Assessing Juvenile Salmon Use of Restored Habitat in the K’ómoks Estuary

by

Christopher Mahoney

Technician’s Diploma (Fish, Wildlife, and Recreation), BCIT, 2019

Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the
Environmental Restoration Program
Faculty of Environment (SFU)
and
School of Construction and the Environment (BCIT)

SIMON FRASER UNIVERSITY
BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
Spring 2024

Declaration of Committee

Name:	**Christopher Mahoney**
Degree:	**Master of Science**
Title:	**Assessing Juvenile Salmon use of Restored Habitat in the K'ómoks Estuary**
Committee:	**Dr. Shawn Chartrand** Supervisor School of Environmental Science, SFU
	Dr. Ruth Joy Committee Member School of Environmental Science, SFU
	Dr. Stefanie L. Lane Supervisor Comox Valley Project Watershed Society; Faculty of Forestry, Department of Forest & Conservation Sciences, University of British Columbia

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

or has conducted the research

c. as a co-investigator, collaborator, or research assistant in a research project approved in advance.

A copy of the approval letter has been filed with the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Abstract

The mouth of the Courtenay River on the K'ómoks Estuary has been exposed to a range of anthropogenic stressors and influences over the past one hundred years. Since 1998 organizations such as the Department of Fisheries and Oceans, and Comox Valley Project Watershed Society have conducted restoration projects in hopes of restoring juvenile salmon habitat throughout the K'ómoks Estuary. This study was an overview of the juvenile salmon use of restored salmon habitat in the K'ómoks Estuary. Sampling of juvenile salmon was conducted at three study sites by Comox Valley Project Watershed Society's Sampling Team between April and July 2023. Measurements such as Water Temperature, Dissolved Oxygen Concentration, and Salinity were also sampled and recorded along with Percent Shade Cover at the study sites. These data will be used to assess the success of historic restoration projects, as well as provide baseline data for the upcoming Kus-kus-sum restoration project.

Keywords: Juvenile salmon; Courtenay River; K'ómoks Estuary; Kus-kus-sum; restoration success; Project Watershed.

Acknowledgements

This project was undertaken for Comox Valley Project Watershed Society to inform their ecological monitoring programs, as part of their efforts to support restoration projects partnered with K'ómoks First Nation. This work was supported by a Mitacs Accelerate Fellowship supported by Comox Valley Project Watershed Society.

I respectfully acknowledge that all sampling conducted during this project was conducted on the traditional territories of the Homalco First Nation, the K'ómoks First Nation, the Tla'amin First Nation, the We Wai Kai First Nation, and the We Wai Kum First Nation.

I would like to thank Dr. Shawn Chartrand for overseeing and guiding me through this project.

I would like to thank The Comox Valley Project Watershed Society for allowing me to volunteer for them and aid in data collection, and for allowing me to use the data from their summer season for this project. All data contained within this project is the property of the Comox Valley Project Watershed Society as it was collected by the Project Watershed Sampling Team consisting of Project Watershed staff and volunteers between April and July 2023. A special thank you to Dr. Stefanie Lane for her help navigating this project. Dr. Lane provided her expert guidance and advice throughout the volunteer season and the Mitacs Fellowship portions of this project, without her aid this project would not be this finished product it is today.

I would like to thank the Department of Fisheries Ocean's Community Advisor Jacob Melville for consultation and aid provided for the duration of this project, and for use of a scientific permit to allow Comox Valley Project Watershed Society and associated volunteers to sample fish for scientific purposes during this project.

In addition, I would like to thank Project Watershed staff Jay Baker-French, Stefanie Lane, and Virginia East who were involved in data collection, and volunteers Charles Mahoney, and Sylvie Hawkes for aiding in data collection for this project.

Data availability statement: all data, metadata, and code used for generating analyses are available upon request from Comox Valley Project Watershed Society.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

Pacific salmon (*Oncorhynchus spp.)* are a keystone species that coastal ecosystems rely on (Willson & Halupka, 1995). They are an historic and contemporary food species, an economic asset for humans, and are vital in maintaining coastal ecology as nutrient transport and food for wildlife species (Criddle & Shimizu, 2014; Gresh et al., 2000). However, it well known that salmon populations in the Pacific Northwest of North America are in decline for a variety of reasons such as lack of quality freshwater habitat (Grant et al., 2019), and anthropogenic influences leading to habitat loss (Finn et al., 2021). Studies have shown that salmon species that require more rearing time in freshwater environments are experiencing higher declines, and those that migrate straight to the marine environment upon hatching are experiencing less drastic declines. This suggests that a main cause of salmon decline occurs in freshwater ecosystems. (Grant et al., 2019)

Juvenile salmon use estuaries for rearing and for migration when transitioning between freshwater and marine stages of their lifecycle (Quinn, 2018). Salmon species such as chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), and pink (*Oncorhynchus gorbuscha*) are known to quickly migrate to the marine environment shortly after hatching. Whereas salmon species such as coho (*Oncorhynchus kisutch)* and some chinook are known to spend time in freshwater habitat while rearing as juveniles; coho being known to stay in freshwater habitat for up to three years. (Godwin & Krkosek, 2022) Freshwater is also important based on the salmon species salinity tolerance. Chum and pink are known to exist in high salinity nurseries, whereas chinook and coho can be found in estuary environments, coho being found in areas of higher salinity than chinook (Beamish et al., 2003; Birtwell & Wright, 2014; Macdonald et al., 1987). For those juvenile salmon not acclimated to higher salinity, the transition from freshwater to high salinity water can be lethal (Otto, 1971). Therefore, freshwater habitats and estuary transition zones are important for juvenile salmon survival.

Freshwater habitats, specifically off-channel habitats, are important for juvenile salmon as they contribute to growth, survival, and predator avoidance. In addition, off-channel habitats can serve as refugia during high waterflow during storm or flood events. (Csoboth & Garvey, 2008; Henning et al., 2006; Taccogna & Hillaby, 2011) This is important in places like the Courtenay River, where daily and seasonal tidal fluctuations along with river discharge can dramatically alter the amount of suitable habitat for juvenile salmon during a given period over a day, week, or month. Other benefits of off-channel habitats include shade due to vegetation which can affect the water temperature and in turn the dissolved oxygen concentrations (DO) in the water since DO and water temperature have an inverse relationship (Harvey et al., 2011; Rutherford et al., 2004).

Juvenile salmon survival is reliant on DO, specifically in concentrations greater than 8 mg/L (equivalent of 8 PPM) for fry, which is strongly related to water temperature (Fellman et al., 2018; Geist et al., 2006; McMahon, 1983). It is also noted that 4.5 mg/L (equivalent of 4.5 PPM) is the lower threshold for juvenile salmon, but coho seem to tolerate this limit better than chinook (Whitmore et al., 1960). Generally the upper limit of temperature tolerance for Pacific salmon before the temperature is lethal is around 24.5 °C, and the preferred temperatures ranged from 12 to 14 °C (Brett, 1952). Restoring connectivity between isolated habitats within a watershed, especially off-channel habitat, can allow cooler water to flow into the connected habitat and can be a successful and cost-effective way to increase habitat availability and salmon production (Guimond & Sutherst, 2016; Roni et al., 2002).

As part of their organizational mission of ecological restoration, Comox Valley Project Watershed Society (Project Watershed) has been working to restore connectivity between marine habitat and freshwater habitat, specifically connecting the marine environment with off-channel habitat in the Courtenay River. Project Watershed has conducted two previous restoration projects in the K'ómoks Estuary, increasing waterflow through the sites by creating access points between the restored sites and the Courtenay River at Airpark Lagoon, and at Simms Creek Millenium Park (Simms Creek) (Fig. 1) (Guimond & Sutherst, 2016; Sutherst, 2018). In keeping with their mission to restore habitat in the K'ómoks Estuary, Project Watershed is currently working with the City of Courtenay and K'ómoks First Nation to restore a former industrial sawmill at a site known as Kus-kus-sum to its pre-industrial state as estuary habitat in order to increase off-channel habitat and juvenile salmon rearing habitat (Fig. 1)(Heim, 2021; Comox Valley Project

Watershed Society, 2020). To ensure effective future ecological monitoring, which is a critical part of a restoration project (Palmer et al., 2005), Project Watershed did work between April and July 2023 to collect baseline data of juvenile salmon abundance at the study sites that were restored along the Courtenay River. In addition, data were collected from the local reference site Hollyhock Flats Conservation Area (Hollyhock Flats) (Fig. 1), which is also being used as the reference site for the current Kus-kus-sum restoration project. The main objectives behind collecting juvenile salmon data are to understand whether the diversity and relative abundance of juvenile salmon would be indicated by environmental response variables such as water temperature, DO, salinity, and percentage of shade cover over the restored sites, and what implications this may have for the upcoming restoration of the Kus-kus-sum site.

To contribute to the success of the upcoming Kus-kus-sum restoration project, I worked with Project Watershed to access the effectiveness of their previous restoration projects, and which methods are effective in monitoring juvenile salmon in the K'ómoks Estuary. Water quality data were collected to aid in determining what factors may be contributing to juvenile salmon use of restoration sites in the K'ómoks Estuary.

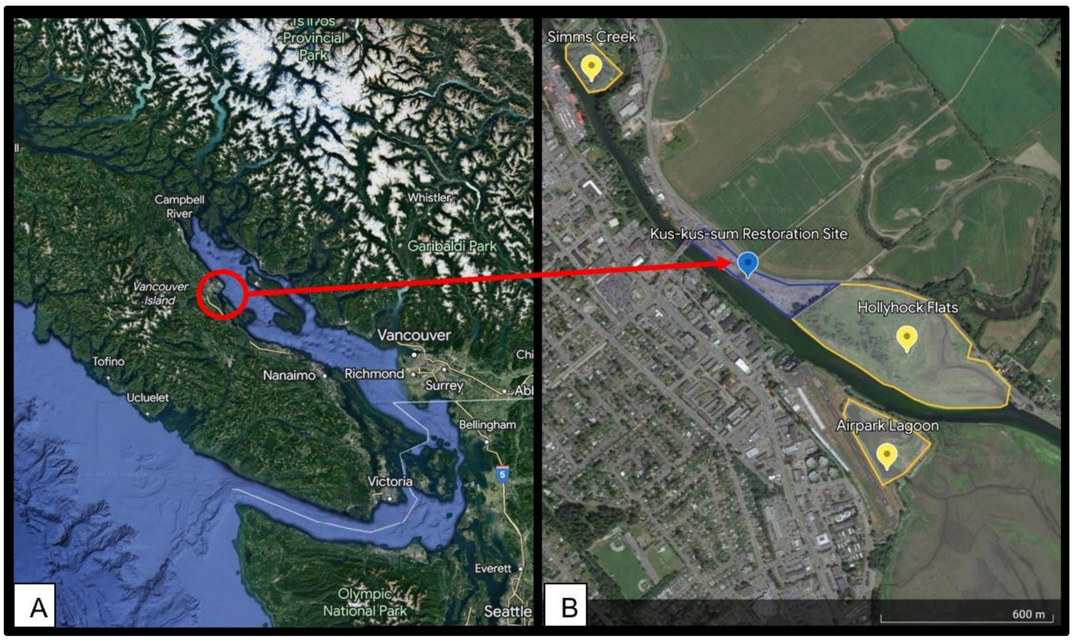


Figure 1: Location of Courtenay, BC on the east coast of Vancouver Island, BC (Panel A). Location of Airpark Lagoon, Hollyhock Flats, and Simms Creek study sites, and location of the Kus-kus-sum restoration site (Panel B). Images sourced from Google Earth (Accessed July 5, 2023).

1.1. Project Objectives

The purpose of this project is to assess the juvenile salmon use of the K'ómoks Estuary by analyzing the data obtained by Project Watershed's sampling efforts at the three study sites along the Courtenay River, and identifying possible causes that lead to one site being suitable over another for juvenile salmon. As such, the following objectives have been identified:

1) To answer the question: Do formerly restored sites such as Airpark Lagoon and Simms Creek have greater or lower relative abundance and diversity of juvenile salmon in comparison to Hollyhock Flats?

We expect restored sites (Airpark Lagoon and Simms Creek) to have higher or equivalent abundance and diversity to the reference site (Hollyhock Flats).

2) To answer the question: What are the relationships between juvenile salmon diversity and abundance and the environmental parameters at each study site?

