Investigating the Life History of Returning iBoF Atlantic Salmon (*Salmo salar*) using Passive Integrated Transponder (PIT) Technology

by

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A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

Bachelor of Science with Honours in Biology

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THE UNIVERSITY OF NEW BRUNSWICK

February 2024

Abstract

Since the 1980s, the inner Bay of Fundy (iBoF) Atlantic salmon (*Salmo salar*) population has significantly declined, in which it was listed as endangered under the Species at Risk Act (SARA) in 2003. Fundy National Park (FNP) contains critical habitat for this population, including the Upper Salmon and Point Wolfe rivers, in which ongoing recovery efforts are being implemented. This study assesses current restoration strategies by evaluating the life history characteristics of successfully returning Atlantic salmon to FNP. Among the 385 salmon that returned to FNP rivers between 2016-2023, I found that fish reared in modified open net pens in the Bay of Fundy exhibited a return rate 1.59 times greater than fish reared in a traditional hatchery environment and juvenile salmon collected as wild smolt returned at a rate twofold higher than that of wild-exposed parr. It was found that maximizing wild exposure is crucial for the restoration of endangered salmon populations and should be a vital component to consider when captive-rearing fish. These findings allow users to adaptively manage and understand the different strategies currently being implemented by the Fundy Salmon Recovery program.

Acknowledgements

I have a multitude of individuals to thank for the guidance and support I have received throughout this project. I want to express my utmost gratitude to my supervisor, Dr. Kurt Samways, for the knowledge, guidance, and support throughout this project and writing process. John Robinson for the immense knowledge, continued advice, and support with R code, as well as for introducing me to the PIT antennas and developing my admiration for this technology. Ava Hart for her insightful feedback, criticism of my thesis, and incredible support. I want to thank all individuals from the Resource Conservation team at Fundy National Park (FNP) (past and present) who generously collected data and contributed to the setup of PIT antennas. I thank all individuals from Kurt's lab (past and present) who assisted with setting up the PIT antennas and collecting data. I would also like to extend my thanks to all Fundy Salmon Recovery partners and staff that have contributed to the conservation of iBoF Atlantic salmon and the FSR program. This project would be impossible without the help of a wide range of experts and organizations! I would also like to thank Dr. René Malenfant for his statistical expertise and feedback on my writing and Dr. Myriam Barbeau for her incredible statistical knowledge.

Statement of Research Contributions

All Passive Integrated Transponder (PIT) tags were administered to salmon by various organizations as part of the ongoing Fundy Salmon Recovery (FSR) project. PIT antenna data collected for this study was acquired by Fundy National Park (FNP) and the University of New Brunswick (UNB) staff from 2016 – 2023 over July through December. During the 2023 field season, I participated in tagging juvenile salmon as well as collecting PIT antenna data with the help of understanding the downloads by John Robinson. I standardized and preprocessed the PIT antenna data in R, using code that I developed (based on existing R code developed by John Robinson for FNP). I conducted the statistical analysis in R, in which I generated code, graphs, and tables. I wrote this thesis, for which I received editorial feedback from Dr. Kurt Samways and Dr. René Malenfant.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

DH - Dark Harbour

FNP - Fundy National Park

FSR - Fundy Salmon Recovery

GLMM - Generalized mixed effects logistic model

iBoF - inner Bay of Fundy

LGB - Live Gene Bank

MBF - Mactaquac Biodiversity Facility

PIT - Passive Integrated Transponder

PWR - Point Wolfe River

RFID - Radio Frequency Identification

UNB - University of New Brunswick

USR - Upper Salmon River

WEP - Wild-exposed parr

WS - Wild Smolt

1. Introduction

The inner Bay of Fundy (iBoF) Atlantic salmon (*Salmo salar*) population is a naturally structured, genetically distinct group of Atlantic salmon that occupies 32 to 42 rivers that drain into the upper region of the Bay of Fundy (DFO, 2010; COSEWIC, 2006). This population is unique in that it has a localized marine migration, and it has been hypothesized that iBoF salmon smolts grow to adulthood entirely within the Bay of Fundy and northern Gulf of Maine (COSEWIC, 2006). Approximately 60 percent of iBoF salmon mature in just one year of being at sea (commonly called grilse), and typically return the following year to spawn consecutively (termed iteroparous) (COSEWIC, 2006), unlike their West Coast Pacific salmon counterparts which spawn only once (termed semelparous) (Schindler et al., 2003). Species with high survival rates between annual spawning events are worthy of special conservational attention as this may play an important role in population persistence (Halttunen, 2011; DFO, 2010). Unfortunately, the iBoF population of Atlantic salmon has seen a significant decline throughout their entire range since approximately the 1980s and the drivers of this decline are not well understood (COSEWIC, 2006). A major contributor to this significant reduction in iBoF Atlantic salmon abundance is due to poor marine survival and low smolt-to-adult survival rates (Hubley & Gibson, 2011; Pardo et al., 2021). The decline can also be attributed to overfishing and the previous construction of dams, which served as a barrier in the migratory path of spawning adults (Dadswell, 2021; COSEWIC, 2006). In response to this decline, the iBoF Atlantic salmon population was listed as endangered under the Species at Risk Act (SARA) in 2003 (DFO, 2010).

The iBoF population of Atlantic salmon is a unique Canadian endemic and is known for its cultural significance, as Indigenous peoples previously harvested them for food and ceremonial purposes (DFO, 2010). Moreover, this species transfers key nutrients from the marine environment to their respective freshwater watersheds, which contributes greatly to the overall ecological integrity of these ecosystems (Bryson et al., 2022). Atlantic salmon migrating from marine to freshwater environments to spawn can be important vectors of marine-derived nutrients through egg deposition, excretion of metabolites, and carcass decomposition, enriching their surroundings at all trophic levels (Bilby et al., 2001; Marczak et al., 2007; Wheeler et al., 2017; Samways et al., 2018; Bryson et al., 2022). Increased nutrient levels have been observed in rivers and can be correlated directly with the time of spawning and when salmon density is higher (Bryson et al., 2022).

The success of recovery efforts for the iBoF Atlantic salmon population depends on the commitment and cooperation of a wide range of organizations (DFO, 2010). The Live Gene Bank (LGB) program, operating out of the Mactaquac Biodiversity Facility (MBF) in Fredericton, NB, functions to conserve the unique genetics of the iBoF population (DFO, 2010; Parks Canada, 2017). The LGB program is a captive breeding and rearing program that operates to effectively minimize the rates of wild genetic variation loss, as well as to reduce the probability of extirpation from iBoF rivers, including those in Fundy National Park (FNP), Alma, NB. Factors such as the species' genetic uniqueness, the lack of knowledge surrounding the high level of marine mortality, and the need to protect the remaining individuals has shaped the development of the LGB (DFO, 2019). This program has two main components: (1) "in-river" live gene bank, which is through the collection of wild exposed juveniles (parr) and their rearing to maturity in captivity to be broodstock, and (2) the production of offspring for the next generation of salmon to be released back into the wild (DFO, 2019). The LGB is housed in a traditional landbased facility that rears fish in a freshwater environment.

Fundy Salmon Recovery (FSR) is a collaboration between academia, Indigenous peoples, federal and provincial governments, non-government organizations, and private industry. Currently, the FSR program is being carried out in both the Upper Salmon and Point Wolfe rivers in FNP, as well as on the Petitcodiac River by Fort Folly Habitat Recovery. The FSR program aims to overcome the high marine mortality phase bottleneck by capturing ~10 – 15% of out-migrating smolts, using Rotary Screw Traps (RST). RSTs are widely used to collect and hold fish swimming downstream for sampling purposes (Music et al., 2010). Once collected, smolts are transported to the world's first wild salmon Marine Conservation Farm located in Dark Harbour on the island of Grand Manan, NB, where they are reared to maturity in modified marine net pens maintained by Cooke Aquaculture (Parks Canada, 2017). The captive marine exposure experienced at Dark Harbour is thought to influence return success and reflect an improvement in fitness (DFO, 2013). After reaching maturity, fish are reintroduced back to their native rivers to spawn.

