May 27 (1998-2000). Recapture efforts on the system terminated on July 31 in each year. The mean number of days that could have elapsed between marking and the termination of recapture sampling was 68 days. The mean number of degree-days for this time is 937. Approximately 600 more degree-days were experienced in the wild during sampling compared to the duration of the hatchery experiment. However, it seems unlikely that in the Western Brook system fin regeneration would occur at a rate fast enough to make marked individuals unrecognizable over the 2 month field season.

During \( T_0 - T_1 \) tag wound healing began for most individuals, as partial healing was diagnosed for many. However, as time progressed, irritation increased. This is likely due to an increase in the duration of time that friction between tag and tank, or more importantly the monofilament and the external body surface of the fish, was endured.

All Carlin tagged wild smolts died soon after tagging. Hansen (1988) concluded that mortality associated with Carlin tagged smolts released for subsequent recapture was due to the handling and anesthetizing associated with marking. The findings of this study
agree, however the mortality rate of Carling tagged individuals after one day was not directly assessed.

Three Panjet tattooed smolts died during some point in the 24 hr holding period (98.4% rate of survival). No individual marked this way died before being placed in the live trap. Herbinger et al. (1990) and Laufle et al. (1990) recommended that ink-jet tattoos be applied to the base of pectoral and pelvic fins only on fish with fork-lengths longer than 100 mm. Cases of piercing the ventral surface of smaller juvenile Atlantic salmon were described by Dussault et al. (1997). Although Panjet tattoos were applied on the ventral surface of the smolts in this study, most fish marked were greater than 100 mm in fork-length and no piercing was observed. The white “bellies” of the smolts created good visual relief for the Alcian Blue tattoos. Ink tattoos placed on fins of smolts may be difficult to see since during smoltification the fins of juvenile Atlantic salmon may become quite darkened (Wedemeyer et al. 1980).

No significant difference in initial (24 hr) mortality was found between Atlantic salmon smolts marked by Carlin tag or Panjet tattoo in the field. The stress associated with Panjet tattooing smolts is likely less due to reductions in the handling, anesthetization, and marking times compared to Carlin tagging.

The success of recapture for both Carlin tagged and Panjet tattooed smolts provided a means to compare the survival of smolts with each mark type after a 24 hr holding period in the wild. The lack of significant difference in recapture success indicates that survival of smolts marked by Panjet tattoo is not significantly greater than that of Carlin tagged individuals. Therefore, Carlin tagging does not seem inferior as a marking technique to dye injection on the short-term in the field. However, Carlin
tagging with individually numbered tags allows for the accumulation of data on individuals smolts. This advantage was important in the research carried out on the Western Brook river system when the individual migratory behaviour of Atlantic salmon smolts was observed (Chapter 3). Individuals can be identified using tattoos by giving each smolt a unique tattoo configuration. However, this is tedious and requires substantial planning. Dussault et al. (1997) reported as much as a 11% loss of dye injected marks after four weeks and an increase in mortality with an increase in the number of marks applied. Over two months (the duration of this study) the loss of marks would result in the significant loss of data pertaining to individual smolts.

**Conclusions:**

Carlin tagging presented a relatively low threat of initial mortality both in hatchery conditions and in the wild. Short-term survival (5 months) of Carlin tagged
smolts was 100% in the hatchery, and was likely similar to that of Panjet tattooed smolts in the wild, as represented by similar recapture success for the two mark types.

Tagged hatchery individuals showed no tag loss and do not seem to suffer any reductions in growth or condition factor compared to non-tagged salmon juveniles. The type of fin clip does not affect growth or condition factor. However, for monitoring marked individuals past 340 degree-days, anal fin clipped juvenile Atlantic salmon may be more successfully (or with less subjectivity) classified as marked due to a slower rate of fin regeneration compared to other fins. The results of this study indicate that Carlin tagging is a suitable technique for marking juvenile Atlantic salmon both in the hatchery environment and in the wild, and just as successful as dye injection.

References:


Chapter 3 – Migratory behaviour of Atlantic salmon (*Salmo salar* L.)

smolts in a Newfoundland fjord lake
Abstract:

Spring and summer migratory patterns of Atlantic salmon smolts through a fjord lake in the Western Brook system, Newfoundland, were studied over three years using mark-recapture experiments. It was hypothesized that the change in physical conditions encountered by smolts upon entering the lake, from the nursery (inlet) stream (Stag Brook), would delay migration. Differences of up to 8 °C between the stream and the lake were observed during the period of peak migratory activity. The peak in migration was 3-4 weeks later for smolts exiting the lake than those leaving the inlet stream. In all three years, smolts exiting the lake were significantly larger and appeared more advanced in smoltification (i.e., silver, darker fins, loss of parr marks) than smolts entering the lake from the nursery stream. Age analysis indicated the modal age of smolts captured in both locations was 3 years with a slightly higher percentage of age 4 smolts captured exiting the fjord lake. Smolts marked in Stag Brook were recaptured in the outlet stream in the same year, thereby proving the successful navigation of the fjord lake by smolts. A delay in migration of 3 weeks on average was found for these smolts. However, variability in time spent navigating the lake suggested the differences were individual-based rather than a function of group responses (i.e., schooling behavior). Scale analyses indicated an increased growth rate (0.35 mm • day$^{-1}$) during movement through the pond.

Introduction:

In the past, estimations of the potential for a river system to produce Atlantic salmon smolts were based on the amount of fluvial habitat available for the rearing of
parr. Typical parr rearing habitat was described as riffles, runs, and pools where cobble, rubble, boulders and bedrock substrates dominate (Allen 1969). However, Huntsman (1945) described rearing of Atlantic salmon parr in the slower flow portions of a river system. Parr were observed to populate both lakes and fresh or brackish parts of estuaries.

More recent studies have shown that Atlantic salmon parr may accompany, or precede, the downstream migration of smolts from a river to estuarine environments (Birt et al. 1990; Cunjak et al. 1989, 1990). Parr that moved into the estuary remained there, often for the duration of the summer months. Larger parr smoltified and continued to sea, while smaller parr moved back to the fluvial environment. However, parr that did reside in the estuary showed increased growth rates compared with parr that remained in fresh water (Cunjak et al. 1989, 1990).

Lakes and steadies have also been shown to be important rearing habitat for juvenile Atlantic salmon (Chadwick and Green 1985; Pepper 1976). Parr have been observed migrating both downstream and upstream to access lacustrine habitats (Erkinaro and Gibson 1997; Erkinaro et al. 1998a; Erkinaro et al. 1998b; Hutchings 1986). Residence in lakes resulted in increased growth rates for parr and also provided important overwintering habitat (Hutchings 1986; O’Connell et al. 1989; Erkinaro and Gibson 1997). Consequently, lacustrine habitat is considered important in the rearing of Atlantic salmon parr and in the production of smolts (Hutchings 1986; Pepper 1976, 1985).

Parr undergo various behavioural and physiological changes to facilitate their seaward emigration. Parr abandon a territorial behaviour for one of schooling as a smolt (Kallberg 1958; Thorpe and Morgan 1978; Wedemeyer et al. 1980). Atlantic salmon parr
that migrate into lakes likely smoltify there and then move to the sea (Hutchings 1986). Smolts produced in a lacustrine environment are often larger than those produced in the river environment (Erkinaro and Gibson 1997) and may therefore realize a survival advantage at sea (Lundqvist et al. 1988). River-produced smolts that have not experienced the characteristics of a lentic environment may have a different response than smolts produced in a lake. What are the effects of encountering a deep, cool lake environment during smolt migration in a natural situation?

Previous studies have concluded that the movement of wild Atlantic salmon through lakes is by means of passive displacement, and directed active migration is not significant (Hansen et al. 1984; Thorpe and Morgan 1978; Thorpe et al. 1981; Thorpe 1984; Tytler et al. 1978). Thorpe et al. (1981) found surface flow along the longitudinal axis of Loch Tummel, Scotland (maximum depth of 45 m) to be influenced by the current speeds from inlet to outlet. It was only slowed by winds in the opposite direction, however, a hydroelectric generating station at the outlet also influenced water movement. In Loch Voil, Scotland, another lake studied by Thorpe et al. (1981), it was found that smolt movement was significantly and positively correlated with the direction of surface water movements. A study by Berry (1933) (referenced by Thorpe et al. 1981) found that winds blowing in the direction of the outlet influenced the number of smolts leaving Loch Ness, Scotland. Therefore, in a situation of weak surface currents smolts may have difficulty finding their way out of the lake and therefore delay migration. Hansen et al. (1984) showed that smolt migration by both hatchery reared and wild smolts can be delayed when released above lakes. This delay was attributed to the slow current speeds in the lakes studied.
Bourgeois and O’Connell (1988) studied the migration of Atlantic salmon smolts moving through the Exploits River, Newfoundland, using radiotelemetry and Carlin tagging. One of their questions was whether salmon smolts successfully migrate through Red Indian Lake, a large lake (180.4 km²) with a maximum depth of 146.3 m, when transported to a location upstream of the lake. Approximately 1800 smolts captured downstream of the lake were tagged and released upstream of Red Indian Lake. Recaptured smolts successfully navigated the lake using some degree of active migration.

Juvenile sockeye salmon (*Oncorhynchus nerka* (Walbaum)) are predominantly reared in lakes and smolts of this species have been shown to exhibit directed active migration through large lakes (Brett et al. 1958; Johnson and Groot 1963; Groot 1965).

What are the consequences for Atlantic salmon smolts that begin smoltification in wild fluvial conditions only to emigrate into a large lacustrine environment with relatively colder temperatures? Temperature may affect the physiological and morphological status of a smolt. It has been suggested that warm water temperatures in the winter may be detrimental to the subsequent survival of Atlantic salmon smolts in colder sea water (Dickoff et al. 1989).

The present paper reports on the migration of wild Atlantic salmon juveniles from an upstream fluvial environment through the cooler lentic environment of a fjord lake. The observation of wild juvenile Atlantic salmon migrating through such an ecosystem offers a unique test of smolt migratory behaviour. It was hypothesized that the change in physical conditions encountered by smolts upon entering the fjord lake, from the nursery (inlet) stream, would delay migration. Specifically, it was predicted that: (1) smolts emigrating out of the lake would be older and larger due to a delay in migration of one
year, and (2) the rate of movement through the lake would be significantly reduced relative to the movement in running water.

**Study Site:**

The Western Brook system is located in Gros Morne National Park of northwestern Newfoundland (49° 44’ N, 57° 46’ W) and has a catchment area of 171.2 km². Western Brook Pond is an ultraoligotrophic fjord lake that was separated from the ocean after the retreat of glacial ice and isostatic rebound (Kerekes 1994). Steep igneous rock faces that reach elevations of 600 m contain the narrow eastern end of the lake. The western end of the lake widens since relatively flat, low-lying lands surround it. The lake has a surface area of 22.8 km², a mean depth of 72.5 m, a maximum depth of 165 m, and a turnover rate of > 15 years (Kerekes 1994). The lake receives drainage from more than 20 streams; all but one (Stag Brook) cascade off the steep cliffs of the fjord. The lake has been described as extremely low in productivity, as demonstrated by a very high oxygen concentration throughout the water column (Kerekes 1994). Wind action on the pond is variable and often violent. During the months of May and June, the predominant winds are southerly to southwesterly (Environment Canada, 1996). The pond has become a world-renowned tourist destination due to its unparalleled natural beauty.

Stag Brook, located at the southwestern end of the lake (Figure 3.1) is the largest tributary entering the lake. It is approximately 8 km in length, with an average width of 9 m. Stag Brook has a substrate consisting of gravel, cobble and large boulders (at higher gradients). The estimated instantaneous discharge during average summer flows was
1.36 m$^3$/s. Stag Brook has been identified as an important spawning and nursery habitat for Atlantic salmon and other salmonid species that inhabit the system (Ball 1991, Anions 1994).

Figure 3.1: Map showing the location of the Western Brook system including Stag Brook, Western Brook Pond and Western Brook.

Western Brook Pond is drained by Western Brook at its northwestern end. Western Brook flows for approximately 9 km before emptying into the Gulf of St. Lawrence (Figure 3.1). It has a mean width of 35 m and has substrate ranging from bedrock and
boulders to gravel and cobble. Steadies along the length of this brook have substrate of sand and mud with scattered boulders.

Other fish species present in the Western Book Pond river system are threespine stickleback (*Gasterosteus aculeatus* (Linnaeus)), American eel (*Anguilla rostrata* (Lesuer)), alewife (*Alosa pseudoharengus* (Wilson)), brook charr (*Salvelinus fontinalis* (Mitchill)), rainbow smelt (*Osmerus mordax* (Mitchill)), and Arctic charr (*Salvelinus alpinus* (Linnaeus)).

**Methods:**

Juvenile Atlantic salmon emigration was monitored using mark-recapture experiments during the spring and summer for three years, beginning in 1998 and ending in 2000.

**1998 (sampling year 1)**

**Stag Brook:**

On May 26 of 1998 a marking/tagging site was chosen in Stag Brook. This site was approximately 2 km upstream of where it discharges into Western Brook Pond (Figure 3.2).
Figure 3.2: Maps showing location of sampling sites in Stag Brook, Western Brook Pond and Western Brook (1998 – 2000).
A fyke trap with 18 mm mesh size was used to capture downstream migrating fish. Two wings, each 2 m in length, extended for 85 - 95 % of the width of the brook. All fyke traps were modified with smolt-boxes at their cod ends. The smolt-boxes were constructed of plywood and were 60 cm X 120 cm X 30 cm. A square funnel (15 cm X 15 cm X 90 cm) was fitted through the front of the rectangular box and created a passage from the fyke trap’s cod end into the box. The boxes were submerged by the flow so that the top, which bore a door, was at the surface. Boxes reduced mortality by reducing predation risk, but especially by acting as a flow refuge from fast currents that can cause fatigue and death for smolts crowded into the cod end of a fyke trap.