We expect sites with higher DO, and cooler water temperatures will have a higher abundance of juvenile salmon.

3) To create a standardized sampling method for juvenile salmon and gather baseline data for future monitoring of juvenile salmon at the Kus-kus-sum restoration site upon its completion.

Chapter 2. Methods

2.1. Historical Methodologies

2.1.1. The K’ómoks Estuary Site History

Due to 150 years of anthropogenic influences related to European colonization such as agriculture and development, the Courtenay River has been subject to many changes that have resulted in damage to the estuary affecting its integrity and function. (Guimond & Sutherst, 2016; MacDougall et al., 1999; McAuley, 2014) The Courtenay River, found at the confluence of the Puntledge and the Tsolum Rivers, is an important river for juvenile salmon (Northwest Hydraulic Consultants Ltd., 2020).

To return connectivity and juvenile salmon habitat to the river, Project Watershed conducted two salmon habitat restoration projects. One at Airpark Lagoon in 2015, and the second at Simms Creek in 2017 (Fig. 1B). Both sites are found along the Courtenay River in the City of Courtenay, BC, on the east coast of Vancouver Island (Fig. 1A). Hollyhock Flats (Fig. 1B) will be used as the reference site for upcoming restoration projects as it is the best example of a historical remnant ecosystem in a highly urbanized landscape such as the Courtenay River.

2.1.2. Airpark Lagoon Site History

Airpark Lagoon (Fig. 1, Fig. 2), is a tidally influenced lagoon, which was a former tidal marsh that was enclosed by a dike and converted into a sewage lagoon in the 1950’s. In the 1980s the City of Courtenay ceased using the lagoon for sewage, and in the 1990s the dike was breached on the south end, restoring access to the K’ómoks Estuary. (Guimond & Sutherst, 2016;McAuley, 2014). This site was deemed important for juvenile salmon, yet the water temperatures in the lagoon were considered above the optimal range for juvenile salmon survival, especially in the northern section of the site (McAuley, 2014). In 2015, the dike was breached a second time, and a culvert was placed on the north end of the lagoon (Fig. 2) to allow for greater waterflow and connectivity between the Courtenay River, and the north side of Airpark Lagoon (Guimond & Sutherst, 2016). This was done with the hope of restoring the site, as water temperatures in the lagoon were exceeding the temperatures of surrounding habitat along the Courtenay River, and even reaching temperatures over 25 °C which are lethal to juvenile salmon (Bjornn & Reiser, 1991; McAuley, 2014). The second breach in the dike increased waterflow and nutrient movement through the lagoon. This was done in tandem with creating salt-marsh habitat alongside the lagoon to improve juvenile salmon habitat. (Guimond & Sutherst, 2016) Despite recommendations to do so in previous reports, this site has not been monitored since the Guimond and Sutherst study in 2016.

Figure 2: Airpark Lagoon restoration site. Photo of the lagoon from the north end of the lagoon facing south (left), and photo of the culvert installed at the north end of the lagoon increasing connectivity and waterflow between the lagoon and the Courtenay River (right).

2.1.3. Hollyhock Flats Site History

Hollyhock Flats Conservation Area (Fig. 1, Fig. 3), set aside as a conservation area in 1974 (Comox Valley Project Watershed Society, 2023), was chosen as the reference site for the upcoming restoration of Kus-kus-sum as it is directly adjacent to the Kus-kus-sum site and is the best example of a historical remnant ecosystem in a highly urbanized landscape such as the Courtenay River. Hollyhock Flats is a oligohaline tidal marsh (Odum, 1988) filled with small channels that are accessible to juvenile salmon when the tide rises (Fig. 3). The pool feature (Fig. 1, Fig. 3) was chosen as the study site given it was the only available pool feature in the Hollyhock Flats. This helped to standardize the location features in which sampling took place during this study. Despite anthropogenic influences from the adjacent road and slough flood gates, this is the only available pool feature in the reference site that remains reliably passable to fish and connected to the Courtney River.

Figure 3: Hollyhock Flats reference site. Tidal channels as seen at low tide (left), and the pool feature at the edge of the conservation site (right).

2.1.4. Kus-kus-sum Restoration Site History

The Kus-kus-sum restoration site (Fig. 1, Fig. 4) is adjacent to Hollyhock Flats. Kus-kus-sum was a former sawmill site in the 1950s that was later decommissioned. The site is currently being revegetated and connected to the Courtenay River to restore it to its former state as estuary habitat, and to create juvenile salmon rearing habitat. Upon completion of the restoration project, Kus-kus-sum will connect with Hollyhock Flats to provide a continuous tidal marsh habitat along the Courtenay River within the K'ómoks Estuary.

Figure 4: The current site at Kus-kus-sum as seen on October 8, 2023, which is undergoing removal of contaminated soil, and replanting of native riparian vegetation (Image credit: Comox Valley Project Watershed Society. Accessed March 25, 2023. https://projectwatershed.ca/2020/01/27/kus-kus-sum/).

2.1.5. Simms Creek Site History

Simms Creek (Fig. 1, Fig. 5) restoration site is a series of shaded channels and a pool system adjacent to the Courtenay River (Fig. 5). It was created in 1998, as part of a of a partnership between the DFO and the City of Courtney in order to mitigate prior environmental damages and create juvenile salmonid habitat in the K'ómoks Estuary (Jenkins et al., 2001; Sutherst & Heim, 2017). It is noteworthy that juvenile salmon were using the site after 1998; however, the original culverts were deemed not sufficient for fish passage and site utilization. Modifications were proposed and new culverts were installed in 2018, increasing access between Simms Creek and the Courtenay River, and reducing barriers to fish passage. (Guimond & Sutherst, 2016) This site has not been monitored since the Sutherst study in 2018.

Figure 5: Simms Creek study site. One of the pool features (left), and the new "fish friendly" culvert as seen at high tide when fish can pass in between the pools and the Courtenay River (right).

2.2. Historical Fish Data

Historical studies were done in 1998, 2000, and 2001 by the DFO in and around the Courtney River using a variety of methods including beach seines, pole seines, purse seines, gee minnow traps (gee traps), and snorkel surveys (Hamilton et al., 2008; Jenkins et al., 2001, 2006; MacDougall et al., 1999). Juvenile salmon were caught successfully using beach seines, purse seines, and gee traps. (Hamilton et al., 2008; Jenkins et al., 2001; MacDougall et al., 1999) The studies show that pole seining was not an effective method for capturing juvenile salmon (Hamilton et al., 2008; Jenkins et al., 2001).

It has been suggested that sampling for juvenile salmon abundance should occur starting in early spring through July, as those are the peak times for juvenile salmonid abundance (Carter et al., 2009; Jenkins et al., 2006). Other times for emergence have been suggested as juvenile coho have been caught in gee traps in the Courtenay River as early as January (Hamilton et al., 2008). Given that Pacific salmon have different life histories (Bisson et al., 2009), juvenile salmon present in the location of study along the K'ómoks Estuary may be limited to species that spend their early life in freshwater environments, as well as species that appear favor gee traps, such as coho (Hamilton et al., 2008; McMahon, 1983).

2.2.1. Airpark Lagoon Salmon Studies

During the DFO studies, Airpark Lagoon was only sampled during the 2000 study using a beach seine (Jenkins et al., 2001). Only chinook and coho were noted during this study. Sampling at Airpark Lagoon did not occur during the 1998 or the 2001 studies (Hamilton et al., 2008; MacDougall et al., 1999).

Further sampling was conducted at Airpark Lagoon by Project Watershed in preparation for the 2015 culvert breach restoration project. The 2010 consultant study sampled in Airpark Lagoon with beach seines (Tryon, 2011). The 2013 study was conducted using a beach seine from late May through August though no juvenile salmon were caught in the lagoon after June (McAuley, 2014). Sampling was again conducted in 2015 using a beach seine in Airpark Lagoon from April through September. Three samples were conducted before the breach was made, and three were conducted after. It was noted that a total of four juvenile salmon were caught in the lagoon during the entire study, and only during the month of April 2015, which is in contrast to juvenile salmon being found in the lagoon in higher numbers in the 2010 and 2013 studies. (Guimond & Sutherst, 2016)

2.2.2. Hollyhock Flats Salmon Studies

The DFO beach seine and pole seine studies in Hollyhock Flats were conducted at a site the DFO referred to as "Duck Slough". No juvenile salmon were successfully caught using pole seines at this site, but chinook and coho were successfully caught using beach seines during the 1998, the 2000, and the 2001 studies. (Hamilton et al., 2008; Jenkins et al., 2001; MacDougall et al., 1999) This is the same site selected for Project Watershed's 2023 study. The site was also surveyed during the 2010 consultant study using a beach seine (Tryon, 2011).

2.2.3. Simms Creek Salmon Studies

The Hamilton et al. 2001 study's gee trapping method confirmed that juvenile salmon were using Simms Creek after its construction in 1998. However, the Jenkins et al. 2001 study was not successful in capturing salmon in Simms Creek using pole seines the year prior. Coho appeared to be the most commonly caught salmon species at this site (Hamilton et al., 2008).

In addition to the DFO's studies, Simms Creek was sampled in 2011 by Lake Trail Environmental Consulting, and in 2017/2018 by Project Watershed staff (Sutherst, 2018; Sutherst & Heim, 2017; Tryon, 2011). Gee traps were used in all three studies and appear to be an effective method for sampling juvenile salmon in Simms Creek. The Sutherst studies only mention coho being caught in their studies, but they also mention an abundance of sculpins and sticklebacks (Sutherst, 2018; Sutherst & Heim, 2017). The 2011 consultant study mentions using gee traps but does not mention which method they used to sample in the Simms Creek channels. Given they only used beach seines to conduct their catch per unit effort (CPUE) calculations, we known they utilized beach seines in the area, but this was among four sites labelled 2a, 2b, 2c, and 2d, yet they only report CPUE for site 2, they do not delineate among the four subsites. It seems unlikely they used beach seines in site 2b and 2c due to space constraints of the channels in the study sites. These appear to be in the same channels that were used for this project, whereas site 2a and 2d appear to be in the Courtenay River at the mouth of the study site. However, the report does not specify which specific method was used at these sites. (Tryon, 2011) Overall, coho appears to be the most abundant fish observed and calculated across all studies done at Simms Creek, and gee traps would appear to be the likely method.

2.3. Missing Data

Given the lack of consistency in collection methods used across all three sites it is difficult to compare current data to historical data as the CPUE was only calculated in some of the studies using beach seines (Tryon, 2011). However, it is not specified whether beach seines were used in the channels at the Simms Creek site. Therefore, it is difficult to choose one method to use across all three sites in the current study. This is why one of the goals of this project is to be able to create a standardized method which will aid Project Watershed's sampling efforts in upcoming studies.

2.4. Site Selection

A total of six gee traps were deployed across all three sites. The traps were placed in a semi random sampling distribution based on site accessibility and safety during the short time window in which sampling could occur after the daily high tides. The areas that were deemed accessible during high tides were determined, and then the traps were distributed relatively evenly along the shoreline in the designated zones.

2.4.1. Airpark Lagoon Site Selection

Due to muddy substrates on the eastern side of Airpark Lagoon that posed a tripping hazard and safety risk, the sites were semi-randomly distributed along the western side of the lagoon, so they were accessible without the risk of getting stuck in the mud when conducting sampling on foot. The traps were distributed at relatively equal distances from the northeast perimeter of the site, along to the southwest corner of the site (Fig. 6).

Figure 6: Distribution of gee traps at Airpark Lagoon. Each blue marker is the location of a single gee trap. Images sourced from Google Earth. (Accessed July 5, 2023)

2.4.2. Hollyhock Flats Site Selection

The traps at Hollyhock Flats were originally set in the channels on the western side of the site (Fig. 3). However, it was noted that even though some fish were travelling through these channels, they were not entering the traps. The trap locations were changed to the pool feature on May 9th, 2023, and they were relatively evenly distributed along the north and eastern sides of the site. The site was accessible from the highway, but the western/southern side of the site was not accessible during the high tide as access was cut off by the rising water. All traps were placed on the north/eastern side of the site where they could be accessed at high tide (Fig. 7). This change of site will have an impact on the data, as we do not know the number of potential juvenile salmon using the Hollyhock Flats pool feature before May 9th, 2023.