Prior to release, all fish receive a uniquely coded 28mm half-duplex (HDX) Passive Integrated Transponder (PIT) tag which allows their movement in and out of each river to be monitored. Fish movement is estimated through the establishment of PIT arrays, large antennas capable of reading the PIT tags as the fish swims through, located at the mouth of the Upper Salmon River (USR) and Point Wolfe River (PWR) in FNP (Parks Canada, 2017). While accurate assessments of fish populations are limited by individual identification, PIT technology serves as a unique approach to confirm individual identity within a population (Zydlewski et al., 2006; Gibbons & Andrews, 2004). This method offers advantages in that the tags are internal and permanent and do not have an internal battery. Thus, they last the life of the fish and have a high reliability in tag detection and reading accuracy (Gibbons & Andrews, 2004). Data from PIT arrays can better inform research and management questions associated with fish movement and population dynamics and enable the monitoring of fish populations with no disruption to movement or normal fish behaviour (Zydlewski et al., 2006), which has yet to be investigated in the FSR program.

PIT technology serves as the primary method of assessing the number of fish that return to FNP rivers. However, both snorkelling surveys and angling serve as supplementary and cost-effective assessment methods for estimating the population abundance of returning fish. Snorkelling surveys are used as a capture-mark-recapture assessment as well as when environmental conditions may limit the effectiveness of other methods (O'Neal, 2007). They are often selected as the preferred approach for surveying salmonids because it allows for little disturbance and reasonable accuracy (O'Neal, 2007). Moreover, while recreational angling is predominantly recognized as a leisure activity, a growing body of research suggests that catch-and-release angling may serve as an approach to reduce injury and mortality when compared to other traditional capture methods (i.e., trap net) (Cooke & Schramm, 2007). Catch-and-release angling can enhance conservation measures, and anglers may provide vital information to assist conservation initiatives by reporting of fishing efforts and population demographic data (Gupta et al., 2016). Data on fish caught can aid scientists and policymakers in developing management actions, as this allows for supplementary information to be incorporated (Gupta et al., 2016). In the context of this study, angling is considered as a potential factor influencing the movement and return success of iBoF Atlantic salmon.

Reintroductions of adult Atlantic salmon to FNP for conservation occurs via one or a combination of three release strategies: helicopter, manual release by hand, or the use of a sliding mechanism. Reintroductions via helicopter are employed when fish relocation occurs in remote areas inaccessible by vehicles and involves loading fish into large, oxygenated, water-filled holding tanks, flying them to the upper reaches of the river, where a crew receives them for release into holding pools (Nason, 2023). Alternatively, hand-release techniques are used for distribution into more accessible sections of the rivers. This requires individually transporting fish in a large rubber tube filled with water, commonly referred to as a "boot." The slide release method is employed on the PWR, which features a large black tube extending from the top of the road into the estuary, with a constant flow of water, creating a "water slide." Salmon are transferred from an Xactics™ tank on the back of a truck to the mouth of the tube, where they slide down into the river. Handling and transport are stressors known to affect anadromous salmonids and their migratory movement (Finstad et al., 2003); therefore, these release strategies may affect salmon return rates.

The purpose of this study was to assess which factors lead to successfully returning Atlantic salmon to FNP between 2016-2023. Specifically, the objective was to determine if river of origin, rearing strategy, release strategy, sex, maturation, and handling result in greater returns, or increased straying. It is through a large-scale conservation program such as Fundy Salmon Recovery, that accurate and efficient monitoring of virtually the entire population is impossible. PIT telemetry provides information at the level of the individual fish for long-term application for the conservation of iBoF Atlantic salmon. Our findings can provide profound insight into current restoration initiatives and will allow users to adaptively manage and understand the different strategies of the FSR program.

2. Methods

2.1. Fundy Salmon Recovery (FSR) Study Design

As per the framework of the FSR program, juvenile Atlantic salmon (*Salmo salar*) are collected as wild smolt or wild-exposed parr/pre-smolt in Fundy National Park (FNP) in the spring and fall, respectively. Wild hatched salmon smolt are collected from the Upper Salmon River and Point Wolfe River in Rotary Screw Traps throughout their migratory period (April – June) and transported to the conservation farm in Dark Harbour, on Grand Manan Island, NB, to be reared in modified open-net marine pens to adulthood (Figure 1). Here, fish spend one year (grilse) or two years (multi-sea-winter) before being released back to their natal river. Early in the program's history, there were a few occurrences where fish spent three years before being released, but that is no longer a component of the program.

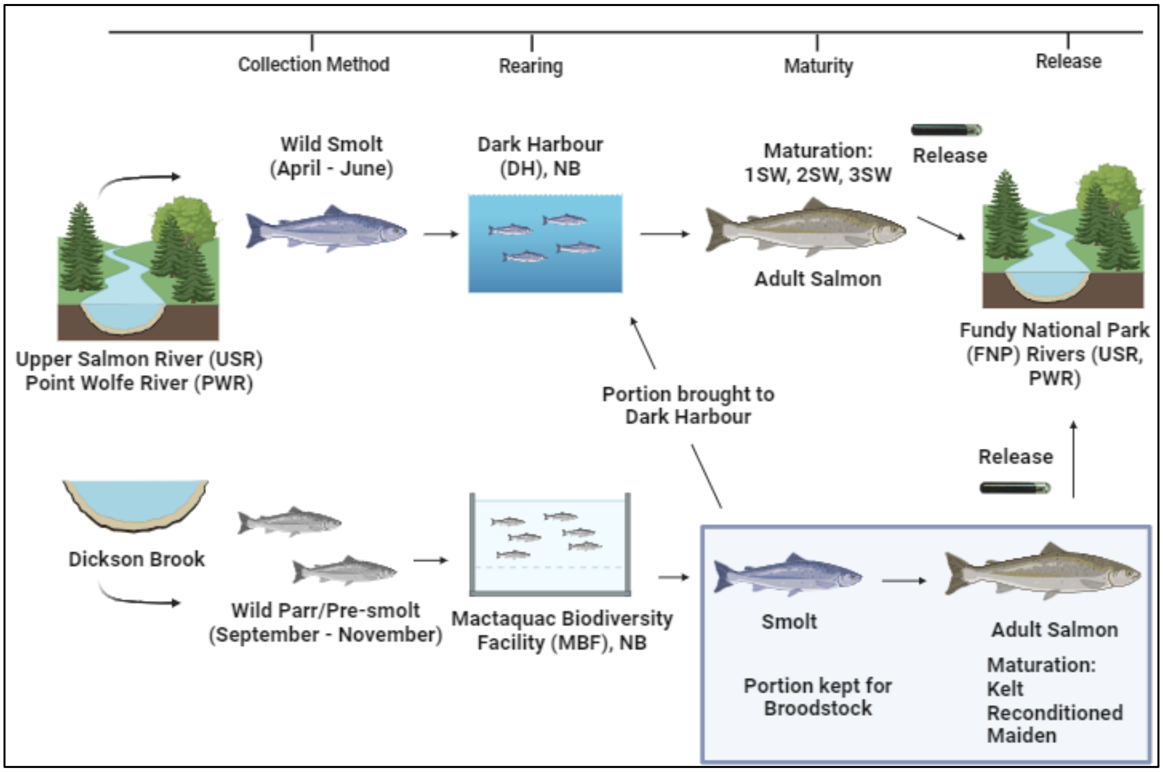

Figure 1. Fundy Salmon Recovery (FSR) program detailing collection method (wild smolt or wild parr/pre-smolt), rearing strategy (Dark Harbour or Mactaquac Biodiversity Facility), maturity (grilse, multi-sea winter, Kelt, Maiden, or Reconditioned) release type (hand, helicopter, slide), and river (Upper Salmon River (USR), Point Wolfe River (PWR)). Created using BioRender.com.

As part of the greater Live Gene Bank (LGB) program, parr/pre-smolt are collected in the fall (October – November) from Dickson Brook, an isolated stream in FNP, and taken to the Fisheries and Oceans Mactaquac Biodiversity Facility (MBF) in Fredericton, NB to be reared. At the smolt stage (April – June), fish are selected to be part of the LGB program (approximately half of the group) remaining at MBF to be broodstock, with the remaining individuals not selected being transported to the conservation farm in Dark

Harbour, on Grand Manan Island (Nason, 2023). Broodstock fish at MBF can be released back to FNP rivers as a Maiden (mature, unspawned), Kelt (post-spawned), or Reconditioned (over-wintered at MBF after spawning). Dependent on how long fish stay at their respective rearing facilities, they may be released as either mature or immature. This study focuses on fish released into the USR and PWR, in FNP, from 2015 – 2022 and fish returning to these river from 2016 – 2023.