Emigrating juvenile Atlantic salmon caught in the trap were anesthetized using CO$_2$ (ENO$^\circledR$), and then identified for life stage and measured for fork-length (mm) and weight (g). The life stage of an emigrant was based on the classification described by Wedemeyer et al. (1980). Parr were classified as such when bearing distinct parr marks, and the small red dots along the lateral line, no darkening of fins, and no signs of silvering; smolts were classified as such only if they had darkening of fins, complete body silvering and absence of parr marks. Scale samples were taken from all fish and each juvenile $\geq$ 9 cm was marked with a caudal fin clip for the purpose of monitoring movements of older parr through recapture. Water temperature was monitored daily with a hand-held thermometer, and hourly by a thermistor placed in the stream. A water level benchmark was also measured daily and recorded. Sampling at this site continued until July 3 (Table 3.1).
Table 3.1: Table showing the start of sampling, the start, peak, and end of the smolt run, the termination date of sampling, and the number of smolts and parr captured at each site on the Western Brook system (1998 – 2000).

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Start of Sampling</th>
<th>First Smolt Caught</th>
<th>Peak in Captures</th>
<th>Last Smolt Caught</th>
<th>End of Sampling</th>
<th>Total Smolts Captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>May-26</td>
<td>May-27</td>
<td>May 27, 31, Jun 5, 13</td>
<td>Jun-29</td>
<td>Jul-30</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>May-20</td>
<td>May-21</td>
<td>Jun-21, Jul-2,7</td>
<td>Jun-27</td>
<td>Jul-30</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>May-20</td>
<td>May-22</td>
<td>Jun 12-13</td>
<td>Jun-29</td>
<td>Jul-03</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>May-31</td>
<td>Jun-01</td>
<td>Jun 25-28</td>
<td>Jul-25</td>
<td>Aug-02</td>
<td>482</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>Jun-03</td>
<td>Jun-03</td>
<td>Jun-25</td>
<td>Jul-30</td>
<td>Sep-08</td>
<td>1707</td>
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<tr>
<td></td>
<td>Western Brook Pond</td>
<td>Jun-14</td>
<td>Jun-17</td>
<td>Jul 3-7</td>
<td>Jul-28</td>
<td>Jul-28</td>
<td>916</td>
</tr>
</tbody>
</table>

Western Brook Pond:

The first downstream recapture site was established on May 20, 1998, in Western Brook, approximately 60 m downstream from the outflow of Western Brook Pond (Figure 3.2). A fyke trap with 18 mm mesh size and two 2 m wings sampled approximately 7% of the river width. All juveniles caught were subjected to the same protocol as in Stag Brook to obtain measurements of fork-length and weight, and to identify life stage. Each smolt caught was carefully checked for marks given in Stag Brook. After handling, smolts were released approximately 50 m downstream of the recapture site. Sampling extended until July 30 (Table 3.1).
Western Brook (mouth):

On May 20, 1998, a third capture site was established approximately 500 m upstream from the mouth of Western Brook where it discharges into the Gulf of St. Lawrence (Figure 3.2). One fyke trap (18 mm mesh and 2 m wings) was installed that extended 15 - 25% of the river width. Emigrants captured at this site were treated in the same manner in which they were at the site near Western Brook Pond. Each smolt caught was scrutinized for any caudal fin clip marks that would denote a fish from Stag Brook. Sampling extended until July 3 (Table 3.1).

1999 (sampling year 2)

Stag Brook:

In 1999, a fyke trap with 18 mm mesh size and two 2 m wings was placed in Stag Brook on May 21 in the same location as in 1998 (Figure 3.2). This trap was estimated to cut off over 85% of the flow at this site as low water conditions persisted over much of the sampling period (May 21 – July 2)(Table 3.1). Protocol for temperature and water level measurements followed that of 1998. Unlike the previous year, all emigrants with a fork-length \( \geq 9 \) cm were anesthetized using a 40 ppm clove oil bath (Anderson et al. 1997, Keene et al. 1998), and marked with 7 mm Carlin tags. Tagging procedures followed that of Saunders (1968). The individually numbered tags were fastened with polyethylene monofilament, just anterior of the dorsal fin. All individuals that were fitted with a Carlin tag were also given an anal fin clip (AFC) as a check for tag retention in downstream recaptured individuals. All individuals marked were also sampled for scales from the left side of the body, dorsal to the lateral line and just posterior to the dorsal fin.
Tagged individuals were allowed to recover for 20 minutes before they were released into Stag Brook approximately 50 m downstream of the capture site.

**Western Brook Pond:**

Between May 31 and June 15, 1999, two fyke traps with 10 mm mesh size and two 3.75 m wings were secured in Western Brook approximately 60 m downstream from the outflow of Western Brook Pond, the same site as in 1998 (Figure 3.2). Due to high water events at this site in the spring of 1999, difficulty was experienced in keeping these traps intact. The sampling regime was changed on June 16 to two fyke traps with 1.5 m wings and 18 mm mesh size set up side by side closer to the true left side of the river; a single fyke trap with 3.75 m wings and 10 mm mesh size was used on the right side of the river. This configuration was used until sampling terminated on August 2. Smolt-boxes were again used to reduce smolt mortality. All emigrating smolts and pre-smolts that were captured in these traps were sampled for scales and given left pelvic fin clips (LPFC) to indicate they were marked at this site if later recaptured.

The two fyke traps, initially installed, spanned approximately 65% of the river width. The second net configuration spanned 50% of the river width. Water velocities were measured on July 15, approximately 5 m upstream from the nets, to estimate the river discharge during the period of summer low flow. Water depth and velocity were measured every meter along a single transect of river width. Water temperature was monitored both daily with a thermometer and hourly by a thermistor placed in the water column.
**Western Brook:**

A fish counting fence with both an adult upstream trap and a downstream smolt trap similar to that described by Anderson and McDonald (1978) was constructed at the head of tide on Western Brook (Figure 3.2). The fence and adult trap consisted of aluminum conduit spaced 6 mm apart. The smolt trap was constructed for the recapture of emigrants marked upriver at Western Brook Pond or Stag Brook. It was a wood trap with screen panels (< 1 cm mesh). The smolt trap was operational from June 3 - September 8, 1999 (Table 3.1). Water temperature was monitored both daily with a thermometer and hourly by a thermistor placed in the water column. A group of individuals were marked approximately 500 m upstream of the fence to test its efficiency.

**2000 (sampling year 3)**

**Stag Brook:**

A fyke trap with 18 mm mesh size and 2 m wings was set in the brook on May 26 in the same location as in the previous two field seasons (Figure 3.2, Table 3.1). A second fyke trap of the same size was then added at this site on May 30 due to higher water levels than in the previous two years. Velocities were measured on May 31 to ascertain percent discharge sampled by the two traps. Temperature and water level were measured using the same protocol as in 1998 and 1999. As in the previous two field seasons, all juvenile salmon ≥ 9 cm caught migrating in a downstream direction were marked. All individuals were marked with an anal fin clip (AFC). In addition, approximately half of the emigrants were given a 2 % Alcian blue panjet tattoo; the other half was given 8 mm Carlin tags. The position of tattoo administration was ventral and
just anterior to the pelvic girdle. This location was picked due to the lack of pigmentation and the subsequent ease of identifying recaptures with a blue dot on a white belly. Individually numbered Carlin tags were fitted just anterior of the dorsal fin. This type of mark was administered following the same procedures as outlined for the 1999 captures at this site. The type of mark (Carlin tag vs. panjet tattoo) given to an individual was random. At each trap-check half the fish were given one mark and half the other. Initial survival and rate of recapture for the Carlin tag and panjet tattoo mark were compared (See Chapter 2). All captured individuals had scales taken for analysis. All individuals that were marked were put in a 85 cm X 110 cm rectangular wood framed, plastic screened (12 mm mesh), live-trap anchored close to the centre of a flat/pool about 50 m downstream of the Stag Brook capture site. The trap was covered with plywood for cover from predators and sun. The marked individuals were held for 24 hours to observe mortalities that may be due to marking. Sub-samples of smolts and parr were also marked approximately 500 m upstream of the capture site in Stag Brook to assess the capture efficiency of that site. Sampling terminated on July 27 at this site in 2000 (Table 3.1).

**Western Brook Pond:**

A number of high water events near the end of May in 2000 made it unsafe to work in Western Brook until June. Four fyke traps were placed in the river on June 14. On June 21 a fifth fyke trap was added. The location of these nets was different from that of the previous two years. The fyke traps were positioned approximately 65 m upstream of Long Steady, and about 330 m downstream from Western Brook Pond (Figure 3.2).
The fyke traps had 18 mm mesh size and were positioned to sample both sides and the middle of the river. Water velocities and depths were taken at this site on July 15 to estimate discharge and ascertain the percent of stream flow sampled by the fyke traps at this site.

Emigrants at this site were checked carefully for any marks from Stag Brook in 2000 or from previous years. Recaptures were anesthetized with a 40 ppm clove oil bath (Anderson et al. 1997, Keene et al. 1998), re-measured for length and weight, and scale samples were taken for a second time. On a daily basis, a sub sample of ten unmarked smolts were randomly selected and anesthetized with 40 ppm clove oil bath, and measured for length, weighed and sampled for scales. All captures at this site were then released downstream into Long Steady (Figure 3.2). Sampling terminated on July 28 at this site in 2000 (Table 3.1).

Temperature and relative water height were recorded through the duration of the sampling period at this site.

**Western Brook:**

Due to the scarcity of recaptures at this site in 1999 it was decided that the focus of the study be the migration of Atlantic salmon smolts from Stag Brook through Western Brook Pond. As a result, the time and energy needed to operate a downstream smolt-counting fence was diverted into increased fishing effort at Western Brook Pond (Figure 3.2).
**Temperature Regimes:**

The temperature regime of Stag Brook, Western Brook Pond and Western Brook at Long Steady was logged using thermistors to relate movement patterns with temperatures encountered by downstream migrating salmon smolts. Temperatures were recorded at two locations in Western Brook Pond. The first location was situated near the mouth of Stag Brook in approximately 8 m of water. The thermistor was suspended approximately 4 m from the substrate. This setup was duplicated at a site near the outflow of Western Brook Pond (Figure 3.2). This was done to record the temperatures that may be encountered by emigrants as they reach the lake and pass through it back into a riverine environment.

**Aging of Scale Samples:**

All scales samples collected from all three sites and all years were later mounted on glass slides and examined using a microfiche viewer. Aging was carried out using the protocol and nomenclature set out by the International Council for the Exploration of the Sea (ICES) in their Report of the Atlantic Salmon Scale Reading Workshop (1984). A sub-sample of scale samples was re-aged, and then sent to a second identifier at the Department of Fisheries and Oceans, Moncton, NB. No discrepancies were found with respect to age designation for scale samples. Scales were examined using a Canon® 360T microfiche reader with a 1:2.8 magnification. The percent of captured smolts of each age class was calculated for each site for all three years. Scales were closely examined for the presence of “plus” growth (thick circuli created by increased growth rates typically associated with spring/summer). Calculation of the percentage of
individuals showing plus growth during each half of the smolt run, at each site sampled for each year was also done. The incidence of “plus” growth was especially examined for those scale samples from recaptured individuals. Year 2000 scale samples from recaptured individuals were measured for length from focus to scale margin along the $360^\circ$ axis and from the first edge of plus growth circulus of the current year to the tip margin of the scale. These measurements were taken for calculation of a plus growth to scale length ratio ($L_+ : L_{tot}$) to compare the relative increase in growth for an individual at its time of capture and marking and at its time of recapture having traversed the lake. The widths of individual plus growth ciculi were also calculated from these measurements. These measurements were then repeated on the matching scale samples for the same individual at its time of marking in Stag Brook.

**Statistical Analyses:**

Mean fork-length of captured smolts was compared between sites for each year using one-way ANOVA. Condition factors ($C_f$) were calculated using the formula:

$$C_f = \frac{\text{weight}}{(\text{length})^3} \cdot 100$$ (Lundqvist et al. 1988). A one-way ANOVA was used to compare mean condition factor of captured smolts between sites for 1999 and 2000.

One-way ANOVA was used to compare mean water temperature at each site (from May 26 – July 27) and between years for individual sites.

Recaptured smolts marked in Stag Brook allowed for a calculation of migration speed (km \cdot day$^{-1}$). Regression analysis was used to test if there was a linear relationship.
between the date a smolt was marked in Stag Brook and lake residence time or migratory speed.

Student’s $t$-test was used to compare mean fork-length of tagged smolts when marked versus when recaptured. The same analysis was used to test for significant differences in the ratio of $L_+: L_{tot}$ for tagged smolts when marked compared to when recaptured in 2000. A student’s $t$-test was also used to analyze the difference in the mean number of plus growth circuli present on tagged smolt scales when marked compared to when recaptured. This test was used again to test for difference in the mean plus growth circulus width for tagged smolts when marked versus when recaptured in 2000.
Results:

Fish Movement:

Smolt emigration in the Western Brook system occurred from mid to late May until late July. In all three years of sampling, emigration from Stag Brook occurred in pulses and generally coincided with fluctuations in water temperature as opposed to the other two sites where smolts migration was generally more continuous.