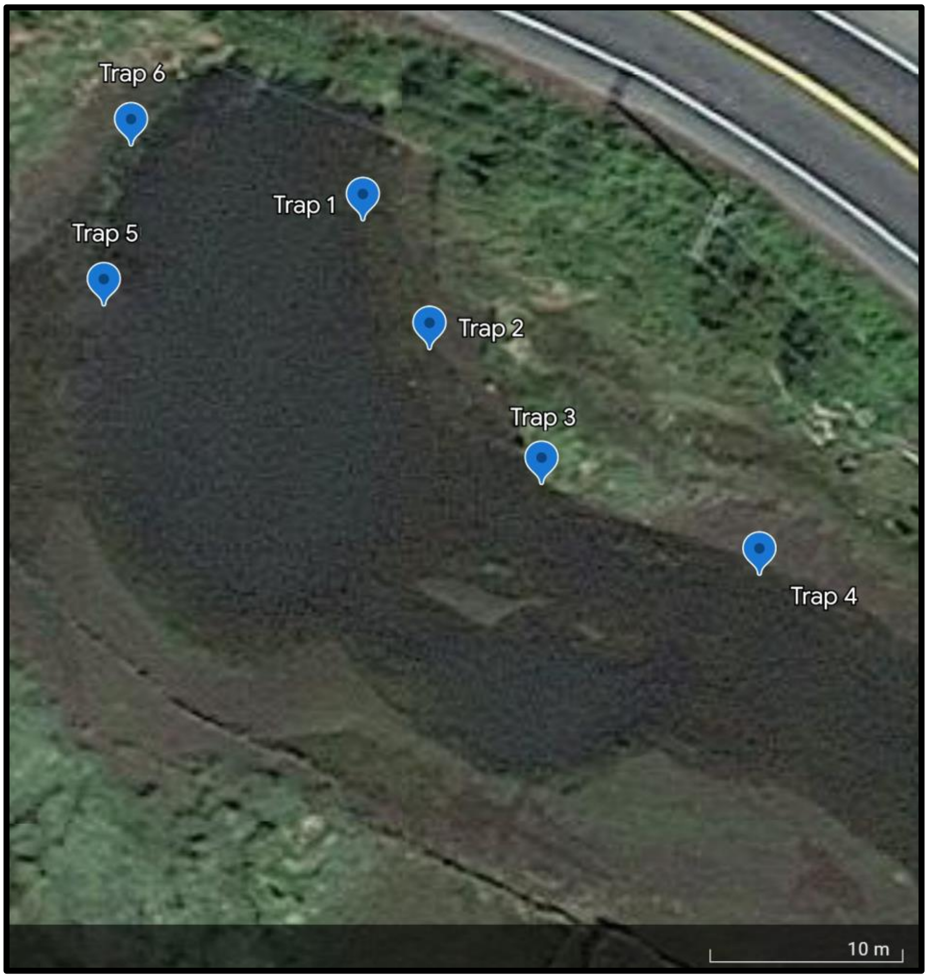


Figure 7: The distribution of gee traps at Hollyhock Flats. Each blue marker represents a single gee trap. Images sourced from Google Earth. (Accessed July 5, 2023)

2.4.3. Simms Creek Site Selection

The Simms Creek site was relatively accessible from all areas of the site, so the traps were semi-randomly distributed evenly along the full shoreline of the pool features at Simms Creek, and in the feature known as the finger. (Fig. 8)

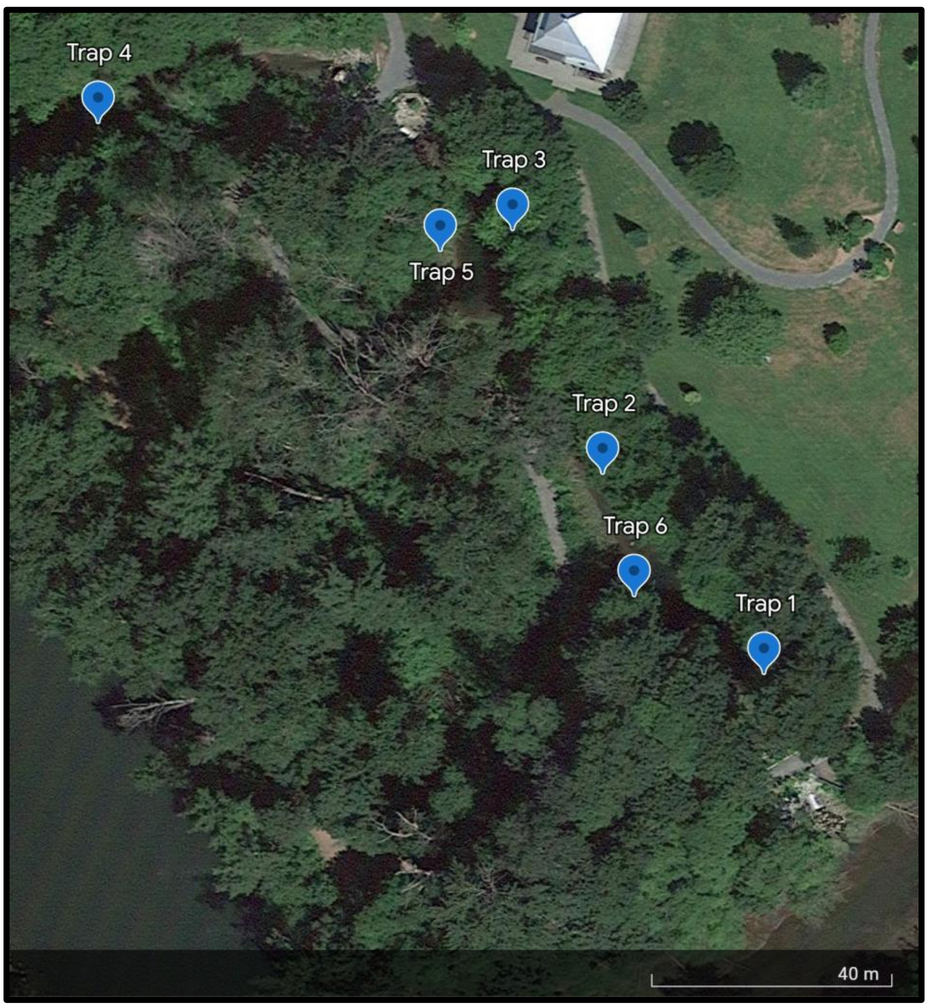


Figure 8: The distribution of gee traps at Simms Creek. Each blue marker represents one gee trap. Images sourced from Google Earth. (Accessed July 5, 2023)

2.5. Sampling Methods

2.5.1. Fish Sampling

Juvenile salmon sampling was conducted by Project Watershed Staff along with the aid of volunteers, henceforth referred to as the Project Watershed Sampling Team. All sampling occurred under DFO Community Advisor Jacob Melville's Scientific Permit (Appendix A).

Juvenile salmon sampling was conducted by the Project Watershed Sampling Team using gee traps over consecutive three-day periods every 10-14 days (coinciding with monthly tidal maxima) beginning in April 2023 and ending in July 2023. Traps were placed after low tide the afternoon before the sampling date and were retrieved after high tide the following morning. Only one site was sampled per day. For example. If sampling Simms Creek on a Saturday, Airpark Lagoon on Sunday, and Hollyhock Flats on Monday, the Project Watershed Sampling Team would deploy traps for sampling at Simms Creek on the Friday evening after the low tide. The team would sample the traps at Simms Creek Saturday morning after the high tide, and then set the traps at Airpark Lagoon Saturday evening after the second low tide. Sampling of Airpark Lagoon would then occur Sunday morning after the high tide, then the traps would be set at Hollyhock Flats Sunday evening after the low tide. Finally, Hollyhock Flats would be sampled Monday morning after the high tide.

All fish captured during the study were captured using fine mesh gee traps (Fig. 9), an approved method of juvenile salmon sampling under the BC RISC standards fish collection (B.C Ministry of Environment, Lands and Parks, Fish Inventory Unit, 1997). Gee traps were the chosen trap method, standardizing the sampling effort between sites. Although literature and trial studies suggest that differing methods would be preferable across different sites, gee traps were the traps that were deployed, as they could easily be deployed across all three sites where seine nets and fyke nets would have been difficult at Simms Creek.

Figure 9: Gee traps used for the study. The traps were baited with cat food and have a long string line that could be used to pull the trap to the shoreline for easy retrieval during high tide.

Six traps were set per site in a semi-randomized distribution pattern. Given the tidal nature of the sites, the traps could not be left out during low tides after a high tide in which the trap was accessible to fish. This would lead to a chance the traps would be exposed to the air and endanger the fish. A standardized tide height of 3.4 m above chart datum was selected as the minimum low tide height at which sampling could occur. This insured that the traps were sufficiently submerged when left overnight across all three sites. The traps were set during a period in which the high tides for sampling and setting were during daylight hours, and in which the overnight low tide did not drop below 3.4 m to ensure fish safety. Traps were placed after low tide the afternoon before sampling, and allowed to remain in place during the overnight high tides and low tides when tidal amplitude was at least 3.4 m above chart datum. Traps were retrieved the following morning before tide heights dropped below 3.4 m, ensuring that water always covered the trap, and that water depths were on average greater than 0.5 m when fish were able to access the traps.

The traps were attached to bamboo stakes with a rope length of approximately 1.5 m. The bamboo stakes were wedged into the muddy substrate adjacent to the placement of the gee traps. The rope was attached to prevent the traps from getting pulled around by the currents and potentially beached during high tides. In addition, rope was used to attach the bamboo stakes to a wooden post that was staked onto the shoreline approximately 1 m above the high tide line. This allowed the Project Watershed Sampling Team to pull on the rope attached to the wooden post, which would then pull on the bamboo stake in the water, and in turn pull the trap. This allowed the Project Watershed Sampling Team to pull the traps to shore for sampling without risking getting stuck in the muddy substrate (Fig. 10).

Figure 10: Photo of submerged gee trap, the bamboo stake and the string attaching the gee trap to the bamboo stake and the stake further up the shoreline.

The traps were baited using cat food as approved by the BC RISC standards for fish collection (B.C Ministry of Environment, Lands and Parks, Fish Inventory Unit, 1997). A standardized amount of 50 g of cat food was added to the traps to ensure that there would be enough food in the traps for the juvenile salmon captured. In addition, larger fish such as a sculpin (*Cottus ssp.)* have been known to prey on juvenile salmon (Swain et al., 2014). Therefore, the 50 g of cat food was also to ensure there was ample food available for larger fish if they got into the trap, reducing the chance they would prey on juvenile salmon. As well, ample food was provided to reduce competition with bycatch species such as threespine sticklebacks (*Gasterosteus aculeatus)* which are not know to prey on juvenile salmon (Ruggerone, 1992).

Upon retrieval, the fish in the traps were gently emptied into buckets containing cool oxygenated water retrieved from the study site, ensuring high DO for fish health. Water temperature in the bucket was monitored using a Hanna HI98194 multiprobe. If the water temperature raised by 2 °C all fish in the trap were released, even if sampling was not completed, ensuring fish safety. Juvenile salmon were transferred to a viewing device and identified to species as rapidly as possible using the Pacific Salmon Field Guide by Godwin and Krkosek (2022), and the Project Watershed Sampling Teams' personal knowledge, then promptly released back into the estuary to ensure fish health. Photos of indicative species can be found in Appendix B.

After the juvenile salmon were sampled, the Project Watershed Sampling Team then counted all other identifiable species of fish found in the trap and released them back to their place of retrieval. The number of non-salmon fish caught during the study was documented as supplemental data of other species present and their relative abundance in relation to juvenile salmon. The number of each species of juvenile salmon caught was recorded to analyze the diversity and relative abundance of juvenile salmon caught over the season.

2.5.2. Water Quality Sampling

Water quality data were taken using a Hanna HI98194 multiprobe to measure the water temperature, DO, and salinity in the water surrounding each trap at the time of sampling. Water quality data was recorded each time a sampling event for juvenile salmon occurred. Water temperature was measured in degrees Celsius (°C), DO was measured in parts per million (PPM), and salinity was measured in practical salinity units (PSU).