2.2. Passive Integrated Transponder (PIT) Technology

At the smolt stage, all individuals receive an 8mm full-duplex (FDX) Biomark Passive Integrated Transponder (PIT) tag injected into the dorsal muscle (above the lateral line and posterior to the dorsal fin). This PIT tag is used to identify individual juvenile salmon at their associated rearing facilities. At the adult stage, when individuals at Dark Harbour and/or MBF are ready to be released, they receive a 28mm half-duplex (HDX) Biomark PIT tag injected into the dorsal muscle and are transported back to their natal rivers to spawn. Reintroductions of adult Atlantic salmon to their native rivers occurs via one or a combination of three release strategies: helicopter, manual release by hand, or slide. The FDX tags do not interfere with the reading/detectability of the larger HDX tags. The unique PIT tags and their associated information are compiled and stored in a large database. For this project specifically, information in the database includes year of release (2015 – 2023), collection method (wild smolt or wild-exposed parr), rearing strategy (Dark Harbour, MBF), maturity (grilse, multi-sea winter, Kelt, Maiden, or Reconditioned), release type (hand, slide, helicopter), sex (male or female), sampling type (angled or not angled), river of release (USR or PWR), and year of return (2016 - 2023).

A PIT antenna is constructed at the mouth of both the USR and PWR in FNP, NB, by Parks Canada staff in collaboration with the University of New Brunswick (UNB) to assess returning fish per year, and salmon movements in and out of the river (Figure 2). The USR antenna has been operated annually from 2016 until 2023, whereas the PWR antenna has been operated annually from 2020 until 2023, over the months of July through December. Although acknowledged as a limitation to detection probability, PIT antenna efficiency was not considered as this study is focusing on fish that were successfully detected. However, PIT antenna operation is an important factor in assessing return success (Figure 3).

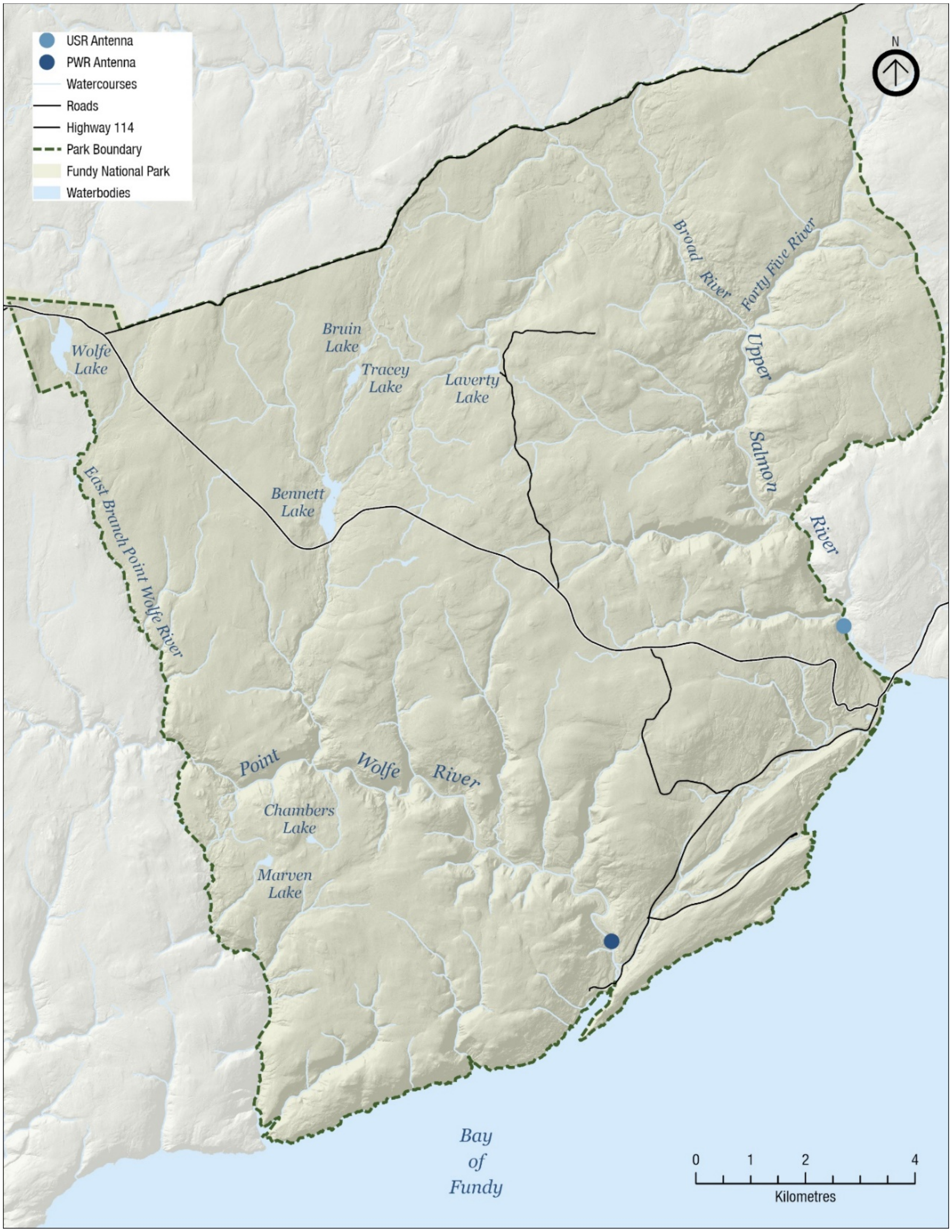

Figure 2. Locations of the Passive Integrated Transponder (PIT) antennas in the Upper Salmon River (USR) (light blue) and Point Wolfe River (PWR) (dark blue) in Fundy National Park (FNP), Alma, NB.

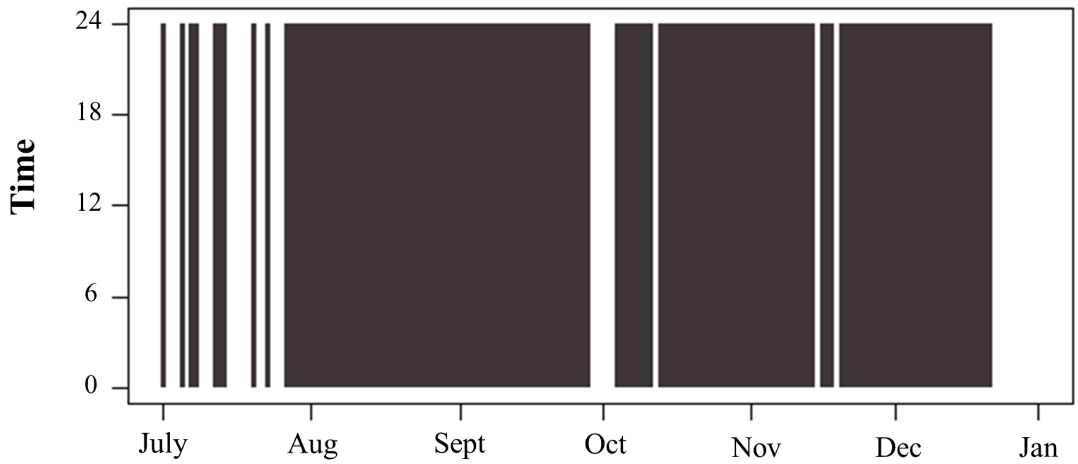

Figure 3. An example of PIT antenna efficiency/operation (24 hours) on the Upper Salmon River (USR) in Fundy National Park (FNP), NB, 2016 (July through December). Dark grey indicating when the antenna was running (i.e. detecting fish), and white indicates when it was not.

The USR antenna is located at the mouth of the USR just above the head of tide (Figure 2). The USR antenna is 18m wide by 2m tall, powered by on-grid AC power sourced from a nearby cabin. This power is transmitted through a 300m extension cable, connected to a power filter that filters out electrical noise before entering an Oregon Radio Frequency Identification (RFID) AC-DC power supply at 13.8V. The antenna is fabricated using 1/0-gauge welding cable, threaded through a 6mm conduit for structural integrity. The upper and lower antenna sections are secured to a 10mm steel cable tightened between two trees with cable ties. The bottom cable is run through rock climbing anchors secured to the substrate every few metres using 10mm anchor bolts. The welding cable runs into a watertight ammunition box housing the auto tuner. This tuner is connected to Twinax cable, which extends back to the reader. To ground the system and minimize noise, a 60cm grounding spike is connected to the shield of the Twinax cable at the reader and inserted into the ground.