1998:

Sampling at Stag Brook began on May 26 in 1998 and a pulse in migration occurred the next day (May 27). Therefore, the smolt run was well underway before sampling commenced in 1998. Three more peaks or pulses in emigration occurred at Stag Brook when temperatures were > 10°C (Figure 3.3).
Figure 3.3: Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook, Western Brook Pond, and Western Brook with daily mean water temperatures, 1998.
The run was finished by June 29, by which time 178 smolts had been captured (Table 3.1). 58 Atlantic salmon parr were caught at Stag Brook in 1998 (Table 3.2), 27 of which were $\geq 9$ cm and marked with upper caudal fin clips. None of these individuals was recaptured during the 3 years of the study.

Table 3.2: Table showing the start of sampling, the first and last captured, peak, the termination date of sampling, and the total number of parr captured and $< \text{and} \geq 9$ cm size categories where applicable at each site on the Western Brook system (1998 – 2000).

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Start of Sampling</th>
<th>First Parr Caught</th>
<th>Peak in Captures</th>
<th>Last Parr Caught</th>
<th>End of Sampling</th>
<th>Total Parr Captured</th>
<th>Parr Caught $&lt; 9$ cm</th>
<th>Parr Caught $\geq 9$ cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>May-26</td>
<td>May-29</td>
<td>–</td>
<td>Jun-29</td>
<td>Jul-03</td>
<td>58</td>
<td>31</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>May-20</td>
<td>May-21</td>
<td>–</td>
<td>Jun-29</td>
<td>Jul-30</td>
<td>42</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>May-20</td>
<td>May-25</td>
<td>–</td>
<td>Jun-26</td>
<td>Jul-03</td>
<td>27</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1999</td>
<td>Stag Brook</td>
<td>May-21</td>
<td>May-26</td>
<td>–</td>
<td>Jun-25</td>
<td>Jul-02</td>
<td>21</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>May-31</td>
<td>Jun-01</td>
<td>Jul-11, Jul-21</td>
<td>Jun-28</td>
<td>Aug-02</td>
<td>118</td>
<td>–</td>
<td>–</td>
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<tr>
<td></td>
<td>Western Brook</td>
<td>Jun-03</td>
<td>Jun-03</td>
<td>Jun-20</td>
<td>Sep-06</td>
<td>Sep-11</td>
<td>370</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2000</td>
<td>Stag Brook</td>
<td>May-26</td>
<td>May-27</td>
<td>Jun-24</td>
<td>Jul-02</td>
<td>Jul-27</td>
<td>679</td>
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<td></td>
<td>Western Brook Pond</td>
<td>Jun-14</td>
<td>Jun-14</td>
<td>Jul-02</td>
<td>Jul-21</td>
<td>Jul-28</td>
<td>114</td>
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<td>–</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

The smolt run began later and lasted longer at the outflow of Western Brook Pond than at the other two sites sampled in 1998 (Figure 3.3). Sampling at this site commenced on May 20 and the first smolt was captured the next day (May 21)(Figure 3.3). Peak smolt migration occurred when the water temperature reached $11^\circ$C on June 21, July 2 and 7 (Table 3.1). A short break in migration occurred when the water
temperature dropped below 10°C from June 28 – July 1 (Figure 3.3). The run was finished by July 28 at which time 153 smolt had been caught. A small number of parr (42) were caught (Table 3.2) and no trend in movement was observed. They were not divided into size classes as in Stag Brook and no parr were marked at this site.

At the mouth of Western Brook sampling commenced on May 20 in 1998 with the first smolt caught two days later (May 22). A peak in movement occurred from June 12 – 13 (Table 3.1) and the run was over by June 29 by which time 181 smolts had been caught. As at the outflow of Western Brook Pond, very few parr (27) were captured at the mouth of Western Brook in 1998 (Table 3.2).

1999:

In 1999 sampling at Stag Brook started earlier than in 1998 (Table 3.1) on May 21. The first smolt was caught two days later (May 23). Two peaks in migration occurred: the first was over May 25 – 27, when daily mean water temperatures reached 10°C and the second occurred when the water temperature reached 14°C on June 2 (Figure 3.4). The run finished by June 16 in 1999 and by this time 252 smolts were caught at Stag Brook, a larger number than in 1998 (Table 3.1). 21 Atlantic salmon parr were caught at this site in 1999, 11 of which were ≥ 9 cm and fitted with Carlin tags. None of these marked parr were recaptured in 1999 or 2000. Although more smolts were caught in 1999 at Stag Brook, a decrease in parr movement was observed compared to 1998 (Table 3.2).
Figure 3.4: Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook, Western Brook Pond, and Western Brook with daily mean water temperatures, 1999.
Sampling began later (May 31) at the outflow of Western Brook Pond in 1999 than in 1998. The first smolt was caught the day after sampling commenced (June 1) (Table 3.1) indicating a later date of initial movement out of the lake than out of Stag Brook (Figure 3.4). The peak in smolt migration at this site occurred from June 25 – 28, when water temperature was 10 to 12°C (Figure 3.4). The run was finished by July 25 by which time 482 smolts were caught, which was a much larger number of captures for this site as compared to 1998 (Table 3.1). This increase was due to an increase in fishing effort in 1999 over 1998. 118 salmon parr were captured from June 1 – 28, with a peak in movement occurring on June 11. All parr movement occurred before the smolts began migration out of the lake in 1999. The greatest amount of parr movement occurred in the two weeks leading up to the peak in smolt captures (Figures 3.4, 3.5).
Figure 3.5: Daily counts of Atlantic salmon parr captured at the discharge of Western Brook Pond, and the mouth of Western Brook with daily mean water temperatures, 1999.
Sampling began on June 3 at the mouth of Western Brook in 1999 and the first smolt was caught on this date (Table 3.1). Therefore smolt movement commenced only a few days apart at mouth of Western Brook and at the outflow of Western Brook Pond 1999 (Figures 3.4). The peak in smolt emigration occurred on June 25 at the mouth of Western Brook, and the run was finished by July 30 by which time 1707 smolts had been caught by the fish-counting fence. The number of Atlantic salmon parr captured in the downstream trap of the counting fence was 370, the first being caught on June 3 (Table 3.2). The majority of parr caught were < 9cm, however, parr were not divided into size classes as no parr were marked at this site. The peak in parr movement at this site occurred on June 20. The peak, and in fact the majority, of parr movement occurred before the peak in smolt migration at this site (Figures 3.4, 3.5), similar to the pattern observed at the outflow of the lake.

2000:

Sampling began on May 26 at Stag Brook in 2000, and the first smolt was caught on May 28 (Table 3.1). Two peaks in smolt migration occurred when the water temperature was near 7 °C. The first occurred on June 1 and the second on June 7. A third peak in migration occurred on June 18 when the water temperature reached 14.7 °C (Figure 3.6).
Figure 3.6: Daily counts of Atlantic salmon smolts captured emigrating from Stag Brook and Western Brook Pond with daily mean water temperatures, 2000.

470 smolts were caught by the time the run ended on June 30. A considerably greater number of Atlantic salmon parr were caught in Stag Brook in 2000 compared to 1998 or 1999 (Table 3.1). This likely reflects the increase in fishing effort. 679 parr were captured at this site in 2000 (Table 3.2). 546 of these were < 9 cm and scale analysis showed them to be age 1+. The first parr was caught on May 27 and the peak in
movement occurred on June 24. The peak in parr movement occurred after the peak in smolt migration yet the majority of parr were caught during the smolt run. Parr $\geq 9$ cm moved earlier than those $< 9$ cm. Parr movement stopped when the smolt run ended on July 2 (Figure 3.7).

![Graph of salmon parr capture at Stag Brook and Western Brook Pond](image)

Figure 3.7: Daily counts of Atlantic salmon parr captured at Stag Brook (for size classes $< 9$ cm and $\geq 9$ cm) and at the discharge of Western Brook Pond (all size classes), with daily mean water temperatures, 2000.
317 parr < 9 cm were captured and given upper caudal fin clips at the efficiency trap, 500 m upstream from the main capture site in Stag Brook. Only 2 parr marked in this fashion were recaptured at the downstream capture site indicating that many parr < 9 cm are mobile but they likely tend to stay in Stag Brook.

26 parr ≥ 9 cm were marked with Carlin tags at the efficiency trap. 9 of these individuals were recaptured at the downstream capture site. The rate of recapture between the efficiency site and main capture site in Stag Brook was much less for parr (35 %) than for smolts (60 %) indicating less downstream movement by parr than smolts.

Sampling began on June 14 at the outflow of Western Brook Pond in 2000, which was later than in 1998 or 1999. The late start of sampling was due to the persistence of higher water levels in 2000 compared to 1998 and 1999. The first smolt was caught on June 17 (Table 3.1). The peak in migration out of Western Brook Pond occurred from July 3 – 7 when the water temperature reached 11 °C. Sampling ended on July 28 by which time a total of 916 smolts had been captured (Figure 3.6, Table 3.1). A greater number of smolts was caught at this site in 2000 than in the previous field seasons as a result of increased fishing effort and a more efficient site of capture due to lower flows. 114 parr were caught at this site in 2000 with the first caught on June 14. Parr movement generally occurred during the same time as smolt migration, but the peak in parr movement occurred on July 2, the day before the peak in smolt migration (Figure 3.6, 3.7).
Fork-Lengths and Condition Factors:

In all three years sampled, the mean fork-length of smolts captured at the outflow of Western Brook Pond was significantly greater than the mean fork-length of smolts captured at Stag Brook \((P < 0.001)\). The difference in mean fork-length between Stag Brook and Western Brook Pond smolts was 2.7 cm in 1998, 3.6 cm in 1999 and 3.1 cm in 2000 (Table 3.3).

Table 3.3: Mean fork-lengths (± 1 SD) and mean condition factors (± 1 SD) for Atlantic salmon smolts caught at each sampling site on the Western Brook system over 3 years (1998 – 2000).

<table>
<thead>
<tr>
<th>Year</th>
<th>Sampling Site</th>
<th>n</th>
<th>FL (cm)</th>
<th>Cf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>178</td>
<td>13.1 ± 1.4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>153</td>
<td>15.8 ± 2.1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>181</td>
<td>13.8 ± 1.6</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>Stag Brook</td>
<td>252</td>
<td>12.8 ± 1.1</td>
<td>0.91 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>482</td>
<td>16.4 ± 1.7</td>
<td>0.90 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>Western Brook (June 3 - June 18)</td>
<td>137</td>
<td>14.6 ± 1.8</td>
<td>0.95 ± 0.20</td>
</tr>
<tr>
<td></td>
<td>Western Brook (June 18 - July 22)</td>
<td>265</td>
<td>17.1 ± 1.7</td>
<td>0.90 ± 0.09</td>
</tr>
<tr>
<td>2000</td>
<td>Stag Brook</td>
<td>470</td>
<td>12.9 ± 1.0</td>
<td>0.93 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>916</td>
<td>16.0 ± 1.7</td>
<td>0.87 ± 0.10</td>
</tr>
</tbody>
</table>

In 1998, the smolts caught at the outflow of the lake were significantly larger then smolts caught at the mouth of Western Brook \((P < 0.001)\). The difference in mean fork-length between the two sites was 2 cm (Table 3.3).
In 1999, the smolt run at the mouth of Western Brook lasted from June 3 – July 22 (Table 3.1). However, substantial smolt movement at the outflow of the lake did not begin until June 17 in 1999 (Figure 3.4). Therefore, the smolts caught at the mouth of Western Brook before June 18 were likely produced in Western Brook and the steadies along its course. The mean fork-length of these smolts was significantly smaller (by approximately 2 cm) than the mean fork-length of smolts caught at the outflow of the lake and at the mouth of Western Brook after June 18 ($P < 0.001$)(Table 3.3). The mean fork-length of smolts caught at the mouth of Western Brook after June 18 was slightly (0.6 cm) yet significantly greater than the mean fork-length of smolts caught at the outflow of Western Brook Pond in 1999 ($P < 0.001$). This may indicate that the fish caught at the mouth of Western Brook after June 18 and the fish caught at the outflow of the lake may have been produced in the same area, Western Brook Pond. The slight increase in the mean length may be a function of time.

Data for comparisons of mean condition factor were only available for 1999 and 2000. No significant difference ($P > 0.05$) in condition factor was seen for Atlantic salmon smolts captured in the Western Brook system in 1999. However, in 2000, smolts caught in Stag Brook had a significantly greater condition factor ($P < 0.001$) when compared to smolts captured at the outflow of Western Brook Pond. No significant reduction in condition factor was evident between years for a given site (Table 3.3).
**Scale Aging Analysis:**

Scale analysis revealed that in all three sampling years the dominant age class of Atlantic salmon smolts captured at each site in the Western Brook system was 3 years (Figure 3.8).

The percentage of captured smolts showing plus growth significantly increased ($P < 0.05$) from the first to the second half of the smolt run at all sites during each year sampled. The exception was in 1998 at the outflow of Western Brook Pond where there was no significant increase in the percentage of captured individuals showing plus growth from the first to second half of the run (Figure 3.9). 1999 had the largest percent of individuals captured throughout the smolt run showing plus growth for all sites in comparison to 1998 and 2000. Almost all of the Atlantic salmon smolts caught in the second half of the smolt run at each site in 1999 showed some plus growth. The percentage of individuals caught at Stag Brook showing plus growth was the lowest during 1998 when compared to both 1999 and 2000 (Figure 3.9).
Figure 3.8: Number of smolts captured by age class for Stag Brook, Western Brook Pond and Western Brook from 1998 – 2000.
Figure 3.9: Percent of Atlantic salmon smolts captured at each sampling site during both halves of the smolt run that showed plus growth (1998 – 2000).
Temperature Regimes During Smolt Movement:

Average daily mean water temperatures were compared for each year by site for comparison to the percent plus growth in each year. The temperature readings compared by one-way ANOVA were those from May 26 to July 27, the maximum duration of juvenile salmon emigration in the system. Stag Brook was significantly cooler in 2000 than in either 1998 or 1999 ($P < 0.0002$). There was no significant difference in mean temperature between 1998 and 1999 at Stag Brook ($P > 0.05$) (Table 3.4).