2.5.3. Vegetation Survey

Vegetation surveys were done using a forest densitometer to assess percent cover (shade) at the edge of vegetation growth along the bank at the point on the bank nearest the trap. *Carex lyngbyei* was the dominant vegetation along the banks of the study sites and the forest densitometer was used at the edge of the *C. lyngbyei* distribution at the study sites to get a general measurement of the shade at the edge of the vegetation near the water line. *C. lyngbyei* was chosen as it was present at all three study sites, and allowed for a comparable analysis point, as it had a defined edge of growth at all three sites and allowed for standardization of measurement with the densitometer across all three sites.

It is acknowledged that this is not the intended use of a forest densiometer, as they are meant to be used while standing, and to assess overstory canopy. However, a method was needed to standardize the shade produced by the *C. lyngbyei* growing along the water's edge. The reading was standardized by taking the reading at the same arm length, height, and aspect each time while crouching at the edge of *C. lyngbyei* growth to obtain a measure of the shade at the water's edge. This was used as a crude method to obtain a measurement for change in shade at the edge of *C. lyngbyei* growth throughout the study observation period. This provided a rough estimate of the increase in shade along the bank over the course of the study and whether there may be a relationship between streamside vegetation, shade, and water temperature. Despite not being the standard method, it was added as a parameter to get a measurable metric across all three study sites, that did not easily have a standardized measurement due to their inherent structural differences.

2.6. Analysis

Analysis of juvenile salmon and environmental data was conducted using R studio (v 4.2.2). Mean testing was conducted along with summary statistics (Base R), and boxplots (ggplot2, ggpubr) and histograms (ggplot2) to visually display the data. Boxplots were used to display the differences between the environmental parameter readings among the study sites, and the differences in juvenile salmon use across all three sites. Boxplots were used to highlight the relationships between the environmental factors at the given sites, and the number of juvenile salmon found there. They do not allow for determination of correlation or causations.

All data were tested for normality as well as homogeneity of variance to determine which statistical analyses were possible for juvenile salmon count, non-salmon fish species count, water temperature, DO, shade, and salinity. Normality was tested using QQ plots (ggplot, ggpubr) and the Shapiro test (rstatix). Homogeneity of variances was tested using the Levene test (car). Data transformations were conducted using square root transformations in an attempt to create homogeneity of variance for data that did not meet the assumptions (Appendix C). ANOVA testing was conducted for the Water Temperature and the DO data sets using Welch's ANOVA due to homogeneity of variances in conjunction with lack of normal data.

Chapter 3. Results

3.1. Pacific Salmon Species

Pacific salmon species caught across all three sites during the study are limited to coho, chinook, and chum. The count of juvenile salmon was highest at Simms Creek (308, Fig.11, Table 1) in comparison to the other two sites. Very few juvenile salmon were caught at Airpark Lagoon (15, Fig. 11, Table 1) or Hollyhock Flats (14, Fig. 11, Table 1).

A month-by-month analysis from April through June 2023 (Fig. 12) shows that the highest average number of juvenile salmon were found at Simms Creek in April 2023, and that the most abundant species was coho (Fig. 12, Table 1). No chinook or chum salmon were caught during June 2023. In addition, during June 2023, juvenile salmon were only found in Simms Creek (Fig. 12). No juvenile salmon were caught at any site during July 2023.

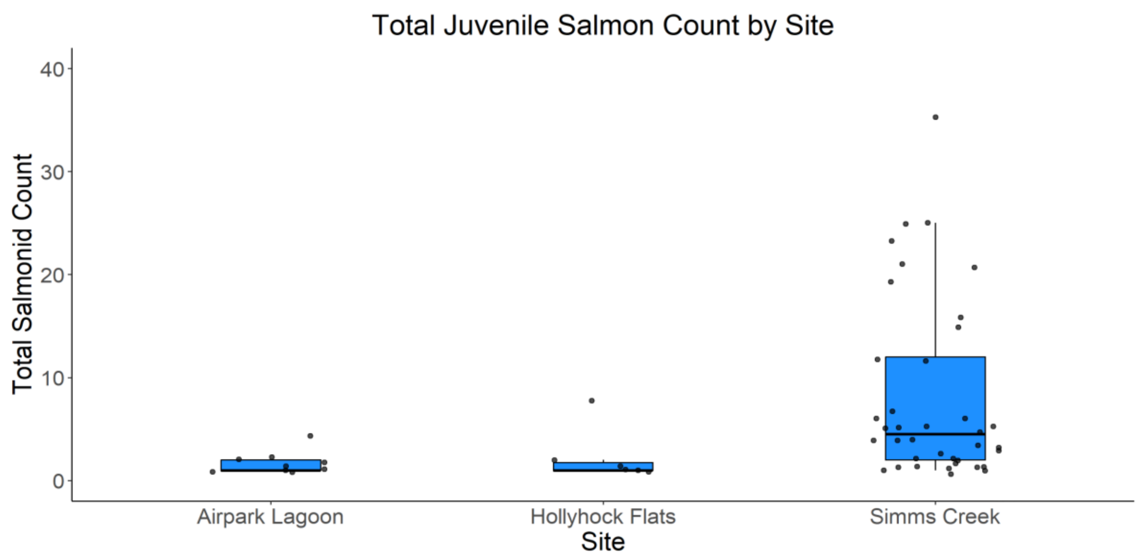


Figure 11: Boxplots displaying total number of juvenile salmon caught at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April, May, June, and July 2023. Each data point represents the total number of juvenile salmon found in a single trap at one time at the given study site.

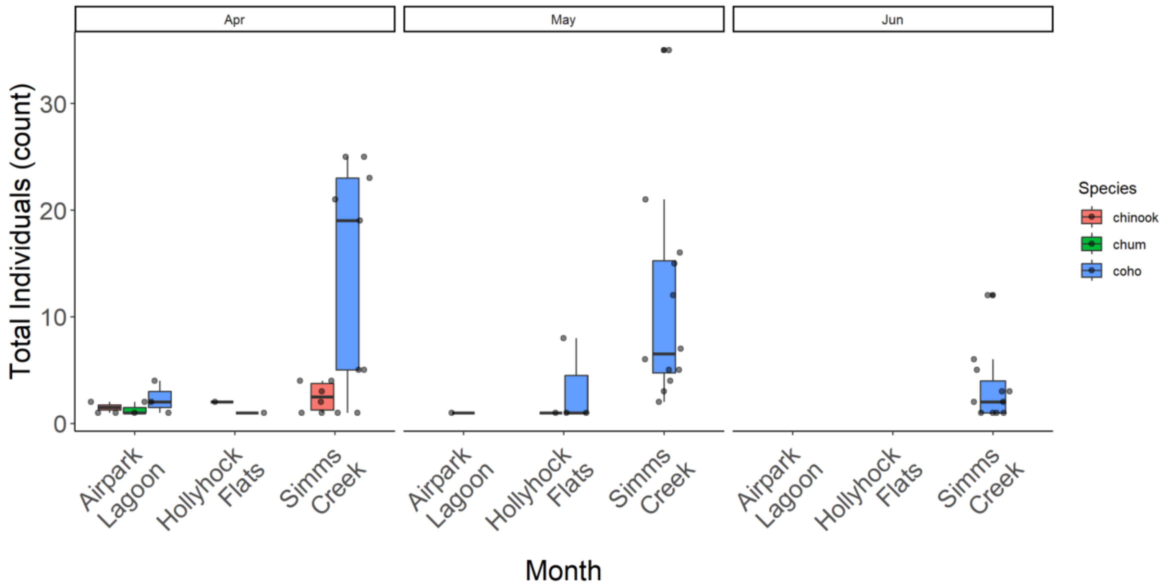


Figure 12: Boxplots displaying total number of juvenile salmon caught at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April, May, and June 2023. Each data point represents the total number of juvenile salmon of the labelled species caught in a single trap at the time of sampling during the month detailed above.

Table 1: Total number of all juvenile salmon caught by species and site.

Location of Sampling	**Salmon Species**		
	Coho	**Chinook**	**Chum**
Airpark Lagoon	8	3	4
Hollyhock Flats	11	1	2
Simms Creek	293	15	0

3.2. Non-salmon Species

Non-salmon species caught across all three study sites during the study include gunnel fish (*Pholis laeta*), various marine invertebrates, pumpkinseed (*Lepomis gibbosus*), Pacific sanddab (*Citharichthys ssp*.), sculpins (*Cottus ssp*., *Leptocottus armatus*), and threespine sticklebacks. Non-salmon species were more abundant at Airpark Lagoon than Simms Creek and Hollyhock Flats (Fig. 13, Table 2). Hollyhock Flats had the lowest average number of non-salmon species caught (Table 2).

A month-by-month comparison shows that sticklebacks were the most abundant species caught during the month of June and July 2023, and there was also an increase in sculpins found across all three sites in June and July 2023 (Fig. 14).

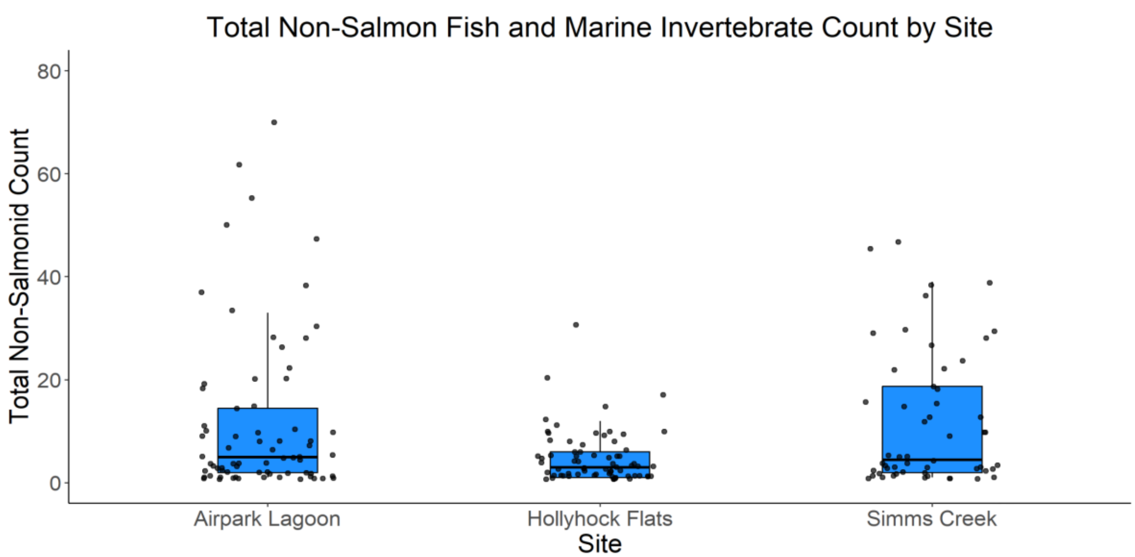


Figure 13: Boxplots displaying total number of non-salmon species caught at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April, May, June, and July 2023. Each data point represents the total number of non-salmon species found in a single trap at one time at the given study site.

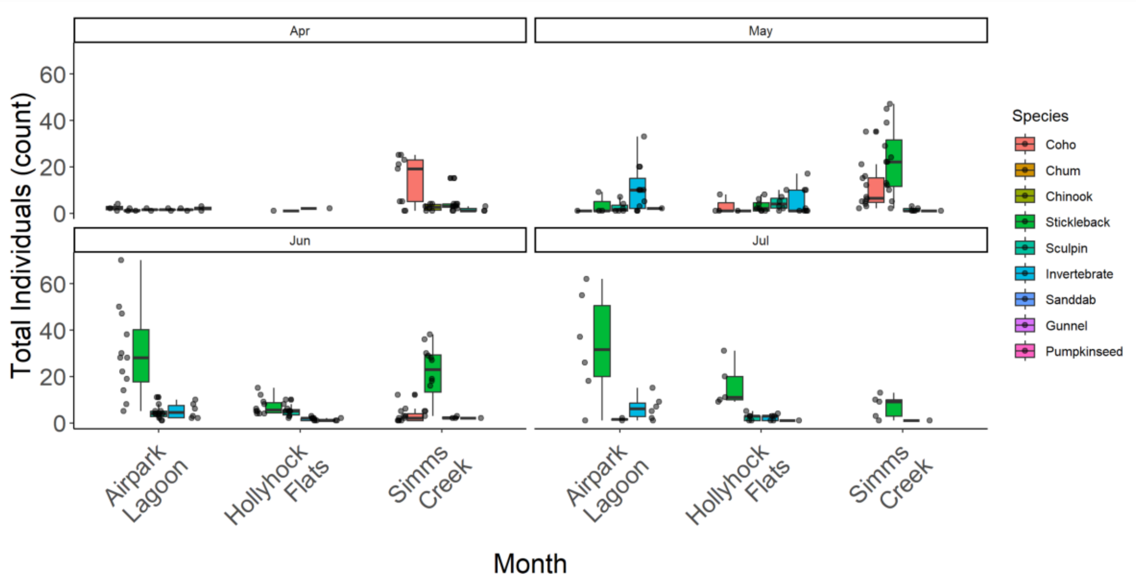


Figure 14: Boxplots showing the difference in the average count of all species caught between study sites between April and July at Airpark Lagoon, Hollyhock Flats, and Simms Creek study sites. Each data point represents the number of each labelled species caught in a single trap at the time of sampling during the month detailed above.