The PWR antenna is located at the mouth of the PWR, approximately 250m above the head of tide (Figure 2). The PWR antenna design is the same as the USR antenna, except it is slightly larger at 24m wide by 2m tall. This accounts for the larger width of the river compared to the USR. Moreover, this antenna is powered by solar energy as no on-grid power is available. To receive solar power, a second 10mm steel cable guide wire is run across the river to which a solar panel is mounted in the center of the river. This is because steep valleys block much of the sunlight on either shore. The solar panel is 270 watts, running through a 30-amp charge controller, and into 4 x 130-amp hour batteries.

2.3. Data Collection & Preprocessing

To estimate the approximate number of fish that have returned per year (2016 – 2023), salmon are detected each time they swim in close proximity to the antenna (~ 1m). Data is stored on the Oregon RFID reader, which is later downloaded by Parks Canada staff. The framework of both (PWR, USR) antennas is checked weekly, with emphasis on checking after rainfall events. Data acquisition occurs via a serial connection from a laptop computer to the Oregon RFID reader and is compiled using the puTTY software program. Data was downloaded from the Oregon RFID reader weekly at FNP, Alma, NB, in the USR from July 2016 to December 2023 and weekly in the PWR from July 2020 to December 2023. The date, time, and PIT number for each detection are referred back to an existing database that includes all information on each iBoF Atlantic salmon released since 2015, including but not limited to, release date, release stage, collection origin, angled (yes or no), rearing strategy, sex, maturity at release, river of release, and release method. The data was preprocessed and standardized in R (version 4.3.1) (R Core Team, 2023) using the tidyr, magrittr, and dplyr packages (Wickham et al., 2023; Bache & Wickham., 2022; Wickham et al., 2023).

To estimate the total number of fish that strayed, straying was categorized as entering one river (USR or PWR) (i.e., detected on the associated reader), to then exit the river and enter the opposite one (USR or PWR) (i.e., detected on the opposite reader after being detected on the first one). Straying fish were only determined from 2020 – 2023 as these are the years both PIT antennas were operating. Prior to 2020, the USR antenna was the only antenna detecting fish. Fish that demonstrated straying upon release was determined as demonstrating straying events in the same year as release, whereas fish that demonstrated straying upon return was determined as demonstrating straying events in the year of return (1 or more years after release year).

As part of the ongoing sampling regime for the program, adult salmon are angled during their migratory period (July – December) supplementary to the PIT antenna data. Angling has been conducted annually from 2020 – 2023 amongst major pools along both rivers (USR, PWR) using fly-rod fishing poles and cast poles. In the context of this study, angling is considered as a potential factor influencing the movement and return success of iBoF Atlantic salmon.

2.4. Statistical Analysis

A generalized mixed-effects logistic regression model (GLMM) was used to determine the log-odds of a fish returning to FNP rivers using the lme4 package in R (Version 4.3.1) (Bates et al., 2015) (Equation 1). This was used to determine if there are differences in the rates of salmon returning to FNP rivers based on the life history of the fish. The model included the response variable (return vs. no return), the random effect year of release, fixed effects river of origin, rearing strategy, sex, collection origin of the juvenile, maturation at release, and release type. The random effect year of release was included to account for annual variability in the dataset.

$$logit(\Pr(Y_{ijklmno} = 1)) = \beta_0 + R_i + C_j + S_k + M_l + X_m + A_n + U_o + \varepsilon_{ijklmno}$$

Equation 1. Generalized mixed-effects logistic regression model, where:

$logit(Pr(Y_{ijklmno} = 1))$ = log-odds of a fish returning.

β_0 is the mean parameter (log-odds of return).

R_i is the random effect to account for variability by year of release (2015 – 2022).

C_j is the fixed effect caused by the collection method of the adult (wild smolt or wild-exposed parr).

S_k is the fixed effect caused by the rearing strategy (Dark Harbour, or MBF).

M_l is the fixed effect caused by maturation at release (Kelt, Maiden, Reconditioned).

X_m is the fixed effect caused by release type (hand, slide, or helicopter).

A_n is the fixed effect caused by sex (male or female).

U_o is the fixed effect caused by river of release (Upper Salmon River or Point Wolfe River)

$\varepsilon_{ijklmno}$ is the error term

To assess the overall significance of predictor variables in the generalized mixed-effect logistic regression model for returning iBoF Atlantic salmon (return vs no. return), a Type III Wald Chi-square test was used in R (Version 4.3.1) (R Core Team, 2023). Subsequently, to identify differences between levels within variables, a Tukey's Honestly Significant Difference (HSD) test for each level of the predictor variables was calculated (Hothorn et al., 2008). Moreover, a significance value of 0.05 was used to determine the significance among predictor variables. Data was then plotted in R using the ggplot2 package (Wickham, 2016).

To account for the possibility of fish mortality post-release/spawning, a supplementary dataset was created only to include released fish departing the river after November 1st. As these fish survived spawning and are leaving the river, fish returning from this group more accurately represent return rates of fish that emigrated from the river and returned the subsequent year. In this analysis, returning fish were determined as leaving the river after November 1st and returning the subsequent year. The same model in Equation 1 was then used to analyze this new dataset. The model was also used to analyze the life history traits of returning fish which exhibited straying. To assess the overall significance of predictor variables in the mixed-effect logistic regression model for straying (straying vs no. straying), a Type III Wald Chi-square test was used.

2.5. Return & Stray Rates

The return rates of fish possessing a particular trait was assessed through calculating relative frequency, where the number of successfully returning fish with a particular trait is divided by the total number of fish released with that specific trait (Equation 2). Return rates were calculated for each year (2016 – 2023) for each variable: adult rearing (MBF and DH), collection method (wild smolt and wild-exposed parr), release stage (Kelt, Maiden, Reconditioned), release method (hand, slide and helicopter), sex (male and female), and river (USR and PWR) (Equation 2). Adjusted return rates were also calculated (i.e. leaving after November 1st), to account for the possibility of mortality post-release and spawning.

$$Relative\ Frequency = \frac{f}{n}$$

Equation 2. Relative Frequency, where:

f is the total number of successfully returning fish or the total number of fish that strayed with a specific trait.

n is the total number of released fish the year before (return), or same year of release with a specific trait.

Stray rates were calculated for each year (2016 – 2023) for each variable: adult rearing (MBF and DH), collection method (wild smolt and wild-exposed parr), release stage (Kelt, Maiden, Reconditioned), release method (hand, slide and helicopter), sex (male and female), and river (USR and PWR) (Equation 2). Stray rates were calculated by dividing the total number of fish that strayed by the total number of fish released the year before (i.e. strayed upon return) and upon release (i.e. strayed upon release). All stray rates were calculated using relative frequency (Equation 2). Additionally, to determine if angling influenced return success of iBoF Atlantic salmon from 2020 – 2023, the relative frequency of returning fish that were previously angled was also calculated.

3. Results

3.1. Mixed-Effects Logistic Regression Model

The Type III Wald Chi-square test revealed significant effects for release stage (χ^2 = 29.238, df = 2, p < 0.001), adult rearing (χ^2 = 38.770, df = 5, p < 0.001), and sex (χ^2 = 35.037, df = 2, p < 0.001), with no significant effects for release method (χ^2 = 10.661, df = 2, p = 0.005), collection method (χ^2 = 4.048, p = 0.132) or river (χ^2 = 1.340, df = 1, p = 0.2470) (Table 1, Figure 4).

Table 1. Analysis of Deviance (ANOVA) table (Type III Wald Chi-square Test) summarizing the significance of the fixed effects collection method, adult rearing, release method, release stage, and sex on the return success (return vs. no return) of iBoF Atlantic salmon (*Salmo salar*) to the Upper Salmon and Point Wolfe rivers in Fundy National Park (FNP) between 2016 – 2023.