Table 3.4: Average, minimum, and maximum daily mean temperatures for Stag Brook, Western Brook Pond and Western Brook from May 26 – July 27 (duration of Western Brook system smolt migration), 1998 – 2000.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sampling Site</th>
<th>Avg. Daily Mean Temperature ($^\circ$C)</th>
<th>Min. Daily Mean Temperature ($^\circ$C)</th>
<th>Max. Daily Mean Temperature ($^\circ$C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>14.0 ± 3.5</td>
<td>6.0</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>9.9 ± 3.5</td>
<td>4.7</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>Western Brook (mouth)</td>
<td>13.7 ± 4.0</td>
<td>6.0</td>
<td>20.2</td>
</tr>
<tr>
<td>1999</td>
<td>Stag Brook</td>
<td>14.8 ± 3.1</td>
<td>6.4</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>10.7 ± 2.8</td>
<td>4.9</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>Western Brook (mouth)</td>
<td>8.9 ± 2.8</td>
<td>4.1</td>
<td>13.7</td>
</tr>
<tr>
<td>2000</td>
<td>Stag Brook</td>
<td>12.3 ± 3.6</td>
<td>5.5</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>8.4 ± 2.9</td>
<td>3.9</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>Western Brook (mouth)</td>
<td>11.3 ± 3.8</td>
<td>4.8</td>
<td>17.9</td>
</tr>
</tbody>
</table>

At the outflow of Western Brook Pond, mean water temperature was significantly different ($P < 0.0002$) each year with 2000 being the coolest ($8.4^\circ$C) compared with 1998 and 2000 (Table 3.4).
At the mouth of Western Brook each year showed significantly different mean temperatures ($P < 0.0002$) with 1999 having the coolest water temperature compared to both 1998 and 1999 (Table 3.4).

Daily mean water temperatures encountered by Stag Brook emigrants in 2000 upon entering the lake are shown in Figure 3.10. A difference of at least 2 °C between Stag Brook and Western Brook Pond occurred throughout the early portion of the smolt run out of Stag Brook. The difference in water temperature between the brook and the lake increased as the smolt run continued. The difference in temperature between Stag Brook and Western Brook Pond, near the inflow of Stag Brook, was as large as 9 °C on the same day (June 21, 2000)(Figure 3.10).

![Figure 3.10: Daily mean water temperature readings taken from May 26 to July 28, 2000, at Western Brook Pond near the inflow of Stag Brook (WBPS), Western Brook Pond near its drainage by Western Brook (WBPD), and Stag Brook and the start (S), peak (P) and end (E) of smolt migration from Stag Brook.](image)

Figure 3.10: Daily mean water temperature readings taken from May 26 to July 28, 2000, at Western Brook Pond near the inflow of Stag Brook (WBPS), Western Brook Pond near its drainage by Western Brook (WBPD), and Stag Brook and the start (S), peak (P) and end (E) of smolt migration from Stag Brook.
Mark-Recapture Results:

1998 (sampling year 1):

None of the 144 individuals marked at Stag Brook were recaptured at downstream recapture sites in 1998. No individuals marked in Stag Brook in 1998 were captured in either of the following field seasons (Table 3.5).

Table 3.5: Number of smolts captured, marked and recaptured during migration in Stag Brook (STB), Western Brook Pond (WBP) and Western Brook (WB), 1998 – 2000.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Duration of Smolt Migration</th>
<th>Captured</th>
<th>Marked</th>
<th>Site of Recapture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STB</td>
</tr>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>May 27 - June 29</td>
<td>178</td>
<td>144</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>May 21 - July 27</td>
<td>153</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>May 22 - June 29</td>
<td>181</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>Stag Brook</td>
<td>May 23 - June 16</td>
<td>252</td>
<td>236</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>June 1 - July 25</td>
<td>482</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>June 3 - July 30</td>
<td>1707</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>Stag Brook</td>
<td>May 28 – June 30</td>
<td>470</td>
<td>470</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Western Brook Pond</td>
<td>June 17 - July 28</td>
<td>916</td>
<td>42</td>
<td>5</td>
</tr>
</tbody>
</table>
1999 (sampling year 2):

Of the 252 emigrants captured at Stag Brook in 1999, 236 were fitted with Carlin tags and given anal fin clips. 16 smolts were recaptured at this same site; 4 smolts tagged in Stag Brook were recaptured at the outflow of Western Brook Pond. The fish fence at the mouth of Western Brook recaptured 4 fish marked in Stag Brook. None of the recaptured smolts were caught more than once in 1999. No individuals marked in 1999 were recaptured in 2000.

The majority of individuals recaptured after navigating the pond were 3 years of age and showed plus growth when caught and marked in Stag Brook. The linear distance between the mouth of Stag Brook and the pond outflow was approximately 5 km. The time to migrate this distance ranged from 9 – 36 days. Emigrants marked earlier in the season took longer to migrate through the Pond. For example, a smolt marked on May 27 took 36 days to reach the outflow of Western Brook Pond, indicating a trip speed of 0.14 km • day\(^{-1}\). However, a smolt marked on June 2 reached the same location in 9 days, moving at a pace of 0.56 km • day\(^{-1}\) (Table 3.6).
Table 3.6: Fork-length, migration time, distance traveled, and trip speed of emigrant

Atlantic salmon smolts from time of marking in Stag Brook until the time of recapture at the outflow of Western Brook Pond for 1999 and 2000.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mark Date</th>
<th>Mark Length (cm)</th>
<th>Mark Date of Recapture</th>
<th>Recapture Site of Recapture</th>
<th>Recap. Length (cm)</th>
<th>Migration Time (days)</th>
<th>Distance (km)</th>
<th>Trip Speed (km • day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>May-27</td>
<td>12.9</td>
<td>Jul-02</td>
<td>Western Brook Pond</td>
<td>—</td>
<td>36</td>
<td>5.0</td>
<td>0.14</td>
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<tr>
<td></td>
<td>May-30</td>
<td>11.7</td>
<td>Jun-23</td>
<td>Western Brook Pond</td>
<td>—</td>
<td>24</td>
<td>5.0</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>Jun-02</td>
<td>14.3</td>
<td>Jun-11</td>
<td>Western Brook Pond</td>
<td>—</td>
<td>9</td>
<td>5.0</td>
<td>0.56</td>
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<tr>
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<td>Jun-02</td>
<td>15.5</td>
<td>Jun-15</td>
<td>Western Brook Pond</td>
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<tr>
<td></td>
<td>Mean</td>
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<tr>
<td></td>
<td>Std. Dev.</td>
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<td></td>
<td></td>
<td>12</td>
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<td>0.2</td>
<td></td>
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<tr>
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<td>May-27</td>
<td>13.9</td>
<td>Jun-12</td>
<td>Western Brook (mouth)</td>
<td>—</td>
<td>16</td>
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<td>May-30</td>
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<td>5.4</td>
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<td>0.17</td>
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</tbody>
</table>
The 4 individuals recaptured at the mouth of Western Brook migrated approximately 14 km. The time to migrate this distance ranged from 10 – 26 days. Despite the added distance to migrate down Western Brook, the smolts caught at the mouth of the river migrated at a speed more than twice as fast as those smolts caught at the outflow of the lake. This indicates an increased migratory speed once exiting the lake and entering Western Brook. Unfortunately, none of the 40 smolts Carlin tagged at the discharge of Western Brook Pond were recaptured at the counting fence at the mouth of Western Brook in 1999. Therefore, actual speed of migration through this portion of the system is only a guess. Emigrants marked earlier in the season did not show faster migration times. A smolt marked on June 2 was recaptured 10 days later on June 12 at the mouth of Western Brook. The pace of migration was approximately 1.40 km • day\(^{-1}\). The slowest rate of migration for a recapture at the mouth of Western Brook pond was 0.54 km • day\(^{-1}\) (Table 3.6). Scale samples were not taken from recaptures during this field season.

2000 (sampling year 3):

470 smolts were marked in Stag Brook in 2000. The number recaptured at the outflow of Western Brook Pond was 28 (Table 3.5). Out of this number 17 had been marked with Carlin tags and 11 with panjet tattoos. The individuals recaptured after having navigated the lake ranged from 2 – 4 years old with 10 of 17 individuals being age 3. The majority of individuals showed plus growth when marked in Stag Brook. The distance migrated from the marking site in Stag Brook to the recapture site at the outflow
of Western Brook Pond was approximately 5.4 km. The number of days taken to reach the recapture site ranged from 6 – 38, with the average being 20. An emigrant marked on June 24 was recaptured 6 days later on the other side of the pond. The pace of migration for this fish was 0.9 km • day\(^{-1}\). However, the other end of the range is represented by a smolt marked on June 15, which took 38 days to navigate the lake for a migratory pace of 0.14 km • day\(^{-1}\) (Table 3.6). All recaptured individuals showed a greater degree of smoltification than when tagged, showing complete body silvering, darkening of fins, and loss of scales.

Smolts that were marked on the same day and released at the same time showed variance in the time it took to navigate the pond. Two smolts marked on June 5 in Stag Brook differed in their migration time to the outflow of Western Brook Pond by 5 days. Seven days difference in migration time was observed for three smolts marked on June 14. Three individuals marked on June 24 also showed a 8-day difference in migration time. Therefore, “temporal cohorts” did not move together through the pond (Table 3.6).

Correlation between the day of the smolt run that an individual was tagged to lake residence time was marginal, with a small negative slope. Only 11 % of the variation in lake residence time could be accounted for by the day of marking (Figure 3.11).
Lacustrine Growth of Recaptured Emigrants (2000):

The average fork-length of individuals captured after migrating through the lake (13.3 cm ± 0.9) was significantly greater than for the same individuals when caught in Stag Brook (12.6 cm ± 0.9) \( (P < 0.05) \) (Table 3.7). The average increase in fork-length was 7.7 mm. The increase in length of individuals migrating through the lake ranged from 0.1 mm • day\(^{-1}\) to 0.66 mm • day\(^{-1}\), the mean being 0.35 mm • day\(^{-1}\). One individual that took 38 days to migrate from the marking site to the recapture site on the other side of the pond also increased its length by 25 mm. (Table 3.7).
Table 3.7: Differences in fork-length, number of plus growth circuli and ratio of plus growth circuli length to total scale length $L^+ : L_{tot}$, migration time, and growth per day, between the time of marking in Stag Brook and the time of recapture at the outflow of Western Brook Pond, 2000.

<table>
<thead>
<tr>
<th>Date of Mark</th>
<th>FL (mm)</th>
<th>Age</th>
<th>Num. of circuli</th>
<th>L^+ : L_{tot}</th>
<th>Date of Recapt.</th>
<th>FL (mm)</th>
<th>Mig. Time (days)</th>
<th>Num. of circuli</th>
<th>L^+ : L_{tot}</th>
<th>Diff. in FL (mm)</th>
<th>Diff. in L^+ : L_{tot}</th>
<th>Growth/Day (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun-01</td>
<td>119</td>
<td>2.5</td>
<td>2</td>
<td>0.087</td>
<td>Jun-21</td>
<td>125</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>6</td>
</tr>
<tr>
<td>Jun-05</td>
<td>114</td>
<td>3.0</td>
<td>0</td>
<td>0.000</td>
<td>Jul-05</td>
<td>131</td>
<td>4</td>
<td>0.146</td>
<td>0.146</td>
<td>17</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Jun-05</td>
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<td>3.0</td>
<td>0</td>
<td>0.000</td>
<td>Jun-30</td>
<td>124</td>
<td>3</td>
<td>0.122</td>
<td>0.122</td>
<td>4</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Jun-07</td>
<td>138</td>
<td>4.5</td>
<td>1</td>
<td>0.031</td>
<td>Jul-05</td>
<td>146</td>
<td>4</td>
<td>0.156</td>
<td>0.125</td>
<td>8</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Jun-07</td>
<td>135</td>
<td>3.5</td>
<td>2</td>
<td>0.077</td>
<td>Jun-30</td>
<td>142</td>
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<td>0.122</td>
<td>0.045</td>
<td>7</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Jun-11</td>
<td>127</td>
<td>3.5</td>
<td>2</td>
<td>0.143</td>
<td>Jul-03</td>
<td>137</td>
<td>4</td>
<td>0.180</td>
<td>0.037</td>
<td>10</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Jun-14</td>
<td>134</td>
<td>3.5</td>
<td>2</td>
<td>0.065</td>
<td>Jun-27</td>
<td>13</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Jun-14</td>
<td>127</td>
<td>3.5</td>
<td>2</td>
<td>0.095</td>
<td>Jul-04</td>
<td>135</td>
<td>4</td>
<td>0.140</td>
<td>0.045</td>
<td>8</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Jun-14</td>
<td>140</td>
<td>4.5</td>
<td>2</td>
<td>0.056</td>
<td>Jul-04</td>
<td>142</td>
<td>3</td>
<td>0.081</td>
<td>0.025</td>
<td>2</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Jun-15</td>
<td>118</td>
<td>3.5</td>
<td>2</td>
<td>0.074</td>
<td>Jul-23</td>
<td>143</td>
<td>6</td>
<td>0.231</td>
<td>0.157</td>
<td>25</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Jun-18</td>
<td>122</td>
<td>3.5</td>
<td>2</td>
<td>0.067</td>
<td>Jul-06</td>
<td>126</td>
<td>3</td>
<td>0.125</td>
<td>0.058</td>
<td>4</td>
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</tr>
<tr>
<td>Jun-20</td>
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<td>5</td>
<td>0.152</td>
<td>Jul-07</td>
<td>115</td>
<td>6</td>
<td>0.250</td>
<td>0.098</td>
<td>8</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Jun-23</td>
<td>144</td>
<td>4.5</td>
<td>3</td>
<td>0.081</td>
<td>Jul-08</td>
<td>150</td>
<td>4</td>
<td>0.136</td>
<td>0.055</td>
<td>6</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Jun-24</td>
<td>122</td>
<td>3.5</td>
<td>3</td>
<td>0.116</td>
<td>Jul-07</td>
<td>128</td>
<td>4</td>
<td>0.150</td>
<td>0.034</td>
<td>6</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Jun-24</td>
<td>122</td>
<td>3.5</td>
<td>3</td>
<td>0.100</td>
<td>Jun-30</td>
<td>123</td>
<td>3</td>
<td>0.100</td>
<td>0.000</td>
<td>1</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Jun-24</td>
<td>128</td>
<td>3.5</td>
<td>5</td>
<td>0.216</td>
<td>Jul-07</td>
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<td></td>
</tr>
<tr>
<td>Jun-26</td>
<td>131</td>
<td>3.5</td>
<td>2</td>
<td>0.053</td>
<td>Jul-09</td>
<td>135</td>
<td>3</td>
<td>0.098</td>
<td>0.045</td>
<td>4</td>
<td>0.31</td>
<td></td>
</tr>
</tbody>
</table>