Table 2: Total count of all non-salmon species caught by site.

Location of Sampling	**Fish Species**					
	Gunnel Fish	Invertebrate	Pumpkinseed	Sanddab	Sculpin	Stickleback
Airpark Lagoon	0	188	0	2	74	572
Hollyhock Flats	4	68	0	1	93	178
Simms Creek	0	1	3	0	20	615

3.3. Comparison Histograms

A side-by-side histogram analysis confirms that the total number of juvenile salmon caught at Simms Creek was greater in number than at the other two sites. The histogram also display that the total number of non-salmon fish was greater at Airpark Lagoon than at the other two sites. (Fig. 15)

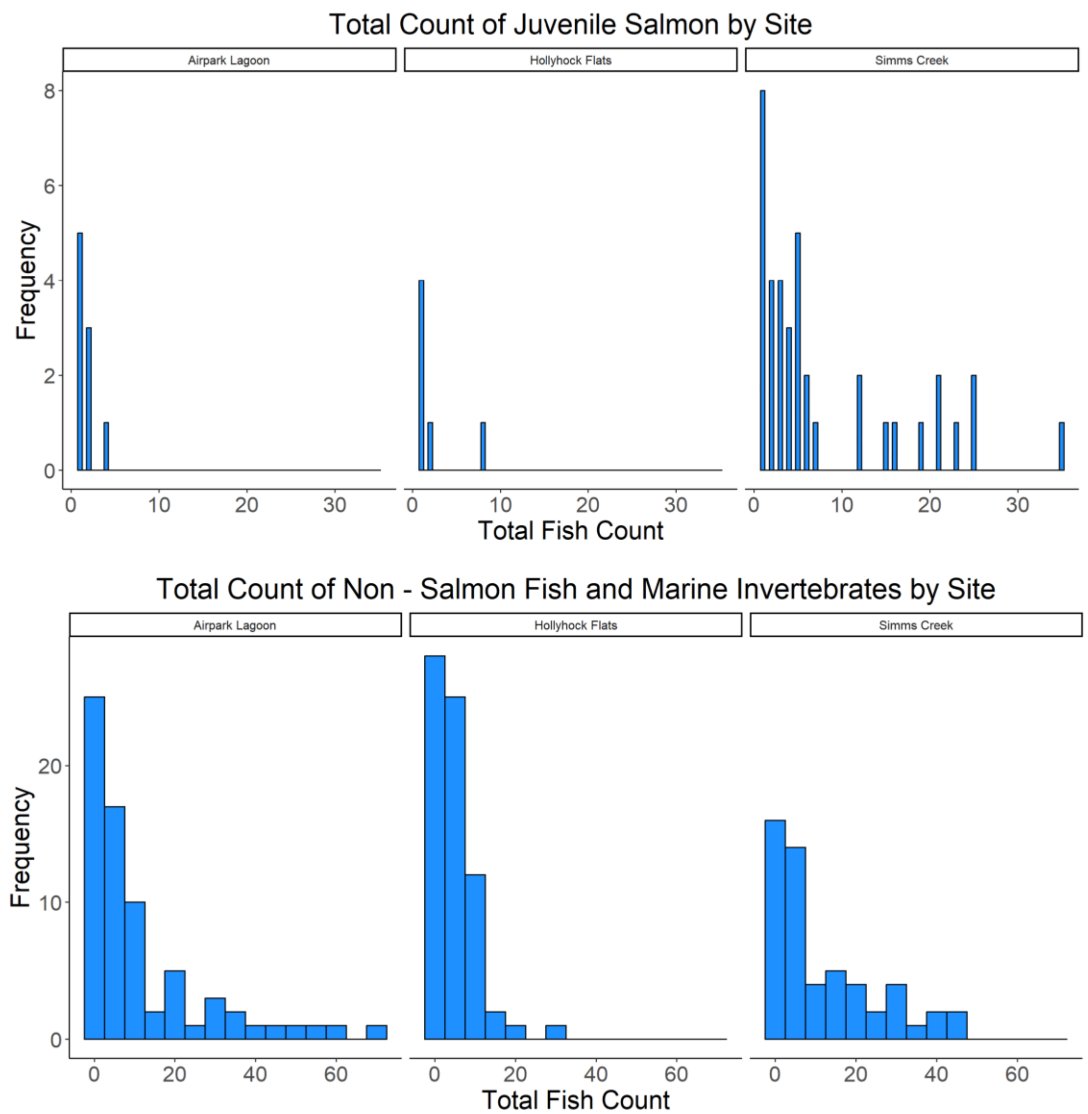


Figure 15: Two sets of histograms displaying the difference between average salmon count frequency (top) and average non-salmon count frequency (bottom) between the Airpark Lagoon, Hollyhock Flats, and Simms Creek. Total fish count represents the number of individual fish caught in a single trap, and frequency represents the number of times the total fish count occurred.

3.4. Environmental Parameters

3.4.1. Water Temperature

The highest average water temperatures were found at Airpark Lagoon, and the lowest average water temperatures were found at Simms Creek (Fig. 16, Table 3). Welch's ANOVA and Games Howell Post hoc testing confirms that there is a significant difference in the water temperature between Airpark Lagoon and Simms Creek, as well as between Hollyhock Flats and Simms Creek (Table 4).

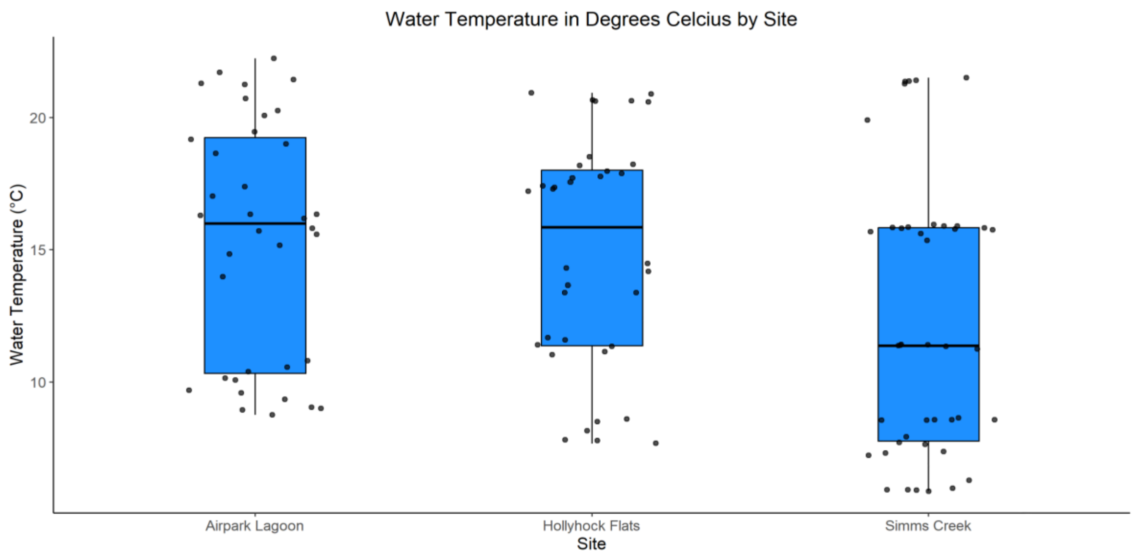


Figure 16: Boxplots showing the average difference in Water Temperature (°C) between the Airpark Lagoon, Hollyhock Flats, and Simms Creek. Each data point represents the average water temperature (°C) beside the trap at the time of sampling.

Table 3: Max water temperature, minimum water temperature, and the average water temperature recorded at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April and July 2023.

Site	Max Water Temperature (°C)	Minimum Water Temperature (°C)	Average Water Temperature (°C)
Airpark Lagoon	22.23	8.76	15.34
Hollyhock Flats	20.93	7.63	14.93
Simms Creek	21.50	5.87	12.30

Table 4: Welches ANOVA, and Games Howell Post Hoc Test outputs for significant differences in water temperature between Airpark Lagoon, Hollyhocks Flats, and Simms Creek.

ANOVA Results

Method	n	Statistic	DFn	DFd	P
Welch's ANOVA	114	4.45	2	73.8	0.015

Post Hoc Test Results (Games Howell)

Group 1	Group 2	Estimate	Conf.low	Conf.high	p.adj
Hollyhock Flats	Airpark Lagoon	0.408	-2.107	2.923	0.920
Hollyhock Flats	Simms Creek	-2.625	-5.191	-0.059	0.044
Airpark Lagoon	Simms Creek	-3.0328	-5.654	-0.411	0.019

3.4.2. Dissolved Oxygen Concentration

The highest average DO was found at Simms Creek, and the lowest average DO was found at Hollyhock Flats. However, the lowest minimum DO reading was found at Airpark Lagoon (Fig. 17, Table 5). Welch's ANOVA and Games Howell Post hoc testing confirms that there is a significant difference in DO between Airpark Lagoon and Simms Creek, as well as between Hollyhock Flats and Simms Creek (Table 6).

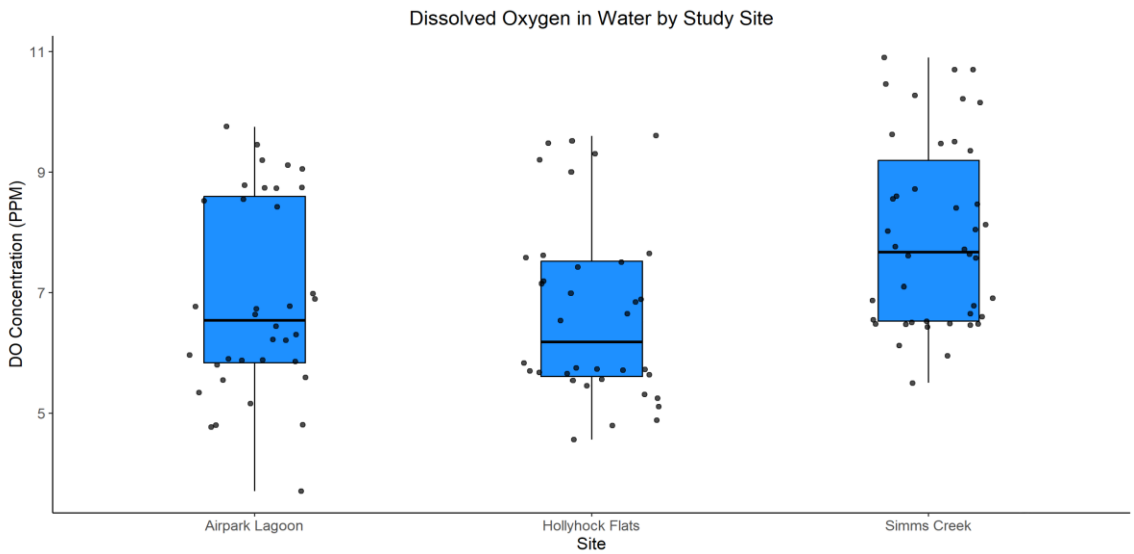


Figure 17: Boxplot displaying the differences in average dissolved oxygen concentration between Airpark Lagoon, Hollyhock Flats, and Simms Creek. Each data point represents the dissolved oxygen concentration (PPM) in the water beside the trap at the time of sampling.

Table 5: Max dissolved oxygen concentration, minimum dissolved oxygen concentration, and the average dissolved oxygen concentration recorded at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April and July 2023.