Model	***Random Effect***	***Fixed effects***	***χ2***	***df***	***P-value***
Returned ~ 1 + (1| Release Year) + Collection Method + Release Stage + Release Method + Adult Rearing + Sex + River	Release Year	Collection Method	0.142	1	0.706
		Adult Rearing	38.770	5	< 0.001 ***
		Release Method	2.488	2	0.2883
		Release Stage	29.238	2	< 0.001 ***
		Sex	35.037	2	< 0.001 ***
		River	1.340	1	0.2470

Significance values: < 0.001 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

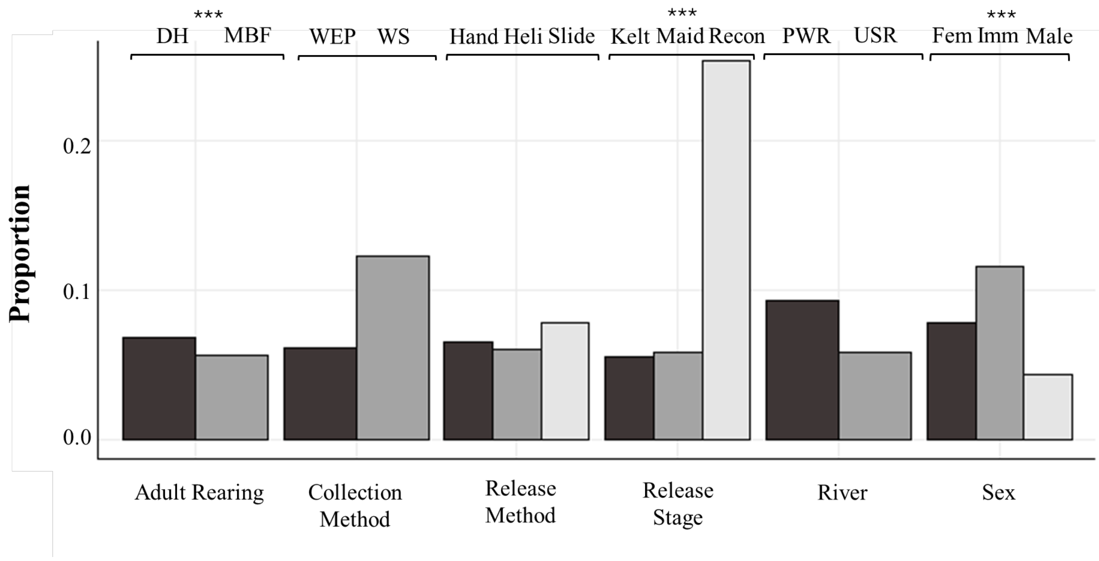

Figure 4. The proportion of adult iBoF Atlantic salmon (*Salmo salar*) returns to Fundy National Park (FNP), NB, in the Upper Salmon River (USR) and Point Wolfe River (PWR) from 2016 – 2023 based on adult rearing (Dark Harbour (DH), Mactaquac Biodiversity Facility (MBF)), collection method (wild-exposed parr (WEP), and wild smolt (WS)), release method (hand, helicopter (Heli), and slide), release stage (Kelt, Maiden, Reconditioned), and sex (female (Fem), immature (Imm), male). The asterisk (***) indicating significance of p>0.001.

For adult rearing, the Tukey HSD test revealed significant differences in the log-odds ratio between fish released as one-sea-winter from the Mactaquac Biodiversity Facility (1SW-MBF) and one-sea-winter fish from Dark Harbour (1SW-DH) (SE = 0.654, Z-ratio = 3.647, p = 0.005) (Table 2, Figure 5). Additionally, there was a significant difference in the log-odds ratio between fish released as 1SW-DH-reared fish and two-sea winter (2SW) MBF-reared fish (SE = 0.322, Z-ratio = -4.189, p < 0.001) and between 1SW and 2SW DH-reared fish (SE = 0.194, Z-ratio = -3.390, p = 0.014) (Table 2, Figure 5). There was a significant difference between females and males (SE = 0.135, Z-ratio = -

4.997, $p < 0.001$), as well as fish released as immature compared to fish released as males (SE = 0.192, Z-ratio = -4.900, $p < 0.001$). There were no significant differences between female released fish and fish released when immature (Table 2, Figure 4). For release stage, there was a significant difference in the log-odds ratio between Kelts compared to Reconditioned (SE = 0.377, Z-ratio = 4.127, $p < 0.001$), and between fish released as Maiden Spawners versus those released after being Reconditioned (SE = 0.355, Z-ratio = 4.852, $p < 0.001$) (Table 2, Figure 4). However, no significant difference was observed between fish released as Kelts and those released as Maiden Spawners.

Table 2. Tukey's Honestly Significant Difference (HSD) test results summarizing the significance of the variables in the mixed effects logistic regression model (Equation 1) on the return success (return vs. no return) of iBoF Atlantic salmon (*Salmo salar*) to the Upper Salmon and Point Wolfe rivers in Fundy National Park (FNP) between 2016 – 2023.

Variable	Estimate	SE	Z- value	P-value
Collection Method				
Wild Smolt - Wild-Exposed Parr	-0.087	0.229	-0.377	1.000
Release Stage				
Maiden - Kelt	-0.170	0.402	-0.423	1.000
Reconditioned - Kelt	1.554	0.377	4.127	**< 0.001**
Reconditioned - Maiden	1.724	0.355	4.852	**< 0.001**
Adult Rearing				
1SW DH - 1SW MBF	2.386	0.654	3.647	**0.005**
2SW MBF - 1SW MBF	1.038	0.693	1.497	0.870
2SW DH - 1SW MBF	1.727	0.667	2.590	0.155
3SW MBF - 1SW MBF	-0.134	1.212	-0.111	1.000
3SW DH - 1SW MBF	1.264	0.769	1.643	0.784
2SW MBF - 1SW DH	-1.348	0.322	-4.189	**< 0.001**
2SW DH - 1SW DH	-0.658	0.194	-3.390	**0.014**
3SW MBF - 1SW DH	-2.520	1.025	-2.458	0.213
3SW DH - 1SW DH	-1.122	0.436	-2.573	0.162
2SW DH - 2SW MBF	0.690	0.317	2.177	0.382
3SW MBF - 2SW MBF	-1.172	1.052	-1.114	0.984
3SW DH - 2SW MBF	0.226	0.492	0.459	1.000
3SW MBF - 2SW DH	-1.862	1.037	-1.796	0.675
3SW DH - 2SW DH	-0.464	0.456	-1.017	0.992
3SW DH - 3SW MBF	1.398	1.109	1.261	0.958
Release Method				
Helicopter - Hand	-0.134	0.231	-0.580	1.000
Slide - Hand	-0.476	0.316	-1.507	0.865
Slide - Helicopter	-0.342	0.377	-0.907	0.997
Sex				
Immature - Female	0.264	0.185	1.426	0.903
Male - Female	-0.675	0.135	-4.997	**< 0.001**
Male - Immature	-0.939	0.192	-4.900	**< 0.001**
River				
USR - PWR	0.255	0.220	1.158	0.978

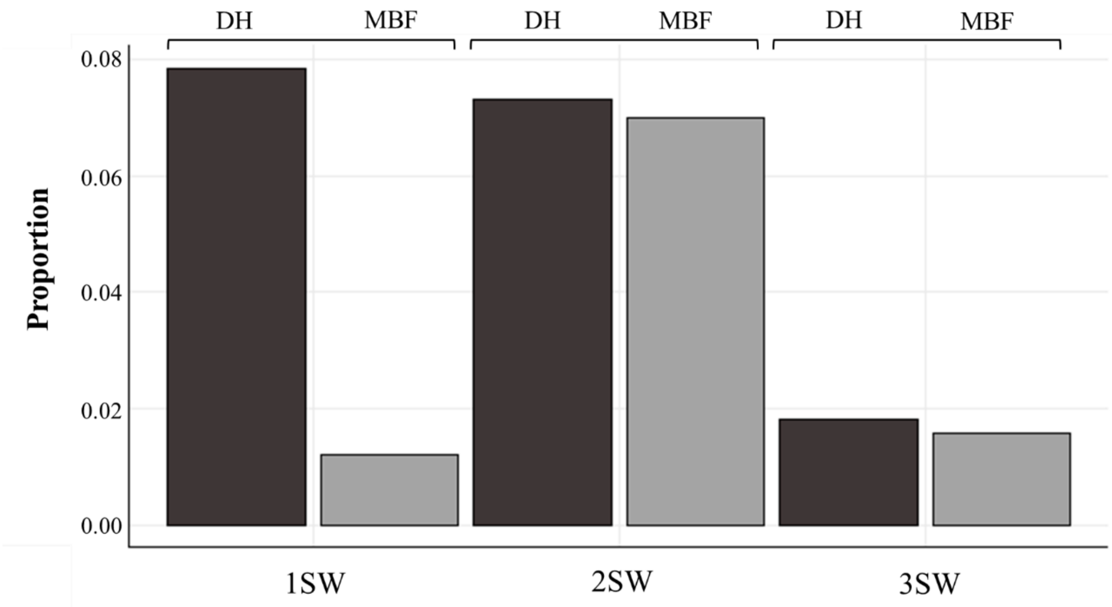

Figure 5. The proportion of adult iBoF Atlantic salmon (*Salmo salar*) returns to Fundy National Park (FNP), NB, based upon their released maturity (one-sea winter (1SW), two-sea winter (2SW), and three-sea winter (3SW) (i.e. total time spent at rearing facilities), between 2016 – 2023. Dark grey represents fish reared in Dark Harbour (DH), and light grey represents fish reared at the Mactaquac Biodiversity Facility (MBF).