**Mean**: 126 2.2 0.083 19.9 133 3.9 0.146 0.071 7.73 0.35

**Std. Dev.**: 10 1.3 0.054 7.9 10 1.0 0.048 0.049 6.09 0.16
The ratio of plus growth circuli length to total scale length ($L_+ : L_{tot}$) indicates the degree of growth and allows for comparison of this parameter between scales collected at the time of marking and at the time of recapture. The average ratio of $L_+ : L_{tot}$ was significantly greater for recaptured smolts at the outflow of Western Brook Pond (0.15 ± 0.05) compared with scales from the same individuals at time of marking in Stag Brook (0.08 ± 0.05) ($P < 0.0005$). In fact the mean $L_+ : L_{tot}$ ratio was more than doubled for the group when recaptured compared to when marked (Table 3.7). The mean number of plus growth circuli present per scale was significantly higher for individuals at time of recapture compared to time of marking. The mean number of circuli at the time of marking was 2.2 ± 1.3, while at time of recapture the same individuals had a mean circuli number of 3.9 ± 1.0 ($P < 0.0014$). The individual that increased its length by 25 mm displayed a large increase in the number of plus growth circuli. At time of marking this emigrant showed 2 plus growth circuli, but at time of recapture had 6 (Table 3.7).

Using the radius length of the plus growth circuli a calculation of individual circulus width was done to quantify the addition of scale material relative to the increase in fork-length. All but two individuals showed a significant increase in the mean width of plus growth circuli from their time of marking in Stag Brook (0.021 ± 0.010 mm) until their recapture at Western Brook Pond (0.029 ± 0.005 mm) ($P < 0.05$). The mean increase in circulus width was 0.008 mm (Table 3.8).
Table 3.8: Differences in number of circuli, radius length of plus growth circuli, and circulus width for Atlantic salmon smolts between the time of marking in Stag Brook until recapture at the discharge of Western Brook Pond, 2000.

<table>
<thead>
<tr>
<th>Date Marked</th>
<th># of L+ circuli</th>
<th>L+ circulus width (mm)</th>
<th>Date Recap.</th>
<th># of L+ circuli</th>
<th>L+ circulus width (mm)</th>
<th>Diff. In L+ width (mm)</th>
<th>Diff. circulus width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun-01</td>
<td>2</td>
<td>0.040</td>
<td>Jun-21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jun-05</td>
<td>0</td>
<td>0.000</td>
<td>Jul-05</td>
<td>4</td>
<td>0.120</td>
<td>0.120</td>
<td>0.030</td>
</tr>
<tr>
<td>Jun-05</td>
<td>0</td>
<td>0.000</td>
<td>Jun-30</td>
<td>3</td>
<td>0.090</td>
<td>0.090</td>
<td>0.030</td>
</tr>
<tr>
<td>Jun-07</td>
<td>1</td>
<td>0.020</td>
<td>Jul-05</td>
<td>4</td>
<td>0.120</td>
<td>0.100</td>
<td>0.010</td>
</tr>
<tr>
<td>Jun-07</td>
<td>2</td>
<td>0.060</td>
<td>Jun-30</td>
<td>3</td>
<td>0.100</td>
<td>0.040</td>
<td>0.003</td>
</tr>
<tr>
<td>Jun-11</td>
<td>2</td>
<td>0.080</td>
<td>Jul-03</td>
<td>4</td>
<td>0.140</td>
<td>0.060</td>
<td>0.005</td>
</tr>
<tr>
<td>Jun-14</td>
<td>2</td>
<td>0.040</td>
<td>Jun-27</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jun-14</td>
<td>2</td>
<td>0.070</td>
<td>Jul-04</td>
<td>4</td>
<td>0.120</td>
<td>0.050</td>
<td>0.005</td>
</tr>
<tr>
<td>Jun-14</td>
<td>2</td>
<td>0.040</td>
<td>Jul-04</td>
<td>3</td>
<td>0.060</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>Jun-15</td>
<td>2</td>
<td>0.040</td>
<td>Jul-23</td>
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<td>0.180</td>
<td>0.140</td>
<td>0.010</td>
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<tr>
<td>Jun-18</td>
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<td>Jul-06</td>
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<td>0.080</td>
<td>0.040</td>
<td>0.007</td>
</tr>
<tr>
<td>Jun-20</td>
<td>5</td>
<td>0.100</td>
<td>Jul-07</td>
<td>6</td>
<td>0.150</td>
<td>0.050</td>
<td>0.005</td>
</tr>
<tr>
<td>Jun-23</td>
<td>3</td>
<td>0.070</td>
<td>Jul-08</td>
<td>4</td>
<td>0.106</td>
<td>0.036</td>
<td>0.003</td>
</tr>
<tr>
<td>Jun-24</td>
<td>3</td>
<td>0.080</td>
<td>Jul-07</td>
<td>4</td>
<td>0.120</td>
<td>0.040</td>
<td>0.003</td>
</tr>
<tr>
<td>Jun-24</td>
<td>3</td>
<td>0.080</td>
<td>Jun-30</td>
<td>3</td>
<td>0.080</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Jun-24</td>
<td>5</td>
<td>0.160</td>
<td>Jul-07</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jun-26</td>
<td>2</td>
<td>0.040</td>
<td>Jul-09</td>
<td>3</td>
<td>0.080</td>
<td>0.040</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Mean: 2.2, 0.056, 0.021, 3.9, 0.110, 0.029, 0.059, 0.008
Std. Dev.: 1.4, 0.039, 0.010, 1.0, 0.032, 0.005, 0.039, 0.010
Discussion:

The prediction that Atlantic salmon smolts from Stag Brook were delayed during their passage through Western Brook Pond was supported. Further, the delay was generally in the order of weeks and not ≥ 1 year. Emigrating juveniles from Stag Brook were successfully recaptured both at the outflow of Western Brook Pond and at the mouth of Western Brook in the same year of marking. Therefore, smolts do navigate the fjord lake and make it to the ocean in one migratory period.

The timing of migration in this system points to a delay in the emigration of individuals moving through Western Brook Pond. Stag Brook smolts were captured moving downstream during May and June, with the peak in the run as early as late May, and never later than the first two weeks of June. In contrast, the peak in emigration at the outflow of Western Brook Pond occurred in late June to early July in all three years sampled. Therefore, up to 3 weeks passed from the time that a large number of smolts entered the pond and a large number of individuals were caught exiting the lake where it is drained by Western Brook. Based on the recapture of marked Stag Brook smolts, the average time to navigate the pond was approximately 20 days for both 1999 and 2000. This time lag (three weeks) coincides with the difference in timing of general smolt movements that occurred at the two sites.

The trip speed of smolts through the pond was 0.32 km • day⁻¹ for both years. In comparison, Carlin tagged smolts moved at a pace of 1.8 to 15.6 km • day⁻¹ through Red Indian Lake of the Exploits River system (Bourgeois et al., 1986) and speeds of 0.59 to 2.84 cm/s (0.51 – 2.45 km • day⁻¹) were observed by Thorpe et al. (1981) for smolts carrying radio transmitters through Loch Voil, Scotland. Both studies describe speeds of
migration greater than smolt migration from Stag Brook to the outflow of Western Brook Pond. Unlike Bourgeois et al. (1986), the individuals used in the present study were not translocated.

The cause of this delay in migration is likely not linked to the distance to be traveled (about 5.4 km). Much larger distances of migration were accomplished by smolts through Red Indian Lake and Loch Voil (Bourgeois et al. 1986; Thorpe et al. 1981). Previous studies have predicted that smolt migration through lakes is passive and controlled by surface water currents that are created by wind and flow through dynamics (Hansen et al. 1984; Thorpe et al. 1981). The slow rate of turnover for Western Brook Pond is directly related to the lack of flow through dynamics there (Kerekes 1994). The regular wind action on the pond is variable and often violent. The prevailing wind direction in May and June is southerly to southwesterly (Environment Canada 1996). However, the steep fjord walls create a funneling effect when winds blow from an easterly or southeasterly direction, which was also common during the juvenile migratory period from 1998 – 2000. It seems highly unlikely that emigrant salmon moving through the lake would use surface currents as a mechanism for orientation during these periods of intense wave action. If surface water currents did assist smolt movement in Western Brook Pond, then migration times would likely be faster than those observed in this study since winds blowing in the direction of Western Brook occur often and with force during May and June. Therefore, the results of this study further solidify the theory of a significant directed active component to the movement of salmon smolts in lakes (Brett et al. 1958; Bourgeois et al. 1986; Johnson and Groot 1963; Groot 1965).

The cause of the delay can more likely be related to the decrease in water
temperature encountered by smolts when entering Western Brook Pond from Stag Brook. Österdahl (1969) observed that salmon smolt runs in a Swedish river normally started when the water temperature reached 10 °C and Solomon (1978) concluded that few Atlantic salmon smolts move below a threshold temperature determined by the prevailing temperature of the preceding weeks. The descent of Atlantic salmon smolts in the River Imsa (Norway) was not considered to be triggered by a specific water temperature or a specific number of degree days, but was controlled by a combination of actual temperature and temperature increases in the water during spring (Jonsson et al. 1985). Water temperatures between 8 and 10 °C were reached in Stag Brook in early June while during the same time period, temperatures in the lake were between 4 and 6 °C. This decrease in the temperature encountered by smolts likely lead to a delay in migration as smolt movement out of the lake did not occur until late June and early July, when the water temperature of the pond reached 8 – 10 °C.

Loss of smolt characteristics has been observed for Atlantic salmon juveniles at higher water temperatures (Duston et al. 1991; McCormick et al. 1999). However, a delay in acquiring smolt characteristics does not seem substantial in cool water conditions. Although some mortality occurs, those that survive continue smolting after entering cold sea water (Arneson et al. 1998; Dickoff et al. 1989). The results of this study indicate that Atlantic salmon smolts that enter a cooler lentic environment from a warmer fluvial one do not suffer a delay in smoltification. Juveniles marked in Stag Brook and recaptured on the other side of the lake all appeared further smoltified. In fact, the mean condition factor of smolts recaptured at Western Brook Pond was significantly lower than for smolts marked in Stag Brook in 2000. The reduction in condition factor by
Atlantic salmon juveniles is accompanied by an increase in Na\textsuperscript{+}-K\textsuperscript{+} ATPase activity, and as a result is a considered a good indication of smoltification (Saunders et al. 1998, Specker et al. 2000, Handeland et al. 2001). Furthermore, the smolts caught at the outflow of the lake showed a higher degree of smoltification than those caught in Stag Brook in all years sampled.

Despite a general increase in smoltification, a small correlation between lake residence time and the day of the smolt run that an individual was marked was observed. An important behavioural change involved in smoltification is the movement away from a territorial strategy of parr to one of schooling in smolts (Kallberg 1958; Wedemeyer 1980). As much as 7 days difference in migration time to the outflow of Western Brook Pond was recorded for individuals marked in Stag Brook on the same day. These results indicate that “temporal cohorts” created in the nursery stream may not be adhered to once entering a lake, and behaviour of an individual nature rather than one of schooling occurs.

None of the smolts marked at the discharge of Western Brook Pond and very few of the smolts marked in Stag Brook were recaptured at the counting fence in 1999. This is likely due to the low number of individuals marked and the low efficiency related to the counting fence. The occurrence of three shallow steadies on Western Brook may have also increased the possibility of predation on these marked smolts. Jepsen et al. (1998) observed significantly increased mortality rates for smolts migrating through a shallow reservoir on the River Gudenå (Denmark) due to predation.

In all three years a significant increase in mean fork-length was measured in smolts moving from Stag Brook to the outflow of Western Brook Pond. The age of smolts exiting the lake was not significantly different from the age that smolts emigrate
from Stag Brook. These results indicate significant growth in the pond. The earliest running smolts at the counting fence in 1999 were assumed to have reared in Western Brook and its steadies because few smolts had begun emigrating from Western Brook Pond before June 18. These “riverine” smolts (of the same age) were significantly smaller than smolts caught exiting the lake, and smolts caught at the counting fence after June 18. Therefore, the fjord lake appears to produce smolts larger than both Stag Brook and Western Brook, which is in agreement with previous studies documenting increased size of juvenile Atlantic salmon reared in lakes (Hutchings 1986; O’Connell et al. 1989; Erkinaro and Gibson 1997).