Site	Max DO (PPM)	Min DO (PPM)	Average DO (PPM)
Airpark Lagoon	9.75	3.70	6.89
Hollyhock Flats	9.60	4.56	6.67
Simms Creek	10.90	5.50	7.94

Table 6: Welches ANOVA, and Games Howell Post Hoc Test outputs for significant differences in dissolved oxygen concentration between Airpark Lagoon, Hollyhocks Flats, and Simms Creek.

ANOVA Results

Method	n	Statistic	DFn	DFd	P
Welch's ANOVA	114	7.71	2	73.0	0.000917

Post Hoc Test Results (Games Howell)

Group 1	Group 2	Estimate	Conf.low	Conf.high	p.adj
Hollyhock Flats	Airpark Lagoon	0.223	-0.654	1.010	0.816
Hollyhock Flats	Simms Creek	1.273	0.449	2.096	0.001
Airpark Lagoon	Simms Creek	1.050	0.190	1.910	0.013

3.4.3. Percent Shade Cover

The highest average percent shade cover was at Simms Creek, and the lowest average percent shade cover was found at Airpark Lagoon. (Fig. 18, Table 7). ANOVA testing was not conducted due to lack of normality and lack of homogeneity of variances.

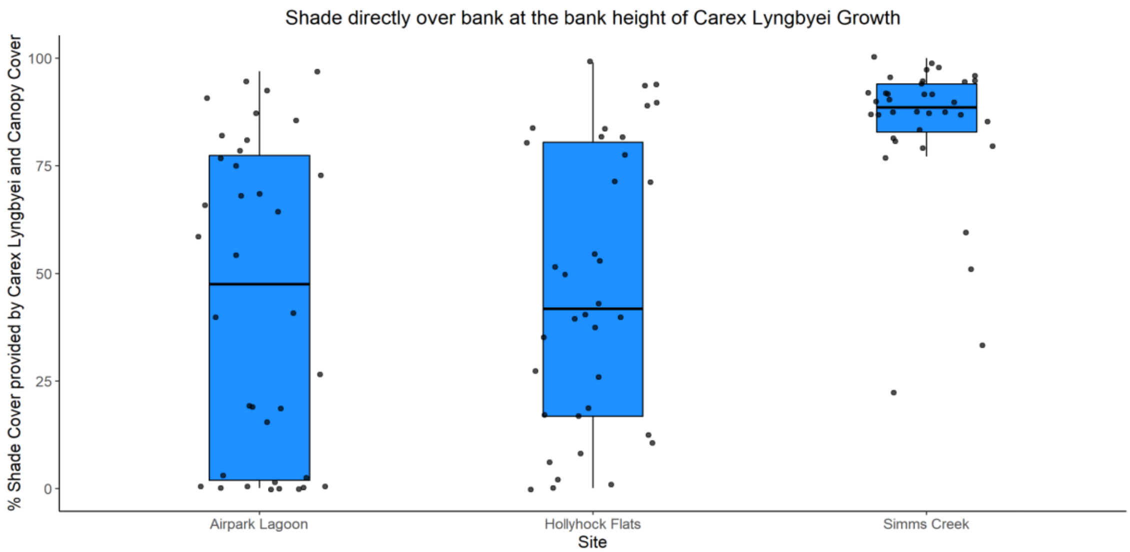


Figure 18: Boxplot displaying the differences in average percent shade cover directly over the bank at the water's edge at the edge of *Carex Lyngbyei* growth between Airpark Lagoon, Hollyhock Flats, and Simms Creek. Each data point represents the percent shade cover recorded by the forest densiometer at the closest point along the bank to the trap at the time of sampling.

Table 7: Max percent shade cover, minimum percent shade cover, and the average percent shade cover recorded at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April and July 2023.

Site	Max % Shade	Min % Shade	Average % Shade
Airpark Lagoon	96.88	0.16	43.93
Hollyhock Flats	98.96	0.16	46.82
Simms Creek	100.00	22.00	84.26

3.4.4. Salinity

The highest average salinity of water was at Airpark Lagoon, and the lowest average salinity of water was found at Simms Creek. (Fig. 19, Table 8). ANOVA testing was not conducted due to lack of normality and lack of homogeneity of variances.

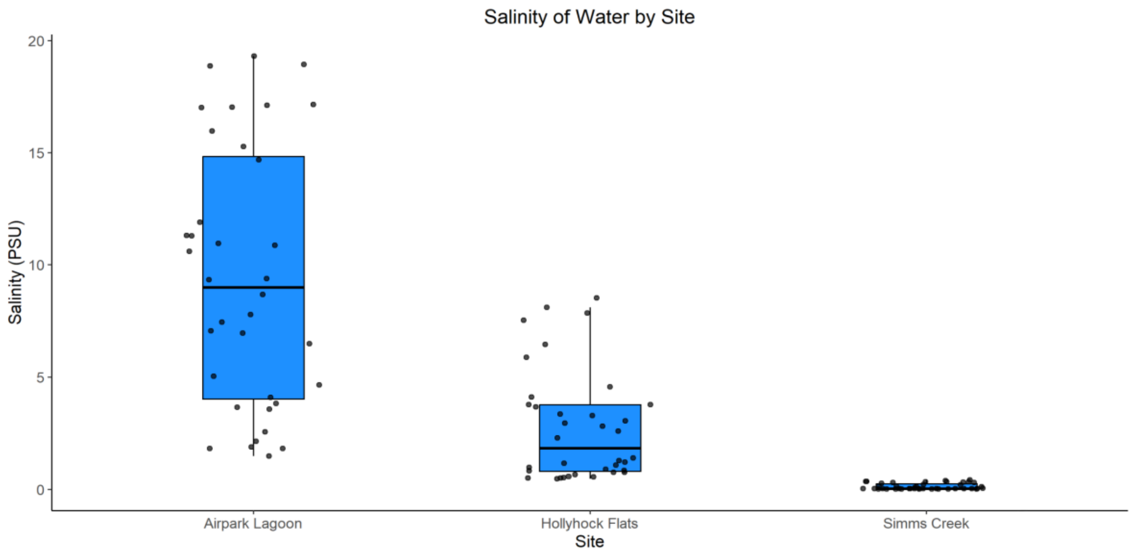


Figure 19: Boxplot displaying the differences in average salinity of the water in practical salinity units between Airpark Lagoon, Hollyhock Flats, and Simms Creek. Each data point represents the average salinity (PSU) of the water beside the trap at the time of sampling.

Table 8: Maximum salinity, minimum salinity, and the average salinity recorded at Airpark Lagoon, Hollyhock Flats, and Simms Creek between April and July 2023.

Site	Max Salinity (PSU)	Min Salinity (PSU)	Average Salinity (PSU)
Airpark Lagoon	19.31	1.48	9.39
Hollyhock Flats	8.53	0.47	2.76
Simms Creek	0.41	0.01	0.12

3.5. Analysis Summary

Analysis shows that coho were the most abundant juvenile salmon caught across all three sites (312, Fig.12; Table 1). Simms Creek had the highest juvenile salmon abundance (308, Table 1) Hollyhock Flats had the lowest number of juvenile salmon (14, Table 1) caught over the season. Airpark Lagoon had a similar juvenile salmon count (15, Table 1) to Hollyhock Flats. No juvenile salmon were found at any of the sites as of July 2023; however, juvenile salmon were present in June 2023 in Simms Creek but were not present in Airpark Lagoon or Hollyhock Flats after May 2023 (Fig. 12) .

Simms Creek had the lowest average water temperature (12.3 °C, Fig. 16, Table 3) of the three study sites as well as the highest average DO (7.9 PPM, Fig. 17, Table 5). Simms Creek had the highest average shade (84.24%, Fig. 18, Table 7) and the lowest average salinity (0.12PSU, Fig. 19, Table 8) across all three study sites. Hollyhock Flats had the lowest average DO reading (6.67 PPM, Fig. 17, Table 5) across all three sites. Airpark Lagoon had the highest average salinity (9.39 PSU, Fig. 19, Table 8), and the lowest average shade (43.93%, Fig. 18, Table 7) across all three sites.

These summary statistics are confirmed for water temperature and DO by the Welch's ANOVA tests with $p=0.015$ for the water temperature ANOVA (Table 4), and $p=0.00092$ for the DO ANOVA (Table 6). Post hoc testing with a Games Howell Test shows a significant temperature difference and a significant DO difference between Airpark Lagoon and Simms Creek, as well as between Hollyhock Flats and Simms Creek (Table 4, Table 6).

Chapter 4. Discussion

4.1. Salmonid Diversity and Abundance as Indications of Restoration Success

Simms Creek may have had the highest juvenile salmon count across the study season (308, Fig. 12, Table 1); however, only chinook and coho salmon were caught at Simms Creek. Meanwhile chum, chinook, and coho were caught at Airpark Lagoon, and Hollyhock Flats (Fig. 12, Table 1). Given coho were the most abundant species across all three sites (312, Fig. 12, Table 1) this may indicate that these sites are preferable habitat for coho over chinook and chum. It could also suggest that coho are the most abundant species in the estuary, or that the traps are biased to coho, failing to detect chinook and chum. Regardless, given the large difference in juvenile salmon caught at Simms Creek (308, Table 1), when compared to Airpark Lagoon (15, Table 1) and Hollyhock Flats (14, Table 1), Simms Creek appears to be the most suitable site for juvenile salmon among the three study sites based off numbers alone.

If only counting juvenile salmon abundance, it appears that Simms Creek is the preferred site for juvenile salmon; however, given the lack of chum detected at Simms Creek we can only conclude that Simms Creek appears to be the preferred site for juvenile chinook, and juvenile coho. This suggests that one of the environmental factors at Simms Creek is not preferable to chum. It is important to note that Simms Creek did not exist before 1998, it was constructed by the DFO for the purpose of increasing salmonid habitat and later modified for easier fish access (Jenkins et al., 2001; Sutherst, 2018). Therefore, the high salmon abundance at Simms Creek compared to Hollyhock Flats suggest it is a restoration success.

Airpark Lagoon does have comparable salmon abundance to Hollyhock Flats and both these sites have considerably lower juvenile salmon abundance than Simms Creek. Given Hollyhock Flats is the reference site, to have comparable juvenile salmon abundance might indicate that Airpark Lagoon is also a restoration success; however, the low abundance in comparison to Simms Creek along with historical data suggests otherwise. During the 2015 Guimond and Sutherst study, only four juvenile salmon in total were caught at Airpark Lagoon. Given the purpose of the dike breach mentioned in the introduction was to restore the habitat for juvenile salmon, an increase of eleven juvenile salmon eight years after the restoration efforts does not indicate restoration success. Guimond and Sutherst's study also indicated that no juvenile salmon were detected in Airpark Lagoon after April 2015. During this study, a single juvenile salmon was captured in Airpark Lagoon during May 2023 (Appendix D). Unfortunately, it was one of the two juvenile salmon that were found dead in the gee trap at the time of sampling. Therefore, this study had comparable results to the Guimond and Sutherst study as no live juvenile salmon were captured in Airpark Lagoon after April 25, 2023. When compared to the Guimond and Sutherst study, Airpark Lagoon does not appear to be a restoration success.

Juvenile salmon were detected in Hollyhock Flats up until May 10, 2023, in Airpark Lagoon till April 25, 2023, and in Simms Creek until June 19, 2023 (Appendix D). A two-week period of extended detection time between Airpark Lagoon and Hollyhock Flats does not indicate that one site is better than the other, which casts doubt on whether Hollyhock Flats is a good reference site, as it has similar fish abundance to Airpark Lagoon. However, this may be due to missing data as no data were collected at the second Hollyhock Flats study site before May 9th, 2024. This will be discussed further in the limitations section.

As stated above, Simms Creek appears to be a restoration success, specifically for coho, and to some degree for chinook. However, chum do not appear to be utilizing the site, possibly indicating that Simms Creek does not provide the required habitat for chum. Regarding juvenile salmon diversity, Airpark Lagoon and Hollyhock Flats appear to have higher juvenile salmon diversity. However, this does not imply that the restoration of Airpark Lagoon has been successful, as juvenile salmon abundance at the site is low.

4.1.1. Study Limitations

The main limitation to the success of this study was missing data due to the juvenile salmon bypassing the traps at the original Hollyhock Flats study site mentioned in section 2.4. The Project Watershed Sampling Team could visually see juvenile salmon schooling in the channels, yet they were not entering the gee traps at this location. The lack of this data creates a knowledge gap in this study as we are not able to account for what species of salmon were present or what their relative abundance was.