3.2. Return Rates

Return rates (% of fish that returned relative to the number released) were calculated for all of the predictor variables (collection method, adult rearing, release stage, release method, sex, and river) and included all fish released from 2015 – 2023 and all fish returning from 2016 – 2023 across both of FNPs rivers (USR, PWR). Across this timeframe, 5667 iBoF Atlantic salmon were released into FNP rivers, with 385 of them returning one or two years following the year of release. For collection method, wild smolt had a cumulative return rate two times higher than that of wild-exposed parr (12.28% and 6.14%, respectively) (Table 3). Regarding sex and release method, males had a cumulative return rate of 4.31%, females 7.82%, and immature fish 11.54% and fish released by hand, helicopter, and slide had return rates of 6.51%, 6.01%, and 7.81%, respectively. Immature fish exhibited the highest rate of return, returning 1.47 times greater than females and 2.67 greater than males. Females, in turn, demonstrated a return rate 1.81 times higher than males, which had the lowest overall return rate (Table 3).

Table 3. Return rates of iBoF Atlantic salmon (*Salmo salar*) to Fundy National Park (FNP) from 2016 – 2023 and cumulative return rate (CRR) (i.e. total number of fish returned with a given trait/total number of fish released with given trait). The dash (-) indicating that no fish were released the year prior.

Variable	Return Rate (%)								CRR
	2016	2017	2018	2019	2020	2021	2022	2023	
Collection Method									
Wild Smolt (WS)	0.00	0.00	-	-	21.43	18.75	7.48	14.07	12.28
Wild Parr (WEP)	2.44	2.65	3.41	2.70	9.51	16.48	11.56	2.31	6.14
Adult Rearing									
Dark Harbour (DH)	2.34	2.10	3.20	3.59	11.78	16.93	9.88	15.56	6.86
Mactaquac Biodiversity Facility (MBF)	-	3.57	4.43	0.00	1.56	16.02	16.09	1.93	5.65
Release Stage									
Kelt	-	4.59	-	0.00	16.67	25.81	6.76	0.00	5.54
Maiden	2.34	2.35	3.41	2.96	9.84	14.44	9.93	4.83	5.87
Reconditioned	-	-	-	-	-	26.97	25.00	0.00	25.42
Release Method									
Hand	10.53	3.46	3.35	0.00	16.67	12.07	12.88	3.95	6.51
Helicopter	2.08	2.21	3.05	3.59	9.12	18.33	-	-	6.01
Slide	-	-	-	-	-	-	9.50	4.44	7.81
Sex									
Female	1.61	1.94	3.52	4.60	13.41	22.97	11.80	2.34	7.82
Male	2.82	2.60	2.66	1.96	7.04	6.76	7.89	3.45	4.31
Immature	0.00	0.00	9.52	0.00	0.00	28.57	15.00	10.85	11.54
Release Maturity									
1SW - DH	2.34	2.10	2.83	14.77	13.50	20.62	10.51	14.93	7.86
2SW - DH	-	0.00	3.26	-	0.00	15.90	7.19	100.00	7.32
3SW - DH	-	-	-	1.81	-	-	-	-	1.81
1SW - MBF	-	-	-	-	0.00	-	0.00	1.23	1.22
2SW - MBF	-	3.57	4.43	0.00	0.00	16.09	16.37	3.08	6.99
3SW - MBF	-	-	-	0.00	1.69	0.00	0.00	-	1.59
River									
USR	2.49	2.64	3.64	2.70	9.95	19.06	12.88	4.48	5.78
PWR	-	-	-	-	-	14.01	9.68	4.13	9.35

With regard to adult rearing, salmon reared at DH exhibited a return rate 1.21 times higher than those reared at MBF (6.86% and 5.65%; respectively). The maturity of released fish also affected return rates among released MBF individuals, where Kelts had a return rate of 5.54%, Maiden Spawners 5.87%, and Reconditioned fish had the highest return rate at 25.42% (Table 3). The return rate ratio of Reconditioned to Kelts was 4.59, and the return rate ratio of Reconditioned to Maiden Spawners was 4.33.

For adjusted returns (i.e. left the river after November 1st), the Type III Wald Chi-square test revealed significant effects for release stage ($\chi^2 = 9.846$, df = 2, p = 0.007), adult rearing ($\chi^2 = 16.662$, df = 5, p = 0.002), sex ($\chi^2 = 6.646$, df = 2, p = 0.036), release method ($\chi^2 = 7.511$, df = 2, p = 0.023), and river ($\chi^2 = 6.716$, df = 1, p = 0.010) with no significant effects for collection method ($\chi^2 = 0.542$, df = 1, p = 0.462) (Table 4).

Table 4. Analysis of Deviance (ANOVA) table (Type III Wald Chi-square Test) summarizing the significance of the fixed effects collection method, adult rearing, release method, release stage, and sex for adjusted returns on the return success (return vs. no return) of iBoF Atlantic salmon (*Salmo salar*) to the Upper Salmon and Point Wolfe rivers in Fundy National Park (FNP) between 2016 – 2023.

Model	***Random Effect***	***Fixed effects***	***χ2***	***df***	***P-value***	
Returned ~ 1 + (1| Release Year) + Collection Method + Release Stage + Release Method + Adult Rearing + Sex + River	Release Year	Collection Method	0.542	1	0.462	
		Adult Rearing	16.662	5	0.002	**
		Release Method	7.511	2	0.023	*
		Release Stage	9.846	2	0.007	**
		Sex	6.646	2	0.036	*
		River	6.716	1	0.010	**

Significance values: < 0.001 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

For adult rearing, the Tukey HSD test revealed significant differences in the log-odds ratio between fish released as two-sea-winter from the Mactaquac Biodiversity Facility (2SW-MBF) and one-sea-winter fish from Dark Harbour (1SW-DH) (Estimate = -2.447, Z-ratio = -3.600, p = 0.005). Additionally, there was a significant difference in the log-odds ratio between 1SW and 2SW DH-reared fish (Estimate = -1.752, Z-ratio = -3.473, p = 0.007). For release stage, there was a significant difference in the log-odds ratio between fish released as Maiden Spawners versus those released after being Reconditioned (Estimate = 2.099, Z-ratio = 2.934, p = 0.045). The Tukey HSD test revealed no other significant differences between the variables.

Adjusted return rates were calculated for all of the predictor variables (collection method, adult rearing, release stage, release method, sex, and river) and included all fish released from 2016 – 2023 and all fish returning from 2016 – 2023 across both of FNPs rivers (USR, PWR). Across this timeframe, 537 iBoF Atlantic salmon were detected leaving the river after November 1st. Of this, 84 of them returned one or two years following the year of release. Annual return rate varied, however, wild smolt had a cumulative return rate 2.29 times higher than that of wild-exposed parr (31.25% and 13.63%, respectively) (Table 5). Individuals reared in modified marine net pens at Dark Harbour experienced a return rate 1.96 times higher than individuals reared at the Mactaquac Biodiversity Facility (Table 5). Similar to return rates, Reconditioned fish had the highest return rate amongst all other treatments (48.15%) (Table 5). Moreover, fish released into the PWR returned at 44.83% with a return rate ratio of 3.61 over fish released into the USR (12.43%) (Table 5).

Table 5. Adjusted Return rates of iBoF Atlantic salmon (*Salmo salar*) to Fundy National Park (FNP) from 2017 – 2023 and cumulative return rate (CRR) (i.e. total number of fish returned with a given trait/total number of fish released with given trait). The dash (-) indicating that no fish left the river after November 1st.