Despite cooler water temperatures throughout the spring and summer at the outflow of Western Brook Pond, the percentage of smolts showing plus growth was greatest there when compared to Stag Brook in all years sampled.

The percent of captured individuals showing plus growth at each site fluctuated between years. The difference in the percentage can be directly related to the average daily mean temperature for that field season. 1999 had the highest spring/summer temperatures at both Stag Brook and the outflow of Western Brook Pond, and 1999 showed the largest proportion of juveniles with plus growth relative to 1998 and 2000.

The proportion of individuals showing plus growth in Stag Brook during the first half of the smolt run in 1998 and 2000 indicates that, even in relatively cooler years, some growth did take place during early spring in the nursery stream. In warmer years such as 1999, the amount of spring growth that is accomplished early in the migratory period and in the fluvial environment was substantial.
This increased potential for growth in Western Brook Pond is more distinctively defined by results of the mark-recapture experiment. These results show a significant increase in the mean fork-length of smolt marked in Stag Brook and recaptured as smolts at Western Brook Pond. On average 7.7 mm of length was added while migrating through the lake. The average growth per day was $0.35 \pm 0.16 \text{ mm} \cdot \text{day}^{-1}$ for smolts in the act of migrating through Western Brook Pond, which has been described as having a low productivity (Kerekes 1994). Cunjak (1992) described growth rates of $0.23 \pm 0.42 \text{ mm} \cdot \text{day}^{-1}$ observed for Atlantic salmon parr / pre-smolts captured in the estuary of Western Arm Brook, Newfoundland. The rate of growth was greater in the estuary than in the river (mean growth rate = $0.12 \pm 0.13 \text{ mm} \cdot \text{day}^{-1}$) for juveniles (parr). Western Arm Brook was described as having relatively low growth in comparison with other rivers, yet the low productivity of Western Brook Pond managed to facilitate the growth of migrating smolts at a faster rate than for estuarine parr / pre-smolts of Western Arm Brook.

This increase in growth was also noticed in a significantly greater number of plus growth circuli being present on scales of recaptured individuals than on marked individuals. In fact, the mean number of plus growth circuli was almost doubled during the time spent in Western Brook Pond. Comparing the ratio of plus growth radius length to total scale radius length gives a good indication of growth between the two capture events. The significant difference in the proportion of the scale that plus growth makes up after time spent in the pond indicates an increased growth rate.

To more precisely compare if there is a difference in growth rate between the fluvial and lacustrine environments, the width of single plus growth circulus was
measured. The circuli that were added during migration through the pond were on average 0.007 mm wider than those laid down in Stag Brook, which provided further evidence for the higher potential for growth in Western Brook Pond. These results corroborate previous findings of increased growth potential by Atlantic salmon juveniles in a lacustrine environment (Erkinaro and Gibson 1997; Hutchings 1986; Pepper et al. 1985). However, this study is the first to report the increased growth potential for smoltifying Atlantic salmon migrating through a lake.

Western Brook Pond has been described as extremely low in production (Kerekes 1994) yet growth rates increased there. Reduced tendencies for interspecific and intraspecific competition, decreased predation, and a lowering of energy requirements needed to maintain position have been presented as possible reasons for increased growth potentials of lakes (Birt et al. 1990; Hutchings 1986; O’Connell and Ash 1989). However, lake-reared Atlantic salmon smolts that migrated down the River Imsa (Norway) in late spring and throughout the summer had reduced survival compared to stream-reared fish that migrated primarily in May (Hansen 1987). Similar migratory timing occurs in the Western Brook system for lacustrine and riverine rearers. However, Lundqvist et al. (1988) concluded that larger sized descending smolts have better survival at sea. For this reason Western Brook Pond may be an important environment for parr and migrating smolts to rear and increase their growth before entering the ocean.

The capture of a large number of smolts exiting Western Brook Pond that had not been marked in Stag Brook suggests some migration of parr into the lake that subsequently smoltify and emigrate. Parr migration into the fjord pond could occur from Stag Brook (downstream) or as an upstream movement from Western Brook. Both
modes of movement have been described for Atlantic salmon parr (Huntsman 1945; Hutchings 1986; Ryan 1986; Erkinaro and Gibson 1997; Erkinaro et al. 1998a, 1998b). The small number of parr captured in 1998 and in 1999 in Stag Brook provided little evidence of significant parr movement to the lake. However, in 1999 the capture of parr at the outflow of Western Brook Pond and at the mouth of Western Brook indicated possible downstream movements at these locations. Since the parr were not marked at these sites it is not known if they were resident and captured repeatedly. The parr captured at the counting fence in 1999 may have been moving into the estuary to take advantage of increased growth potentials (Cunjak et al. 1989, Cunjak 1992).

In Stag Brook, in 2000, a peak in parr movement occurred on June 25, a week after a peak in smolt migration. These parr were 5 – 8 cm and were 1 year old. Parr have been shown to precede or accompany the smolt run (Hutchings et al. 1986). Although parr were captured during the smolt run at Stag Brook in 2000, it appears that movement may increase after the peak in smolt migration. Only 2 of the marked parr < 9 cm were subsequently recaptured downstream, and as a result no affirmation of downstream movement to the lake could be reached. The lack of recaptures may be due to low water conditions at this time, which may have caused a decrease in the fyke trap efficiency at the recapture site. Parr ≥ 9 cm were recaptured with 35 % success, which is significantly lower than the efficiency of smolt recapture of 60 % at the same time. These results indicate that larger parr (2 – 3 years old) are less likely to migrate downstream to the pond, yet show more mobility that younger parr.
Conclusions:

In summary, Atlantic salmon emigrants from Stag Brook do migrate to the sea in one spring/summer. Migration was delayed by the fjord pond due to its relatively cool lentic environment compared to the nursery stream. The observations of this study support the theory of a large directed active component to migration (Bourgeois et al. 1986). Despite the cooler temperatures of Western Brook Pond, an increase in growth and more advanced levels of smoltification were observed for individuals that are likely reared there and those that simply migrate through the pond. Differences in migration times for individuals marked and released on the same day indicate a lack of cohesion to temporal migratory groups when moving through a fjord lake. Parr movement into Western Brook Pond and the estuary of Western Brook are highly likely yet not proven.
References:


Abstract:

The production of Atlantic salmon smolts by the Western Brook system was estimated by electrofishing, fish-counting fence data, and a mark-recapture experiment. The production estimates are for use in preliminary assessment purposes of this watershed for Gros Morne National Park, Newfoundland. Parr densities for the two tributaries of this system were not significantly different within the same year, however, smolt production was greater for Western Brook due to greater area of suitable rearing habitat. No significant difference in parr densities were noticed between years sampled for the same tributary. Estimates of smolt production (1998 – 2000) in the Western Brook system indicated 7 500 – 11 000 smolts produced in one migratory season. The results indicate a substantial contribution by the fiord lake, Western Brook Pond, to the production of smolts for this system.
Introduction:

Knowledge of the production of emigrating smolts for a river system is often required for the management of the Atlantic salmon populations (Chadwick 1985, Dempson & Stansbury, 1991). Smolts are the last stage in the life cycle of Atlantic salmon that can be censused before fishing mortality occurs. Quantifying changes in smolt abundance and age composition can indicate stock problems requiring management attention, and can be a good measure of enhanced production due to management (Power 1985).

Atlantic salmon smolt production has been estimated using a variety of parameters. Estimates of standing parr density for a river system have been used to predict the number of smolts to be produced the following year. This method is based on the area of habitat that is available to rear parr. However, this method often is accompanied by large confidence limits causing both over- and under-estimations of smolt production (Baglinière et al. 1993, Chadwick and Green 1985).

Total counts or complete census sampling have also been used to try to estimate Atlantic salmon smolt production. A complete enumeration of the smolts caught exiting a system or a tributary is often coupled with the efficiency of the sampling gear, most often a fish-counting fence or fish way, to estimate the total run of smolts for a year (Saunders et al. 1967, Chadwick 1981, Chadwick and Green 1985, Baglinière et al. 1993, Cunjak and Therrien 1998). Counting smolts at traps is considered the most accurate method for determining their abundance of smolts (Power 1985). However, traps work best in rivers that are small with relatively low discharges. In this situation, efficiencies are high and smolt mortalities are not substantial (Chadwick 1985). In larger river
systems, which have high fluctuations in discharge, obtaining a complete count may not be feasible.

An alternate method of estimating smolt production is by the enumeration of adults. Fish-counting fences and fish ways have been used to enumerate the number of adults returning to a river to spawn. Chadwick and Green (1985) used counts of adults to calculate smolt production for Western Arm Brook. Previous studies have quantified survival of Atlantic salmon at sea from smolt to adult stages (Saunders et al. 1967, Hansen 1988). Applying the likelihood of survival to adult stage to the number of adults that did return can yield an estimate of smolt production for the previous year.

In situations where total counts are not feasible, mark-recapture estimates of salmon smolt populations have been employed. Many estimates of abundance have been based on the single census Petersen formula (Ricker 1975). Assumptions associated with the such an estimate are: (1) the population is closed (i.e., additions or losses to the population are negligible during the time of study); (2) fish do not lose their marks; (3) fish are correctly identified as marked or unmarked; (4) marking does not affect the catchability of the fish; and (5) marked and unmarked smolts mix randomly in the population (Ricker 1975, Dempson and Stansbury 1991). However, this estimator may not be appropriate when applied to migrating populations, especially if the assumptions of constant probability of capture, closed population, and random mixing of marked and unmarked individuals are not met (Seber 1982). Previous studies have employed a maximum likelihood estimate (Darroch 1961) for stratified populations (Dempson and Stansbury 1991, Schwarz et al. 1994, Schwarz et al. 1997). This type of estimate takes into account differences in the probability of capture/recapture during stratified sampling.
occasions. Estimation using this type of technique requires a large number of smolts to be marked over the stratified time period. A large number of individuals must also be recaptured during each sampling occasion. The Petersen formula may be employed by default in situations of low numbers (Schwarz et al. 1994).

The potential freshwater production of Atlantic salmon smolts was historically attributed to the amount of rearing habitat available to parr (Elson 1975). However, previous studies have shown that, in Newfoundland, juvenile Atlantic salmon rear extensively in lacustrine habitat and, therefore, these habitats should be considered when estimating smolt production (Pepper 1976, 1985, Chadwick and Green 1985, Hutchings 1986, Ryan 1986, O’Connell et al. 1989).

Smolt production in lakes has been difficult to estimate. Chadwick and Green (1985) used a combination of a total census of emigrating smolts as well as electrofishing density estimates of fluvial parr to calculate that 67% of smolts were produced in lacustrine habitats of Western Arm Brook. Mark-recapture estimates have also been used (Ryan, 1986), as well as censusing smolts emigrating out of a lake (O’Connell and Ash 1989). Dempson et al. (1996) compared empirical and back-calculated growth of lacustrine versus fluvial reared Atlantic salmon parr, and concluded that as many as 75% of the juveniles had used lakes for rearing, further indicating the importance of lakes to smolt production.

The purpose of this study was to provide a preliminary estimate of Atlantic smolt production for the Western Brook system, Newfoundland, based on direct enumeration, standing parr densities, and mark-recapture data. An estimate of the contribution to smolt production from Western Brook Pond, a large fjord lake, to the overall production in the
system is discussed. Information pertaining to Atlantic salmon smolt production for this catchment is scarce. Dependable estimates of smolt production would be invaluable for the management of the salmon populations in Gros Morne National Park.

Methods:

Electrofishing:

Electrofishing surveys in 1998, 1999 and 2000 were used to estimate the density of parr in the fluvial portions of the system. Five sites were located on Stag Brook and six on Western Brook (Figure 4.1).

Figure 4.1: Map showing the Western Brook Pond river system and the location of fyke trap sampling sites, fish-counting fence, and electrofishing sites for 1999 – 2000.
The sampling sites represented the habitat types found in the river, which included riffles, runs, and flats. Sampling was carried out during the last week of July and the first week of August in all years as the low water conditions needed for sampling persisted over this time period. Sites were blocked off with barrier nets of 0.5 cm mesh and the area corralled by the nets was measured. The enclosed sections were electrofished 3 to 4 times (sweeps). After each sweep, captured salmon parr were anesthetized (using 40 ppm clove oil/ethanol bath)(Anderson et al. 1997), measured for length and weight, sampled for scales, and retained in a live-box until the end of sampling for that site.

Stag Brook was surveyed for the occurrence of riffles, runs, flats and pools from its headwaters to its mouth. Measurements of river length and width were taken using tape measures at each of these habitat types for subsequent calculation of the area of suitable rearing habitat for juvenile Atlantic salmon. The area of suitable parr rearing habitat was used to estimate the density of parr in Stag Brook from 1998 - 2000. Western Brook was previously surveyed for the occurrence of particular habitat types by Hickey (1983). Measurements of habitat length and width were carried out manually (with a tape measure) and with aerial photographs for calculation of the area of suitable parr rearing habitat for the brook. The area of suitable parr rearing habitat reported by Hickey (1983) was used in this study to estimate the density of parr in Western Brook for 1998 and 1999. Elevated water levels made electrofishing impossible in 2000 and, therefore, parr densities for this river were unattainable for Western Brook.