In addition, there is also missing data from April 11 – May 10, 2023, at the second Hollyhock Flats study site. There is a chance that juvenile salmon were present at the second Hollyhock Flats site between the April 11 – May 10; however, no sampling occurred at the second study site during this time. Given the juvenile salmon abundance at Airpark Lagoon and Hollyhock Flats only differed by one salmon (Table 1), this missing information is critical to understanding the difference between these sites. There is a chance that there was high juvenile salmon abundance in the pool feature during the April 11 – May 10 sampling period, but this data is unknown, and it could change the results of this study. As it stands Airpark Lagoon, and Hollyhock Flats appear comparable in terms of juvenile salmon abundance, which would bring into question whether Hollyhock Flats is a suitable reference site, or a site itself in need of restoration. Without these data, it is difficult to make definite conclusions about the suitability of Hollyhock Flats itself. But if Airpark Lagoon is not considered a restoration success due to the lack of juvenile salmon abundance, Hollyhock Flats having comparable numbers would suggest it too needs restoration work and may not be the most suitable reference site for Kus-kus-sum. Filling this knowledge gap is crucial for future studies.

In addition to salmon data, there is missing water temperature data from all three sites for the week of April 11, 2023, since the 11th/12th/13th of April 2023 were considered the trial run for data collection. At this time, the Project Watershed Sampling Team did not yet have access to the multiprobe. Given this was one of the only times juvenile salmon were sampled at Airpark Lagoon, it reduces the available data for how water temperature, DO, and salinity might affect juvenile salmon abundance in Airpark Lagoon. There is a chance that Airpark Lagoon had acceptable water temperature and DO for juvenile salmon use; however, the data to support these conclusions were not collected.

The final major limitation to this study relates to conducting the study on foot without the use of a boat due to volunteer liability. The trap locations in Airpark Lagoon and Hollyhock Flats were restricted to sites that were accessible by foot during high tide. This led to sampling of Airpark Lagoon only occurring on the western shore of the lagoon due to the danger of walking through muddy substrates. There is a chance that juvenile salmon may have been utilizing the eastern shore of Airpark Lagoon and were not detected during sampling because no traps were deployed on the eastern shore of the lagoon due to safety concerns. The same can be said about Hollyhock Flats as no sampling occurred on the western side of the site as it was inaccessible by foot during high tides.

All these limitations restricted data collection and have led to less analyses. The way to remedy this in future studies is discussed further in the management implications section.

4.2. Environmental Indicators and Relationship to Juvenile Salmon Abundance and Diversity

As previously mentioned, Simms Creek has the lowest average water temperature (12.3 °C, Table 3) and highest average DO (6.89 PPM, Table 5) both of which are essential for juvenile salmon survival. In addition to lower temperatures, Simms Creek had the highest average shade along the bankside (84.26%, Table 7). This is likely attributed to the overstory canopy at Simms Creek that is not present at the other two sites. As discussed in the previous section Simms Creek had the highest juvenile salmon abundance (312, Table 1), so a relationship can be drawn that the lower average water temperature, and the higher DO at Simms Creek are likely leading to Simms Creek having the highest juvenile salmon abundance among the three study sites. The higher percent shade most likely leads to lower temperature as shade can lower the maximum water temperature (Rutherford et al., 2004), and the lower temperatures are most likely leading to higher DO as DO and water have an inverse relationship (Harvey et al., 2011).

Another reason for higher juvenile salmon abundance at Simms Creek could be that Simms Creek is the site that is located the furthest upstream along the river and therefore is the furthest from the ocean at low tide. This is likely what results in the low average salinity concentration (0.12 PSU, Table 8) found in the pools at Simms Creek. The low salinity in these pools could also be due to the fact the pools are only connected to the marine environment during high tide, therefore getting an input of fresh water from the river every time the tide rises. The low salinity, could also explain why chum were not present at Simms Creek, as they are known to go to more saline environments sooner than chinook and coho (Brett, 1952). The chum may be bypassing Simms Creek and moving through Airpark Lagoon and Hollyhock Flats, because they have higher average salinity concentrations. Without a statistical analysis, these relationships can only be inferred and correlation can not be made. But lower temperatures and higher DO both align with the cited literature on what juvenile salmon require to survive (Brett,1952; Fellman et al., 2018; Geist et al., 2006; McMahon, 1983; Whitmore et al., 1960).

In contrast to Simms Creek, the lowest juvenile salmon abundance was recorded at Hollyhock Flats (14, Table 1), with Airpark Lagoon (15, Table 1) being comparably low. Factors detrimental to juvenile salmon survival like higher average water temperatures and lower average DO were present at Hollyhock Flats (14.9 °C, Table 3; 6.67 PPM, Table 5) and Airpark Lagoon (15.3°C, Table 3; 6.89 PPM, Table 5). During the 2015 study by Guimond and Sutherst, it was noted that the temperatures at Airpark Lagoon had already reached 19 °C by May 2015, which may have been the reason so few juvenile salmon had been caught during the 2015 study. It is important to note that during this study, the temperatures at Airpark Lagoon had only reached 16 °C by the end of May 2023 (Appendix D). This is above the desired range of 12 °C to 14 °C (Brett, 1952). Furthermore, during this study, the water temperature in Airpark Lagoon reached 20 °C by early June whereas it only reached 15 °C in Simms Creek (Appendix D). This suggests that Airpark Lagoon is no longer an ideal site for juvenile salmon by June. Water temperatures in Hollyhock Flats were reaching 18 °C by June (Appendix D), suggesting Hollyhock Flats is also not an ideal site for juvenile salmon as of June. In addition to high water temperatures, DO as low as 3.7 PPM were detected in Airpark Lagoon by June (Appendix D), which is detrimental to juvenile salmon survival. DO never dropped below 5.5 PPM at Simms Creek, and never below 4.56 PPM at Hollyhock Flats (Appendix D). Both readings are lower than the recommended 8 PPM, but they are both still higher than the 4.5 PPM juvenile salmon tend to avoid as suggested by the literature. (McMahon, 1983; Whitmore et al., 1960)

Higher temperatures in Airpark Lagoon and Hollyhock Flats are most likely due to the lack of overstory canopy at either site. Despite all three sites having *C. lyngbyei* cover along the bank of the study site, the streamside shade provided by *C. lyngbyei* does not contribute shade cover comparative to the overstory canopy present at Simms Creek. This is a potential cause of the temperature differences between the sites, which in turn could be the cause of the DO differences between the sites, given that oxygen is more soluble in cooler water (Harvey et al., 2011). In addition, this temperature difference is most likely the cause of high abundance of sticklebacks in Airpark Lagoon (Fig. 14), given their temperature thresholds are higher than juvenile salmon. Studies show that sticklebacks prefer temperatures around 18 °C, with lethal temperatures being around 28 °C (Jordan & Garside, 1972). The stickleback's ability to survive in higher temperatures may be why we saw such high numbers of sticklebacks in Airpark Lagoon during June 2023 (Fig. 15).

Other factors leading to low salmon abundance at Airpark Lagoon and Hollyhock Flats, could be the salinity of the sites. Given both sites are downstream of Simms Creek, they are closer to the marine interface, and thus have higher salinities. This may be tolerable to the chum who migrate rapidly to the marine environment, but it is likely less tolerable to the juvenile coho and some chinook as they prefer to stay in fresh water longer (Brett, 1952; Godwin & Krkosek, 2022).

In short, we expected to find the highest juvenile salmon abundance where the water temperatures were lower, and the DO were higher. This aligns with our findings that the highest abundance of juvenile salmon was found in Simms Creek. This abundance could also be due to lower salinity at Simms Creek being preferable for chinook and coho. However, greater salmon diversity at Airpark Lagoon and Hollyhock Flats is likely due to the higher salinity as it would make the sites more appealing to chum. If lower water temperatures and higher DO are the cause of greater juvenile salmon abundance at Simms Creek, it may be due to the overstory canopy and low salinity pools. Implementing these at Airpark Lagoon, could lead to greater abundance at Airpark Lagoon, and in turn restoration success.

4.2.1. Implications to Future Restoration

To complete restoration work at Airpark Lagoon, we would need to reduce water temperatures, increase DO, and potentially reduce the salinity of the water at the site. Given Airpark Lagoon is essentially one large shallow pool, this in an unlikely possibility, especially since one of the purposes of breaching the dike and increasing waterflow through the site was to reduce the water temperatures (Guimond & Sutherst, 2016). If further restoration was to be conducted at the site, it may prove feasible to create pools with overstory canopy adjacent to the Airpark Lagoon. This may be an effective way to create more rearing habitat along the K'ómoks Estuary.

If juvenile coho and chinook are not rearing in Airpark Lagoon itself, creating off-channel habitat adjacent to the lagoon and the river may prove worthwhile. In addition to landscape manipulation to create pool features, this would involve a robust planting regime to ensure that the pool is shaded, potentially keeping the water temperatures cooler. However, this would require further research into the relationships between the factors that lead to Simms Creek being a site with high juvenile salmon abundance. If Simms Creek is valued by juvenile salmon for its low salinity due to being further upstream in the river, then it may not prove useful to create more pool features at Airpark Lagoon if the salinity cannot be manipulated. However, if higher juvenile salmon abundance is related to the presence of pools and canopy, implementing a similar structure to the environment could be implemented at Airpark Lagoon.

In addition, if future studies reveal that Hollyhock Flats is not the ideal site for rearing juvenile salmon, Hollyhock Flats may be a potential future restoration project as well. In the meantime, it may be useful to consider using Simms Creek as a supplementary reference site, as it appears to be effectively utilized by juvenile salmon.

4.3. Sampling Protocols and Recommendations

This study is effectively a pilot study for future environmental monitoring by Project Watershed due to the single season nature of this study along with the lack of standardized baseline data. Despite not getting an effective statistical analysis of the juvenile salmon count and correlating factors, valuable information for how to conduct a future study has been gathered, and this project functions as a robust pilot study for future monitoring of project sites along the Courtenay River, standardizing data collected across all three study sites.

Moving into future monitoring projects I suggest continuing to use gee traps, as they appear to successfully capture juvenile coho and chinook. However, I would suggest supplementing gee traps with a beach seine conducted at the mouth of tidal channel outlets as the tides recedes, as has been done in previous studies like Tryon (2011). This would allow for sampling of juvenile salmon that move quickly through the estuary but are not staying in the estuary to rear. Using this along with gee traps would increase the person hours required of the Project Watershed Sampling Team, but it would also increase the available data on juvenile salmon abundance in the K'ómoks Estuary.

In addition, I suggest attempting to float the gee traps. During the trial run, the Project Watershed Sampling Team placed two gee traps side by side, one trap with a pool noodle for buoyancy, and one trap fully submerged. It was anecdotally noted that there were more juvenile salmon in the floating traps. However, there was a risk of the floating traps getting beached during receding tides, exposing juvenile salmon to suffocation through dewatering of the traps. Beaching did occur once during the trial study period, and there was a single juvenile salmon mortality within the beached trap. It is not known if the juvenile salmon was deceased before the beaching of the trap or due to the beaching trap. To prevent any issues related to beaching traps, this method was not utilized during this study. However, if a permanent structure that allowed the traps to move vertically with the tides but not laterally with the waterflow was installed, sampling with a floating trap could occur safely. Potential floating trap designs could include anchoring a PVC pipe into the substrate and attaching a ring to the trap that can slide freely up and down the pipe on the rising and receding tides. Theoretically this would allow for buoyant gee traps without the risk of them getting beached.

Finally, I suggest extending the study period, and the study area for each site. Given the seasonal nature of this study, and the Project Watershed Sampling Team availability, the study did not begin until April 2023. However, as suggested by Hamilton some juvenile salmon may be in the river as early as January (Hamilton et al., 2008). I suggest the Project Watershed Sampling Team sample all three sites at least once a month between January and July each year to develop a complete picture of the juvenile salmon use of these sites. As well, implementing broader trap deployment in Airpark Lagoon, and Hollyhock Flats could help to fill knowledge gaps. Training the Project Watershed Sampling Team on deploying traps by boat could be an effective way to access hard to reach areas. Expanding both the study area and the study period will lead to a more robust data set, and hopefully more robust data analyses.