Variable	Adjusted Return Rate (%)							CRR
	2017	2018	2019	2020	2021	2022	2023	
Collection Method								
Wild Smolt (WS)	-	-	-	-	37.50	0.00	50.00	31.25
Wild Parr (WEP)	1.93	4.44	-	-	35.35	20.83	0.00	13.63
Adult Rearing								
Dark Harbour (DH)	1.32	4.69	-	-	33.85	23.68	50.00	18.99
Mactaquac Biodiversity Facility (MBF)	2.29	3.85	-	-	38.10	15.38	0.00	9.68
Release Stage								
Kelt	4.26	-	-	-	100.00	5.26	0.00	9.59
Maiden	5.00	4.44	-	-	29.21	21.74	2.56	14.19
Reconditioned	-	-	-	-	60.00	33.33	-	48.15
Release Method								
Hand	2.36	3.23	-	-	30.30	19.70	2.44	10.60
Helicopter	1.25	5.17	-	-	37.84	-	-	18.92
Slide	-	-	-	-	-	18.18	0.00	16.67
Sex								
Female	4.65	5.88	-	-	45.45	19.44	0.00	22.48
Male	0.00	2.63	-	-	17.95	21.62	7.14	13.87
Immature	60.00	-	-	-	50.00	0.00	0.00	23.53
Release Maturity								
1SW - DH	1.32	0.00	-	-	52.94	31.25	50.00	22.14
2SW - DH	-	5.26	-	-	27.08	18.18	-	15.75
3SW - DH	-	-	-	-	-	-	-	-
1SW - MBF	-	-	-	-	-	-	0.00	0.00
2SW - MBF	2.29	3.85	-	-	38.10	15.38	0.00	10.36
3SW - MBF	-	-	-	-	-	-	-	-
River								
USR	1.93	4.49	-	-	30.00	19.70	2.44	12.43
PWR	-	-	-	-	64.71	18.18	0.00	44.83

3.3 Straying & Angling

The Type III Wald Chi-square test found no significant effects attributed to adult rearing, collection method, release stage, release method, sex, or river for straying (Table 6, Figure 6). Between 2020 to 2023, 2936 fish were released into FNP rivers. Of this, 61 fish (2.08%) demonstrated straying (switching to the opposite river). Among these, 40 (65.57%) exhibited straying after release, while 21 (34.43%) demonstrated straying upon returning the subsequent year after release. Six individuals strayed and then returned back to their original river (9.84%). Of the 2936 released fish, 50 were angled for scientific collection purposes (i.e., to collect post-spawn females to assess spawning success) the same year they were released into their respective river. Of these individuals, 9 returned the following year, indicating a return rate of 18.00% after being angled. See Appendix A for stray rates calculated for each year (2016 – 2023) for each variable: adult rearing (MBF and DH), collection method (wild smolt and wild-exposed parr), release stage (Kelt, Maiden, Reconditioned), release method (hand, slide and helicopter), sex (male and female), and river (USR and PWR).

Table 6. Analysis of Deviance (ANOVA) table (Type III Wald Chi-square Test) summarizing the significance of the fixed effects: collection method, adult rearing, release method, release stage, and sex, on iBoF Atlantic salmon (*Salmo salar*) straying (switching rivers) between the Upper Salmon and Point Wolfe rivers in Fundy National Park (FNP) between 2016 – 2023.

Model	**Random Effect**	**Fixed effects**	**$\chi 2$**	**df**	**P-value**
Returned ~ 1 + (1| Release Year) + Collection Method + Release Stage + Release Method + Adult Rearing + Sex + River	Release Year	Collection Method	0.003	1	0.994
		Adult Rearing	0.970	4	0.914
		Release Method	0.882	2	0.644
		Release Stage	2.367	2	0.306
		Sex	2.296	2	0.317
		River	2.211	1	0.137

Significance values: < 0.001 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

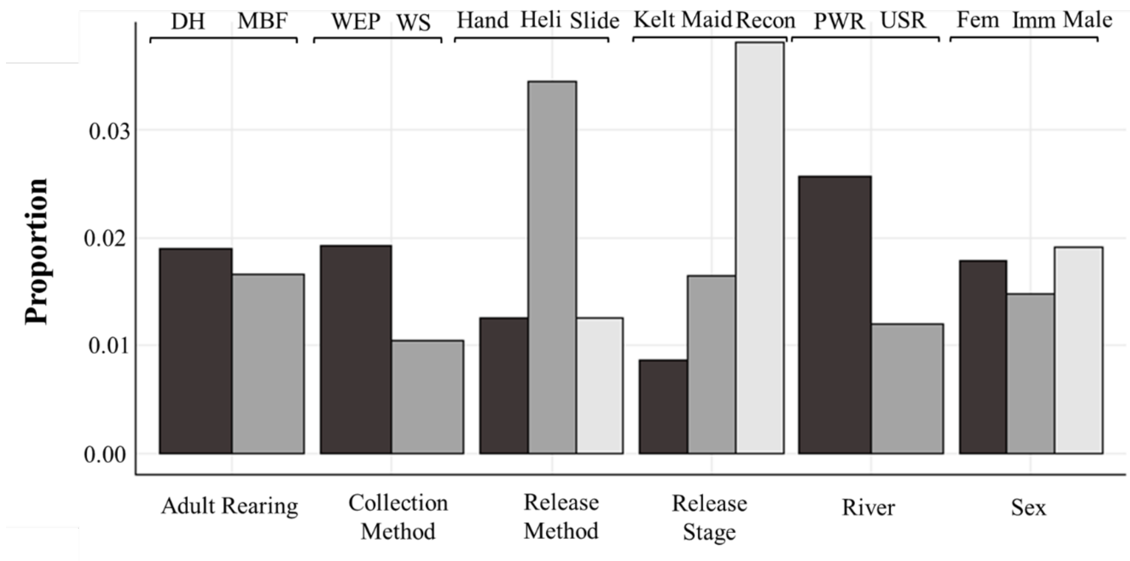

Figure 6. The proportion of adult iBoF Atlantic salmon (*Salmo salar*) that demonstrated straying (switching rivers) at Fundy National Park (FNP), NB, between 2020 to 2023, based on treatments which include: collection method (wild-exposed parr (WEP), and wild smolt (WS)), adult rearing (Dark Harbour (DH), Mactaquac Biodiversity Facility (MBF)), release method (hand, helicopter (Heli), and slide, release stage (Kelt, Maiden, Reconditioned), and sex (female (Fem), immature (Imm), male).

4. Discussion

This study evaluated the rate of iBoF Atlantic salmon returning to rivers within FNP, NB, and the propensity of salmon straying between rivers. I found that the duration, type of captive rearing, and early wild exposure significantly influenced the return success of iBoF Atlantic salmon. The data shows that salmon reared at DH exhibit significantly higher return rates than those reared at MBF, and female and immature salmon returned at a higher rate than males, with immature salmon demonstrating the highest return rate over both males and females. In contrast to what I had expected, MBF fish released after being Reconditioned returned at an approximately threefold higher rate than Kelts and Maiden spawners and had the highest return rate across all levels of treatments. Additionally, no significant characteristics were observed for straying individuals. It was also observed that the effect of angling did not significantly impact the return success of iBoF Atlantic salmon.

Adult rearing significantly affected the return success of iBoF Atlantic salmon, with salmon reared at DH exhibiting higher return rates than those reared at MBF. The increased return rate may be a result of rearing in an open net-pen environment, in which salmon experience many natural marine environmental conditions, including fluctuations in light, temperature, salinity, dissolved oxygen, elements (e.g., iodine), predation, and water currents (Oppedal et al., 2011). These marine parameters are unavailable in a freshwater hatchery-rearing environment, where hatchery-reared individuals experience little natural conditions. Experiencing stressors typically associated with their native environment may better equip salmon from DH for life in the wild. It’s possible that the differences in the observed return rates could also be attributed to differences in the consistency of care between rearing facilities, as rearing care may vary.

Similar to our findings, an increasing body of research has also demonstrated that increased captive exposure results in individuals who experience poorer survival and reproductive success in the wild compared to wild-origin individuals with less early captive exposure (Evans et al., 2014; Clarke et al., 2016). This could be attributed to salmonids being highly susceptible to fitness loss in captivity (Araki et al., 2008; Fraser, 2008). For example, even with selective breeding, there's a risk of fitness loss, which may lead to unintended consequences such as reduced genetic diversity or the loss of traits important for survival in the wild (Fraser, 2008). Even without intentional practices aimed at enhancing target traits, human-built environments can provide conditions for natural selection (Alvarez & Niciaza, 2003).

Juvenile salmon collected as wild smolt returned at a rate twofold higher than that of wild-exposed parr. It has been shown that salmon that have little or no captive exposure early in life (i.e., hatch and grow to the smolt stage within the river) have a higher fitness and have a greater chance of surviving at sea once released than fish hatched in captivity and exposed to the wild later in life (Clarke et al., 2016; Evans et al., 2014). Predation exerts significant pressure on the survival of young salmon in that mortality rates are highest early in life and tend to decrease as they grow larger (Alvarez & Niciaza, 2003). There are strong selective pressures for the early development of antipredator defences (Alvarez & Niciaza, 2003), and predator defences are of major importance during all phases of life (Fuiman & Magurran, 1994). Consequently, fish collected as wild smolt that are exposed to and encounter more predators during their early stages of life are more likely to recognize predators upon release back into the rivers. In addition to increased at-sea survival and return success, it has been found that increasing levels of wild exposure increase spawning success (Nason, 2023). Therefore, exposing fish to the wild as early as possible is of great importance in the conservation of wild fish populations, both in their ability to survive after being released and their spawning ability.