The sampled scales were aged to determine the age distribution of parr captured in each river. This distribution was then used to predict the number of parr age ≥ 2
contributed to smolt production the following year (the vast majority of smolts exiting this system are age 3; see Chapter 3). A survival rate of 30% from summer parr to spring smolts (Cunjak and Therrien 1998) was used to estimate smolt production using age 2 or greater parr densities.

**Counting Fence Operations:**

In 1999 a fish-counting fence was constructed just below the head of tide on Western Brook (Figure 4.1). This fish counting fence was constructed of aluminum conduit spaced 6 mm apart and had both an upstream adult trap and a downstream smolt trap (Anderson and McDonald 1978). It was operational from June 3 to September 8.

Adult Atlantic salmon captured in the upstream fish trap were counted, identified as grilse or multi-winter sea adult, and sexed. All adults were also measured for length and weight, and sampled for scales.

Using a return rate of 4-6% (C. Mullins pers. comm. D. F. O., Newfoundland), an estimate of the previous year’s smolt production for the entire system was calculated from the count of adult grilse spawners caught at the counting fence.

The fish-counting fence was intended to give a total count of smolts exiting the Western Brook system in 1999. Smolts captured in the trap were observed for any marks administered at upstream marking sites. A sub-sample of ten smolts per day was anesthetized and measured for length and weight.

The efficiency of the smolt fence with 6 mm spacing between the conduits was tested. A fyke net was placed approximately 500 m upstream from the fish-counting fence and smolts captured were given upper caudal fin clips (UCFC). The efficiency of
the smolt-counting trap was then applied to the number of Atlantic salmon smolts caught exiting the system in 1999 to estimate the total number of smolts produced by the system for that year.

**Mark – Recapture:**

**Upstream Marking Site – Stag Brook:**

Two fyke traps (18 mm mesh size) were set in Stag Brook on May 30, 2000 (Figure 4.1). The traps were fitted with wood boxes at their cod end to reduce mortality due to capture. Captured smolts were anesthetized using a 40 ppm clove oil bath and measured for fork-length and weight.

A Panjet dental inoculator was used to administer Alcian Blue tattoos to the ventral body surface, just anterior to the pelvic girdle (Hart & Pitcher 1969, Moffett et al. 1997). This location was chosen due to its lack of pigmentation that made the mark easily distinguishable.

Individually numbered Carlin tags were also used to mark migrating smolts. The green plastic tags were attached just anterior of the dorsal fin with double polyethylene monofilament thread. All individuals were marked with an anal fin clip (AFC) to create a check on tag or tattoo loss. Marked smolts were held for 24 hours to observe mortalities that may have been due to marking.

When marking, the total number of smolts captured by both fyke traps was assessed. Half of these smolts were then given Panjet tattoos and the other half were given Carlin tags.
**Downstream Recapture Site – Western Brook:**

Five fyke traps were positioned approximately 440 m downstream from Western Brook Pond on June 14, 2000. This site was approximately 5 km from where smolts were marked in Stag Brook (Figure 4.1). A fyke trap was used to capture and mark smolts approximately 300 m upstream from the main trapping site on this river. Recaptures from this marking site were used to calculate efficiency of the five fyke traps, for estimating the total number of smolts emigrating from Western Brook Pond (Figure 4.1). The captures at this site were checked carefully for marks administered in Stag Brook. Recaptures were anesthetized and re-measured for length and weight. By subtracting the estimate of smolt produced in Stag Brook for the same year, an estimate of the smolt production of the lake was reached.

**Statistical Analyses:**

Densities of salmon parr were calculated using catch-depletion data and the removal method (Zippin 1956, Seber 1982). This analysis gave maximum-likelihood estimates of population size ($\hat{N}$) and the percentage of the population captured after 3 – 4 sweeps for a site. Interannual comparisons of parr density for both Stag Brook and Western Brook were done by General Linear Model analysis followed by pairwise difference testing. Student’s $t$-tests were preformed to compare parr densities between the two brooks for 1998 and 1999.

The mark-recapture data were used in a single census Petersen method to estimate the population of smolts exiting the system in 2000.
The Petersen estimate is calculated in the following manner (Chapman 1951):

\[
\hat{N} = \frac{[(M + 1)(C+1)}{(R + 1)] - 1
\]

where \( \hat{N} \) = size of population at time of marking

\( M \) = number of fish marked

\( C \) = catch or sample taken for census

\( R \) = number of recaptures in the sample

The variance estimate for \( \hat{N} \) (Seber 1970) is:

\[
V(\hat{N}) = \frac{[(M + 1)(C + 1)(M - R)(C - R)]}{[(R + 1)^2(R + 2)]}
\]

The 95 % confidence intervals for the population size (Lohr 2000) were calculated using:

\[\hat{N} \pm 1.96 \sqrt{V(\hat{N})}\]

Results:

a) Estimate of smolt production in Stag Brook and Western Brook using parr densities calculated from electrofishing data:

Although a slight decrease in mean parr density (number of fish per 100 m²) in Stag Brook from 1998 – 2000 occurred, General Linear Model analysis showed that this difference was not significant \((P > 0.05)\). The same analysis indicated there was no significant change in the parr density of Western Brook between 1998 and 1999. The comparison of parr density between tributaries within the same year showed no significant difference \((P > 0.05)\)(Figure 4.2).
The calculated parr density in Stag Brook in 1998 was 32.80 parr/100 m² (Table 4.1). Total parr rearing habitat in Stag Brook was estimated as 82 334 m² by this study. Therefore the total number of parr in Stag Brook was estimated at 27 006, in 1998. 33 % of parr captured during electrofishing were age 2 or 3. Applying this percentage to the estimated total number of parr in Stag Brook in 1998 yields an estimate of 8 912 parr ≥ age 2. Assuming a survival of 30 % for Atlantic salmon from the parr to smolt stage (Cunjak and Therrien 1998), an estimated 2 674 smolts was predicted from Stag Brook in 1999 (Table 4.1).
Table 4.1: Estimated Atlantic salmon smolt production derived from parr densities estimated from electrofishing Stag Brook and Western Brook from 1998 – 2000.

<table>
<thead>
<tr>
<th>Year (n)</th>
<th>Tributary</th>
<th>Density (# fish/100 m²)</th>
<th>Estimate of Parr Pop. (N)</th>
<th>Estimate of Age 2-3 Parr in Population</th>
<th>Estimate of Smolt Production (year n + 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>Stag Brook</td>
<td>32.80</td>
<td>27006</td>
<td>8912</td>
<td>2674</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>20.54</td>
<td>34049</td>
<td>11236</td>
<td>3371</td>
</tr>
<tr>
<td>1999</td>
<td>Stag Brook</td>
<td>25.41</td>
<td>20921</td>
<td>6904</td>
<td>2071</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>22.35</td>
<td>37050</td>
<td>12226</td>
<td>3668</td>
</tr>
<tr>
<td>2000</td>
<td>Stag Brook</td>
<td>18.27</td>
<td>15042</td>
<td>4964</td>
<td>1489</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Means</td>
<td>Stag Brook</td>
<td>25.49</td>
<td>20987</td>
<td>6926</td>
<td>2078</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td>21.45</td>
<td>35558</td>
<td>11734</td>
<td>3520</td>
</tr>
</tbody>
</table>

The same calculations were carried out for Stag Brook densities in 1999 and 2000. The estimated smolt production in Stag Brook was greatest for 1999 when compared to 2000 and 2001. The estimate of smolt production for 2001 was the lowest of all three years sampled (Table 4.1). The estimated smolt production for this tributary ranged from 1 489 – 2 674, with the average being 2 078.

In Western Brook, the estimated the area of suitable parr rearing habitat was 165 770 m² (Hickey 1983). The parr density in Western Brook from electrofishing data in 1998 was 20.54 parr / 100 m² (Table 4.1). The proportion of parr age ≥ 2 in Western Brook was 33 %, the same as in Stag Brook, and the survival from parr to smolt was again assumed to be 30 % (Cunjak and Therrien 1998). Therefore, the predicted smolt
production in Western Brook in 1999 was 3 371 (Table 4.1). Predicted smolt production for 2000 was 3 668, and the mean for the two years was 3 520 (Table 4.1).

Using this method of estimation the sub-catchments were predicted to have produced an average of 5 598 smolts per year from 1999 – 2001. However, this estimate does not take into consideration the number of smolts that may be produced from parr rearing in Western Brook Pond and the steadies of Western Brook.

**b) Estimate of Western Brook Pond smolt production using fyke trap efficiency data:**

A total of 916 smolts was captured emigrating from Western Brook Pond in 2000. The efficiency of capture was 12 % (5 smolts recaptured out of 42 marked). Therefore the total number of smolts that may have migrated past this site in 2000 was 7 633. However, this number includes smolts produced in Stag Brook that migrate through the lake in the same year (Chapter 3). If the estimated number of smolts produced in Stag Brook in 2000 (using the electrofishing data for 1999, Table 4.1) is subtracted from the above estimate, smolt production by the lake in 2000 was:

\[
7 633 - 2 071 \text{ (Stag Brook)} = 5 562 \text{ smolts}
\]

Therefore, the total production of smolts for the entire river system using the above estimates was:

\[
2 071 \text{ (Stag Brook)} + 5 562 \text{ (Western Brook Pond)} + 3 668 \text{ (Western Brook)}
\]

\[= 11 301 \text{ smolts (Table 4.2)}\]
c) Estimate of 1997 Western Brook system smolt production using the number of migrating adult salmon captured in 1998:

The number of Atlantic salmon grilse (1 sea winter) captured moving upstream at the Western Brook fish fence in 1998 was 213. Using a 4-6 % smolt to adult survival coefficient (C. Mullins, pers. comm., D. F. O. Newfoundland) then the total number of smolts emigrating out of the system in 1997 was between 3 550 – 5 325 (Table 4.2).
Table 4.2: Estimates of yearly smolt production created by electrofishing, enumeration and mark-recapture data for Stag Brook, Western Brook Pond, Western Brook, and the system as a whole.

<table>
<thead>
<tr>
<th>Smolt Year</th>
<th>Technique of Estimation</th>
<th>Water Body</th>
<th>Estimated Smolt Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Enumeration (fish fence 1998 - adults)</td>
<td>Total system</td>
<td>3 550 – 5 325</td>
</tr>
<tr>
<td>1998</td>
<td>Enumeration (fish fence 1999 - adults)</td>
<td>Total system</td>
<td>5 383 – 8 075</td>
</tr>
<tr>
<td>1999</td>
<td>Enumeration (fish fence 1999 - smolts)</td>
<td>Total system</td>
<td>8 535</td>
</tr>
<tr>
<td></td>
<td>Enumeration &amp; Electrofishing (fish fence 1999 - smolts) (parr density 1998)</td>
<td>Western Brook Pond</td>
<td>2 490</td>
</tr>
<tr>
<td>2000</td>
<td>Electrofishing (parr density 1999)</td>
<td>Stag Brook</td>
<td>2071</td>
</tr>
<tr>
<td></td>
<td>Western Brook</td>
<td></td>
<td>3668</td>
</tr>
<tr>
<td></td>
<td>Enumeration (fyke traps 2000)</td>
<td>Western Brook Pond</td>
<td>5 562</td>
</tr>
<tr>
<td></td>
<td>Total system</td>
<td></td>
<td>11 301</td>
</tr>
<tr>
<td></td>
<td>Mark-Recapture (Petersen formula)</td>
<td>Stag Brook + Western Brook Pond</td>
<td>14 861 ± 5 081</td>
</tr>
</tbody>
</table>


d) Estimate of 1998 Western Brook system smolt production using the number of migrating adult salmon captured in 1999:

The number of Atlantic salmon grilse (1 sea winter) captured moving upstream at the Western Brook fish fence in 1999 was 323. Using the same 4-6 % smolt to adult survival coefficient, then the total number of smolts emigrating out of the system in 1998 was between 5 383 – 8 075 smolts (Table 4.2).

e) Estimate of total smolt production using the total count of smolts exiting the system in 1999 through the fish fence:

The total number of smolts counted leaving the system at the mouth of Western Brook in 1999 was 1707. However, the efficiency of the smolt fence was estimated at 20 %. As a result, the estimate of smolts leaving the system in 1999 was 8 535 smolts (Table 4.2).

f) Estimate of smolts produced in Western Brook Pond in 1999 using the total count of smolts exiting the system in 1999 and 1998 parr densities of Stag Brook and Western Brook:

The estimate of Atlantic salmon smolts leaving the system in 1999 was 8 535 (Table 4.2). By subtracting the predicted smolt production of both Stag Brook and Western Brook for 1999, which was estimated using the parr densities in these two tributaries in 1998 (Table 4.1), the production of smolts in the lake can be isolated:

\[ 8 535 \text{ (total)} – 2 674 \text{ (Stag Brook)} – 3 371 \text{ (Western Brook)} = 2 490 \text{ lake smolts} \] (Table 4.2).
g) Petersen estimate using mark-recapture data for the 2000 field season:

The total number of smolts marked in Stag Brook was 470. The total number of captures at the Western Brook Pond site was 916. The total number of recaptures was 28 (Chapter 3). The Petersen method yielded an estimate of $14,861 \pm 5,081$ (95% confidence interval) of smolts from both Stag Brook and the lake. This estimate was higher than the other estimate for 2000, and higher than smolt estimates in previous years for the upper portion of the system (Table 4.2).

Discussion:

The parr densities gained by electrofishing from 1998 – 2000 indicate that the density of parr in both Stag Brook and Western Brook pond were stable over the three years sampled. The higher parr densities and smolt production estimates in Stag Brook compared to Western Brook are in contrast to Hickey (1983), who reported little potential rearing habitat in this tributary. However, these results coincide with the opinion of Ball (1991) that Stag Brook was responsible for a significant amount of juvenile production in the system.