It was evident that return rates based on maturity at time of release (1SW, 2SW, or 3SW), exhibited considerable variability across both DH and MBF-reared fish. DH-reared fish returned at significantly higher rates than MBF overall, except for 2SW-MBF fish, which returned at a rate higher than 3SW-DH fish. This suggests that spending more time in sea cages prior to release could decrease the likelihood of returning the following year and decrease their chance of survival. However, it must be considered that the majority (~ 50%) of iBoF Atlantic salmon mature after one winter at sea, with many of those returning the following year to spawn consecutively (COSEWIC, 2006) and rarely do they return and spawn for a third time. As such, it's important to consider that releasing individuals at the 3SW stage of maturity may result in considerably low return rates, given the biological life history of the species, which is observed from both rearing facilities.

Immature fish had the highest return rate compared to mature males or females, which could be attributed to the larger, mature individuals investing more energy towards reproductive output than smaller, immature individuals that may be investing in energy stores (Gregory et al., 2019). Mature fish are more likely to engage in competitive breeding behaviours, with larger individuals being more aggressive and displaying more active courtship (Gregory et al., 2019). In contrast, smaller individuals tend to display more submissive behaviour when competing for females (Fleming et al., 1997). Males have been shown to be significantly more aggressive than females in combat behaviour (Fleming et al., 1997), which may result in increased post-spawn mortalities in males than females and could be a primary factor of the low return rates in males. Moreover, much of the female investment in reproduction is in the form of eggs, whereas the investment in gonads by males is less than a seventh of that of females (Fleming & Einum, 2010). Much of the energy expenditure by males occurs during behavioural activity (i.e. mate competition) and the development of secondary sexual traits (e.g., hooked jaw) (Fleming & Einum, 2010).

Additionally, it has been observed that a higher proportion of males mature after their first winter at sea; therefore, fish released as immature have a higher chance of being female. Therefore, in the years that immature fish were released, they could have been likely to return in their second year as a female. This hypothesis is also supported by the fact that females return at a rate of 1.9 times that of males.

Interestingly, MBF Reconditioned fish demonstrated the highest return rate in the study and returned at a rate approximately threefold higher than Kelts and Maidens, respectively. It has been found, however, that reconditioned fish produce significantly fewer offspring than their MBF or DH counterparts in the year of release (Nason, 2023), raising questions about the potential benefits of holding post-spawned adults over winter for release the following year. Introducing these fish into the rivers after reconditioning may create competition among other males competing for females (Jonsson & Jonsson, 2006), despite their unlikeliness in contributing to future generations. However, it is possible that the reconditioned fish aren't ready to spawn the year post-reconditioning. Although they don't appear to contribute to spawning the same year of release, it may be possible that once they return the following year, they do contribute to subsequent generations.

The model found no characteristics that influenced straying behaviour. However, research has found that more significant stray rates can be associated with hatchery-reared salmon as they may have a less accurate homing instinct than their wild counterparts (Ulvan et al., 2018). Hence, all fish released into FNP rivers may share a similar probability of demonstrating straying, suggesting the need for further considerations and information in decision-making processes. Indeed, not all salmonids return to their natal river, and straying is a natural process in which genetic material is shared (Jonsson et al., 2003). Moreover, the determined stray rates from this study are well within what has been observed previously for Atlantic salmon (Jonsson et al., 2003).

I found that fish that were angled for sampling purposes returned at a relatively high rate, demonstrating that angling may be a preferred sampling method over other methods in determining river population abundance. It must be recognized, however, that angling must be done in a controlled manner under the supervision of ecologists. When conducted properly, the effect on survival appears to be minimal. Parks Canada follows strict guidelines in that angling may only be conducted when the water and air temperature is below 20°C. As temperature increases, the effects of catch-and-release angling are deemed more detrimental to the fish (Havn et al., 2015; Wilkie et al., 1996), further advocating these strict guidelines when pursuing conservation efforts for endangered species and populations.

It must be considered that the inference of proxies (return rates) of marine survival should not be directly interpreted as marine survival rates as the examination of these trends can mask the actual changes in return abundance per year (Pardo et al., 2021; Hubley & Gibson, 2011). Indeed, return rates could be influenced by other factors other than conservation treatment, such as migration patterns or environmental conditions. Other factors that could negatively impact the number of returning adults per treatment are: fishing mortality, ocean acidification, predation, climate-driven changes in the local environment, and adverse effects caused by human activities (Pardo et al., 2021). However, the direct cause(s) of Atlantic salmon decline remain elusive as even with the mitigation of many suspected causal factors, Atlantic salmon populations continue to decline (Dadswell et al., 2022). To account for normal variation in salmon return abundance, as well as the many causal factors of decline, additional factors should be included as random effects in subsequent analyses as their consideration is essential in ascertaining more accurate results and representations.

My findings are consistent with other studies indicating that maximizing wild exposure is crucial for the restoration of endangered salmon populations and should be a vital component to consider when captive-rearing of fish. This study offers an additional resource for understanding the successful rearing strategies employed by the FSR program and that these efforts should continue to be implemented to restore iBoF Atlantic salmon populations. It should be acknowledged that without the employment and usage of Passive Integrated Transponder (PIT) technology, measuring and observing the success of returning salmon of an entire river population would be extremely difficult and, in many cases, cost prohibitive. This technology serves as an essential approach to further understanding migratory salmon movement and their success in returning to rivers within FNP. Successfully returning adults are critical to a self-sustaining population and understanding the efficacy of the current FSR restoration strategy remains crucial moving forward and should continue to be implemented in restoration efforts.

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Appendix

Appendix A. Release and return stray rates of iBoF Atlantic salmon (*Salmo salar*) to Fundy National Park (FNP) from 2020 – 2023 and cumulative stray rate (CSR) (i.e. total number of fish that strayed with a given trait/total number of fish released with given trait). The dash (-) indicating that no fish were released the year prior.

	Stray Rate (%)								
Level	**2020**		**2021**		**2022**		**2023**		**CSR**
Collection Method	**Release**	**Return**	**Release**	**Return**	**Release**	**Return**	**Release**	**Return**	
Wild Smolt (WS)	1.56	0.00	0.00	1.56	0.00	0.00	1.90	0.00	1.05
Wild Parr (WEP)	3.26	0.00	0.50	1.47	0.00	1.13	2.19	0.19	1.93
Adult Rearing									
Dark Harbour (DH)	4.06	0.00	0.55	0.90	0.00	0.55	2.14	0.00	1.90
Mactaquac Biodiversity Facility (MBF)	1.30	0.00	0.00	2.16	0.00	2.87	2.35	0.19	1.66
Release Stage									
Kelt	0.00	0.00	0.00	3.23	0.00	1.35	0.00	0.00	0.86
Maiden	3.43	0.00	0.54	0.90	0.00	0.67	2.31	0.17	1.65
Reconditioned	2.25	-	0.00	3.37	0.00	3.57	2.68	0.00	3.81
Release Method									
Hand	0.57	0.00	0.82	0.57	0.00	1.92	1.01	0.26	1.25
Helicopter	3.98	0.00	-	1.79	-	-	-	-	3.44
Slide	-	-	0.19	-	0.00	0.37	3.54	0.00	1.25
Sex									
Female	0.03	0.00	0.66	1.16	0.00	0.66	0.85	0.00	1.78
Male	0.03	0.00	0.56	1.07	0.00	1.13	2.71	0.00	1.91
Immature	0.00	0.00	0.00	4.08	0.00	1.25	3.85	0.00	1.48
Release Maturity									
1SW - DH	0.00	0.00	0.51	1.03	0.00	0.51	2.14	0.00	0.98
2SW - DH	5.20	0.00	0.72	0.87	0.00	0.72	-	-	4.37
3SW - DH	-	-	-	-	-	-	-	-	-
1SW - MBF	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2SW - MBF	1.30	0.00	0.00	2.17	0.00	2.92	2.12	0.51	2.26
3SW - MBF	0.00	0.00	0.00	0.00	-	0.00	-	-	0.00
River									
USR	0.28	0.00	0.82	1.66	0.00	1.92	1.01	0.30	1.20
PWR	6.37	-	0.19	1.27	0.00	0.37	3.54	0.00	2.57