Previous studies (Porter et al. 1974, Hickey 1983, Ball 1991) do not supply parr densities and do not take into account Western Brook Pond or the three steadyies of Western Brook when estimating smolt production. Sampling by electrofishing was restricted to the lower reaches of Stag Brook and barrier nets were not always used (Hickey 1983, Ball 1991).
Low flow areas (i.e., steadies) of the system were not sampled. Possible utilization of these steadies by Atlantic salmon parr may have caused underestimation of smolt production for the Western Brook (Pepper 1976, 1985, Chadwick and Green 1985, Hutchings 1986, Ryan 1986, O’Connell et al. 1989). However, when compared to estimates derived from different sampling techniques, the predicted production of smolts in Stag Brook and Western Brook are realistic. Furthermore, by supplementing the estimated smolt fluvial smolt production with an estimate of production by Western Brook Pond using enumeration and trap efficiency data, a more complete estimate of production for the system was reached.

Estimations of smolt production were approximately equal for 1997 – 1999. However, the estimate of smolt production for 2000 was greater than in any other year. The estimate of smolt production for 1997 is likely low since adult salmon were observed squeezing between the conduit of the fence and it is unknown how many individuals did this. However, count of grilse caught at the fence in 1999 was almost twice that in 1998. The estimate of smolt production in 1998 is likely a good one as the efficiency of the fish counting fence in 1999 was greatly improved. However, smolt to adult survival was not determined for the Western Brook river system. Rather, a survival rate of 4 – 6 % from nearby Western Arm Brook (Mullins and Caines 2000) was used in the present study. Western Arm Brook is located approximately 180 km north of the Western Brook and was considered representative of Northern Peninsula rivers. The rate of smolt to adult survival used in this study seems applicable since the estimate of smolt production by direct enumeration of smolts in 1999 was quite close. The efficiency of the fish-counting fence for smolt capture in 1999 was 20 %, which is low. Smolts were observed
swimming between conduits that were spaced only 6 mm apart, something not reported previously. The predicted number of smolts exiting the system in 1999 by direct enumeration is also similar to the estimate of smolt production for the same year using parr densities in 1998. Consequently, the estimate of efficiency for the fish fence is reasonable. Previous attempts at smolt enumeration for the system were generally unsuccessful due to improper location of the fish fence and a series of high water events (Ball 1990, Anions 1997).

The estimated increase in smolt production from 1997 – 2000 by the Western Brook system is in contrast to Mullins and Caines (2000), who reported a decline in smolt production in each successive year in the Western Arm Brook system. In 1997, the number of smolts leaving Western Arm Brook was 23 845, and by 2000 only 12 691 smolts were produced by the system (Mullins and Caines 2000). The estimate of smolt production for the Western Brook system in 2000 may be overestimated due to the predicted number of smolts produced in the pond. The number of smolts produced by Western Brook Pond was estimated through enumeration and testing the efficiency of the traps used in enumeration. The efficiency of these traps was tested later in the smolt run (July 6 – 22) when the river discharge was relatively low. The efficiency of these traps may have been greater earlier in the run and therefore the estimate of smolt production by Western Brook Pond may be slightly inflated. The estimate of lake production, using the estimated parr density of Stag Brook and Western Brook (1998) subtracted from the total production of the system in 1999 (as predicted by direct enumeration), indicates approximately 3 000 less smolts produced by the lake in 1999 than in 2000. This further indicates that the 2000 prediction of smolt production by the lake was inflated.
Despite possible inaccuracies with the estimate of smolts produced by Western Brook Pond, it is clear that this lake contributes significantly to the production of smolts in the Western Brook system. The predicted contribution of Western Brook Pond to total smolt production in the entire system ranged from 30% in 1999 to as high as 50% in 2000. From the difference between a total census of emigrating smolts and fluvial standing parr density, Chadwick and Green (1985) estimated that 67% of the smolts produced in Western Arm Brook, Newfoundland, came from lacustrine habitats. Therefore, estimates of lacustrine smolt production for the Western Brook system are realistic. Dempson et al. (1995), through analysis of scale characteristics, estimated that 75% of parr sampled in the Conne River, Newfoundland, used lakes for rearing. Although confirmation of migration to Western Brook Pond by salmon parr from Stag Brook is not available, the large number of smolts caught exiting the lake in 2000 relative to the number of smolts enumerated exiting the system in 1999 indicates some degree of parr rearing and a substantial contribution to smolt production by the fjord lake.

The mark-recapture estimate was used to quantify production for the upper portion of the system (i.e., Stag Brook and Western Brook Pond). The numbers marked, captured, and recaptured were not sufficient to use stratification estimation techniques (Schwarz et al. 1994). As a result, a single-census Petersen estimate was employed by default. The estimated production of the upper part of the Western Brook system using the Petersen estimate was high (14 861 ± 5 081), likely due to the low numbers of smolts tagged and recaptured.

When using the Petersen index for research interests, where the population estimate will be used as a stepping-stone to further research endeavors, the margin of
error divided by the estimated population size (ME / \( \hat{N} \)) is expected to be \( \leq 10\% \), (pers. comm., C. Schwarz via C. Mullins, D. F. O.). An ME / \( \hat{N} \) \( \leq 20\% \) is acceptable for management purposes (pers. comm., C. Schwarz via C. Mullins, D. F. O.). However, an ME / \( \hat{N} \) \( \leq 50\% \) is considered acceptable for preliminary surveys of populations (pers. comm., C. Schwarz via C. Mullins, D. F. O.). The estimate of smolt production for the Western Brook system was known to be a preliminary survey from the beginning of this project as little previous work had been completed in this regard. The smolt population generated using the mark-recapture data from this study is 14 861, with a margin of error equal to 5 081. Therefore, the range of smolt production from this method is 9 811 – 19 973 for Stag Brook and Western Brook Pond combined and the ME / \( \hat{N} \) = 34\%.

Although the ME / \( \hat{N} \) is less than 50\%, the estimate seems too large for this part of the system when compared to the estimates generated by other techniques. If a smolt population within Stag Brook and Western Brook Pond of approximately 7 600 individuals is inferred from the others methods of estimation, and the numbers gained by the mark-recapture experiment are used, the number of recaptures expected was 57 at a standard error of 24\%. This standard error is well under the 50\% put forth by Schwarz (pers. comm., via C. Mullins, D. F. O.) for preliminary survey purposes and close to that usable for management purposes. However, less than half the expected marked smolts were recaptured. To reach a confidence interval of 10\% with the number of individuals marked and captured, 180 recaptures were needed. It seems most likely that a lack of recapture success occurred in this study. The assumptions of constant probability of capture and random mixing of marked and unmarked individuals may have been compromised since the distance traveled between the marking site and recapture site was
through a lake. Reductions in migratory speed (Chapter 4) may have caused inaccuracies in the Petersen estimate. As a result, the estimates generated by electrofishing parr density and enumeration of adults and smolts are likely more reliable.

Due to the error associated with each type of estimating technique, a reliable estimate of smolts produced by the system is not possible. However, the range in smolt production created by most of the estimation techniques provides reasonable bounds for production in the Western Brook system. The contribution by the upper part of the system (Stag Brook and Western Brook Pond) may be as high as 75% of total smolt production.

This paper documents the first successful estimates of Atlantic salmon parr density and both adult and smolt enumeration for the system. Information pertaining to the production of juvenile Atlantic salmon by the Western Brook system was scarce. The results of this study are a successful step in the monitoring of this system, and it presents baseline information on the juvenile salmon population therein. Recent proposals to increase the amount of tourism and research on Western Brook Pond may have impact on the Atlantic salmon community there. This study provides a reference point for the future monitoring of the effects of increased anthropogenic disturbance.
**Conclusions:**

Despite a predicted decline in Atlantic salmon smolt production from 1998 – 2000, parr densities within Stag Brook and Western Brook were similar and stable. Enumeration and standing parr density estimates gave similar results for predicted smolt production. Estimates of smolt production (1998 – 2000) in the Western Brook system indicated 7 500 – 11 000 smolts produced in one migratory season. The use of the Petersen formula was not successful in determining the smolt production of Stag Brook and the fjord lake. However, a substantial contribution (30 – 50 %) by Western Brook Pond to the total smolt production in the system was evident.
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Chapter 5 – Summary and Conclusions

No significant difference in the initial rate of mortality between Atlantic salmon smolts marked by Carlin tag versus Panjet tattoo was observed in this study. However, Carlin tagged individuals were slightly more susceptible to mortality due to the handling, anesthetization, and marking procedure (Hansen 1988, Kennedy 1991). Carlin tagging caused no mortality initially or over time for individuals tagged in the hatchery environment. Hatchery tagged individuals did not suffer any reductions in growth or condition factor when compared to non-tagged salmon juveniles. Therefore, it seems unlikely that the low number of recaptures in the wild can be blamed on the personal technique of the experimenter when Carlin tagging smolts.

Panjet tattooed smolts were not recaptured at a significantly higher rate in the field than Carlin tagged individuals, indicating that Carlin tagging can be used just as successfully as dye injection in mark-recapture experiments. The ease of identifying individuals with Carlin tags with individual identification numbers is a definite benefit to this type of mark. Therefore, it appears just as acceptable to use this mode of marking in the wild, using the protocol described earlier.

The hatchery experiment also indicated that the type of fin clip administered does not affect growth or condition factor. However, for monitoring marked individuals past 340 degree-days, anal fin clipped juvenile Atlantic salmon may be more successfully (or with less subjectivity) classified as marked due to a slower rate of fin regeneration over other fins. In the warmest year sampled, 1999, the number of degree-days reached
approximately 937 (late May – late July) in Stag Brook, which was the tributary of
warmest temperature throughout the study. Even after 937 degree-days the regenerative
properties of all the fin types clipped, in the hatchery experiment, would not likely have
been rapid enough to allow for misidentification of marked juveniles in the field. Fin
clipped smolts and parr would have shown indication of their previous marks. Therefore,
the lack of recaptures at the outflow of Western Brook Pond must be attributed to low
trap efficiency. The estimation of smolt production for Stag Brook and Western Brook
Pond created by the mark-recapture data is not conclusive and should be treated as such.
The use of the Petersen formula was not successful in determining the smolt production
of Stag Brook and Western Brook Pond due to this low number of recaptures.

Estimates using enumeration and standing parr densities gave similar results for
smolt production by the system. Estimates of smolt production (1998 – 2000) in the
Western Brook system indicated 7 500 – 11 000 smolts produced in one migratory
season. A general increase in smolt production from 1997 – 2000 for the Western Brook
system by this study does not agree with a similar study conducted in nearby Western
Arm Brook (Mullins and Caines 2000) that described a significant decrease in smolt
production over these years. The trend observed in the present study was likely a product
of using different estimating techniques to predict smolt production for a particular year.

Despite a lack of clear evidence indicating a large scale migration of Atlantic
salmon parr into Western Brook Pond, the capture of a large number of smolts exiting the
lake in each year and population estimates indicated a substantial contribution to smolt
production by the pond. The contribution of the fjord lake may be 30 – 50 % of the total
smolt production in the system, which is in agreement with previous studies that reported

Parr migration into the fjord pond could occur from Stag Brook (downstream) or in an upstream movement from Western Brook. Both modes of movement have been described for Atlantic salmon parr (Huntsman 1945; Hutchings 1986; Ryan 1986; Erkinaro and Gibson 1997; Erkinaro et al. 1998a, 1998b). The capture of parr at the outflow of Western Brook Pond and at the mouth of Western Brook indicated possible downstream movements at these locations; however, parr were not marked at these sites it is not known if the parr were resident and captured repeatedly. Parr movement has been described as preceding and accompanying smolt migration (Hutchings 1986). The results of this study indicate that peaks in downstream parr movement may also occur directly following a peak in smolt emigration. Parr ≥ 2 years of age were more mobile than 1 year old parr, possibly indicating a greater likelihood of older parr moving downstream to Western Brook Pond. Erkinaro et al. (1998b) indicated that the large majority of parr that shifted from fluvial to lacustrine habitat in the River Teno system (Finland) did so at an age of 2+.

Regardless of the number of parr reared and smolts produced by Western Brook Pond, it is clear that the fjord lake is an important area for juvenile growth. The lake produces larger and well smoltified individuals compared to Stag Brook and Western Brook. The lake also serves as an area to increase growth of smolting individuals migrating through the pond from Stag Brook. The distance migrated through the pond is relatively short (3.5 km) and could be traversed in a matter of days. However, some smolts marked in Stag Brook took as much as a month to reach the outflow of the pond at
Western Brook. Delays in migration are related to cooler water temperatures experienced by fish in the lake. Increases in Western Brook Pond’s water temperature were directly related to the start and peak of smolt migration. The compensatory advantage to prolonging their migration to the sea is an increase in growth that may not be accomplished in the river or estuary. It seems probable that Western Brook Pond is likely more productive than earlier considered (Kerekes 1994). Increased growth potential is available in the lake despite cooler temperatures throughout the migratory season. The present study also indicates that the migration of Atlantic salmon smolts in Western Brook Pond entails a large directed active component to migration (Bourgeois et al. 1986).

The results of this study have created questions such as: what areas and habitats of the fjord lake are Atlantic salmon smolts using during the temperature induced delay in migration? What sort of physiological response accompanies the migration of smolting juveniles into a deeper lentic environment? What are the food items that resident parr and migrant smolt feed on to increase their growth rates while in Western Brook Pond? Little is know regarding the flora and fauna that inhabit this water system. This study presents a minuscule piece of the puzzle. The future holds many answers regarding this beautiful lake and its tributaries, and more importantly many more mysteries.
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