Chapter 5. Conclusion

This study suggests that Simms Creek appears to be the preferred location for juvenile salmon among the three study sites due to high juvenile salmon abundance when compared to Airpark Lagoon and Hollyhock Flats. Given that Simms Creek was a site that was created specifically for juvenile salmon rearing habitat and was later augmented to provide better fish access to the site, we can suggest that this site was a restoration success. However, there is missing data that needs to be collected to fill the knowledge gaps regarding these sites. This means continued study, and more robust sampling at these sites is critical to assess restoration success among these sites, and future restoration projects in the K'ómoks Estuary.

To gain better understanding of the juvenile salmon use of these sites, I recommended extending the juvenile salmon study, by beginning in January, and conducting monthly monitoring until July to ensure a comprehensive look at how juvenile salmon are using these sites during this period. In addition, it is important to standardize the study methods in coming years, and to consider using floating traps in a manner that is safe for juvenile salmon as they may be more likely to enter traps at the surface. More testing of the efficacy of floating traps verses sunken traps may be needed before making this decision. In addition, utilizing boats for trap deployment may also allow for a larger study area and help fill any knowledge gaps due to access restrictions.

In terms of restoration success, we can see that Airpark Lagoon has not yet been fully restored. Juvenile salmon are not utilizing it in great number, and the temperature readings in Airpark Lagoon are not within the desired range for juvenile salmon, suggesting further restoration efforts are needed. Potential restoration actions include creating small streamside pools and a robust riparian vegetation planting effort to provide overstory canopy shade alongside Airpark Lagoon.

For the upcoming Kus-kus-sum restoration project, utilizing Simms Creek as a supplemental structure reference may be prudent as the juvenile salmon seem to be at Simms Creek in greater numbers than in Hollyhock Flats. This suggests that features at Simms Creek such as overstory canopy, and cool water pools, along with low salinity may be features that are attracting juvenile salmon to use the site. Therefore, it may be beneficial to include similar features in the Kus-kus-sum restoration plan. However, more data collection is needed before ruling out Hollyhock Flats as an acceptable early season site for juvenile salmon. Using both sites as reference sites may lead to a more robust restoration at Kus-kus-sum.

Finally, there are still many knowledge gaps to fill, and I think this should be the goal for the Project Watershed Sampling Team during future studies. An expanded study area along with a standardized sampling method will lead to a robust set of baseline data that can be used as comparison data for upcoming restoration projects. Further research is needed to fully understand juvenile salmon use throughout the K'ómoks Estuary, and to understand whether the restoration efforts of Project Watershed are having a significant impact on juvenile salmon rearing in the K'ómoks Estuary. Further study and restoration actions are required to achieve this goal. Pacific salmon are an important part of the Pacific Northwest ecosystem both economically and culturally. Continued research to understand how to restore habitat that leads to resilient salmon populations will be essential restoration work for years to come.

References

B.C Ministry of Environment, Lands and Parks, Fish Inventory Unit. (1997). Fish Collection Methods and Standards. Resource Inventory Committee. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/fishml04.pdf Last Accessed: Apr. 2, 2024.

Beamish, R. J., Pearsall, I. A., & Healey, M. C. (2003). A History of the Research on the Early Marine Life of Pacific Salmon Off Canada's Pacific Coast. *North Pacific Anadromous Fish Commission, Bulletin Number 3, 1-40*. https://www.npafc.org/bulletin/ Last Accessed: Apr. 2, 2024.

Birtwell, I.K., M.E. Wright, & P. Edgell. (2014). Aquatic habitat in the Somass River estuary: a selective review and implications to Chinook salmon. *Canadian Department of Fisheries and Oceans. Pacific Region; Alberni Valley Enhancement Association*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/352934.pdf Last Accessed: Apr. 2, 2024.

Bisson, P. A., Dunham, J. B., & Reeves, G. H. (2009). Freshwater Ecosystems and Resilience of Pacific Salmon: Habitat Management Based on Natural Variability. *Ecology and Society*, *14*(1). https://www.jstor.org/stable/26268060 Last Accessed: Apr. 2, 2024.

Bjornn, T. C., & Reiser, D. W. (1991). Habitat Requirements of Salmonids in Streams. In *Influence of Forest and Rangeland Management of Salmonid Fishes and Their Habitats*. *American Fisheries Society Special Publication, 19, 83 – 138.* https://www.for.gov.bc.ca/hfd/library/ffip/Bjornn_TC1991.pdf Last Accessed: Apr. 2, 2024.

Brett, J. R. (1952). Temperature Tolerance in Young Pacific Salmon, Genus Oncorhynchus. *Journal of the Fisheries Research Board of Canada*, *9*(6), 265–323. https://doi.org/10.1139/f52-016 Last Accessed: Apr. 2, 2024.

Carter, J. A., McMichael, G. A., Welch, I. D., Harnish, R. A., & Bellgraph, B. J. (2009). Seasonal Juvenile Salmonid Presence and Migratory Behavior in the Lower Columbia River. *U.S Department of Energy.* https://doi.org/10.2172/953370 Last Accessed: Apr. 2, 2024.

Comox Valley Project Watershed Society. (Jan 27, 2020). Kus-kus-sum. https://projectwatershed.ca/2020/01/27/kus-kus-sum/ Last Accessed: Apr. 2, 2024.

Comox Valley Project Watershed Society. (Feb 01, 2023). History of the Kus-kus-sum site. https://projectwatershed.ca/2023/02/01/kus-kus-sum-site-history/ Last Accessed: Apr. 2, 2024.

Criddle, K., & Shimizu, I. (2014). Economic importance of wild salmon. In *Salmon: Biology, Ecological Impacts, and Economic Importance. Nova Science Publishers, Inc, 269-306.* https://www.researchgate.net/publication/261175674_Economic_importance_of_wild_salmon Last Accessed: Apr. 2, 2024.

Csoboth, L. A., & Garvey, J. E. (2008). Lateral Exchange of Larval Fish between a Restored Backwater and a Large River in the East-Central USA. *Transactions of the American Fisheries Society*, *137*(1), 33–44. https://doi.org/10.1577/T06-188.1 Last Accessed: Apr. 2, 2024.

Fellman, J. B., Hood, E., Nagorski, S., Hudson, J., & Pyare, S. (2018). Interactive physical and biotic factors control dissolved oxygen in salmon spawning streams in coastal Alaska. *Aquatic Sciences*, *81*(1), 2. https://doi.org/10.1007/s00027-018-0597-9 Last Accessed: Apr. 2, 2024.

Finn, R. J. R., Chalifour, L., Gergel, S. E., Hinch, S. G., Scott, D. C., & Martin, T. G. (2021). Quantifying lost and inaccessible habitat for Pacific salmon in Canada's Lower Fraser River. *Ecosphere*, *12*(7), e03646. https://doi.org/10.1002/ecs2.3646 Last Accessed: Apr. 2, 2024.

Geist, D. R., Abernethy, C. S., Hand, K. D., Cullinan, V. I., Chandler, J. A., & Groves, P. A. (2006). Survival, Development, and Growth of Fall Chinook Salmon Embryos, Alevins, and Fry Exposed to Variable Thermal and Dissolved Oxygen Regimes. *Transactions of the American Fisheries Society*, *135*(6), 1462–1477. https://doi.org/10.1577/T05-294.1 Last Accessed: Apr. 2, 2024.

Godwin, S., & Krkosek, M. (2022). *Pacific Salmon Field Guide*. Lone Pine Publishing.

Grant, S. C. H., MacDonald, B. L., & Winston, M. L. (2019). State of Canadian Pacific salmon: Responses to changing climate and habitats. *Canadian Technical Report of Fisheries and Aquatic Sciences, 3332.* https://salmonwatersheds.ca/document_library_files/lib_467.pdf Last Accessed: Apr. 2, 2024.

Gresh, T., Lichatowich, J., & Schoonmaker, P. (2000). An Estimation of Historic and Current Levels of Salmon Production in the Northeast Pacific Ecosystem: Evidence of a Nutrient Deficit in the Freshwater Systems of the Pacific Northwest. *Fisheries*, *25*(1), 15–21. https://doi.org/10.1577/1548-8446(2000)025<0015:AEOHAC>2.0.CO;2 Last Accessed: Apr. 2, 2024.

Guimond, E., & Sutherst, J. (2016). Courtenay Airpark Lagoon Dike Breach—Phase 3. Comox Valley Project Watershed Society. https://a100.gov.bc.ca/pub/acat/documents/r50809/16.PUN.05_Comox_Lagoon_1471466627006_1454913494.pdf Last Accessed: Apr. 2, 2024.

Hamilton, S. L., Bravender, B. A., Beggs, C., & Munro, B. (2008). Distribution and Abundance of Juvenile Salmonids and Other Fish Species in the Courtenay River Estuary and Baynes Sound, 2001. *Canadian Technical Report of Fisheries and Aquatic Sciences, 2806*. https://publications.gc.ca/site/eng/365142/publication.html Last Accessed: Apr. 2, 2024.

Harvey, R., Lye, L., Khan, A., & Paterson, R. (2011). The Influence of Air Temperature on Water Temperature and the Concentration of Dissolved Oxygen in Newfoundland Rivers. *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques*, *36*(2), 171–192. https://doi.org/10.4296/cwrj3602849 Last Accessed: Apr. 2, 2024.

Heim, C. (2021). Planting Prescription for the Restoration of Kus-kus-sum, Comox Valley, 2021. Carolla Environmental Consulting. Comox Valley Project Watershed Society.

Henning, J. A., Gresswell, R. E., & Fleming, I. A. (2006). Juvenile Salmonid Use of Freshwater Emergent Wetlands in the Floodplain and Its Implications for Conservation Management. *North American Journal of Fisheries Management*, *26*(2), 367–376. https://doi.org/10.1577/M05-057.1 Last Accessed: Apr. 2, 2024.

Jenkins, J. A., Bravender, B. A., Beggs, C., Munro, B., & Miller, D. (2006). The Distribution and Abundance of Juvenile Salmonids and Other Species in the Courtenay River Estuary and Baynes Sound, 2000. *Canadian Technical Report of Fisheries and Aquatic Sciences, 2659*. https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2659-eng.pdf Last Accessed: Apr. 2, 2024.

Jenkins, J. A., Bravender, B. A., Beggs, C., Munro, B., & Miller, D. (2001). Results of Beach, Purse, and Pole Seine Surveys at the Courtenay River Estuary and Baynes Sound, Courtenay, B.C., 2000. *Fisheries and Aquatic Sciences, 1077*. https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2659-eng.pdf Last Accessed: Apr. 2, 2024.

Jordan, C. M., & Garside, E. T. (1972). Upper lethal temperatures of threespine stickleback, *Gasterosteus aculeatus* (L.), in relation to thermal and osmotic acclimation, ambient salinity, and size. *Canadian Journal of Zoology*, *50*(11), 1405–1411. https://doi.org/10.1139/z72-189 Last Accessed: Apr. 2, 2024.

MacDougall, L. A., Bravender, B. A., & Russell, L. R. (1999). Results of beach, mini purse, gee trap, and pole seine surveys at the Courtenay River estuary and Baynes Sound, Courtenay, BC. Canadian Technical Report of Fisheries and Aquatic Sciences. *Canadian Data Report of Fisheries and Aquatic Sciences*, *1054*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/239906.pdf Last Accessed: Apr. 2, 2024.

McAuley, L. (2014). Airpark Lagoon Breach Project: Phase 2. Lake Trail Environmental Consulting.https://a100.gov.bc.ca/pub/acat/documents/r43205/13_PUN02_Airpark_1406732065190_6731713402.pdf Last Accessed: Apr. 2, 2024.

McMahon, T. E. (1983). Habitat suitability index models : coho salmon / by Thomas E. McMahon. Western Energy and Land Use Team, Division of Biological Services, Research and Development, Fish and Wildlife Service, U.S. Dept. of the Interior. https://apps.dtic.mil/sti/tr/pdf/ADA323350.pdf Last Accessed: Apr. 2, 2024.

Northwest Hydraulic Consultants Ltd. (2020). Kus-kus-sum Restoration Draft Conceptual Design Brief (NCH Ref. No. 3002633). Comox Valley Project Watershed Society.

Odum, W. E. (1988). Comparative Ecology of Tidal Freshwater and Salt Marshes. *Annual Review of Ecology and Systematics*, *19*(1), 147–176. https://doi.org/10.1146/annurev.es.19.110188.001051 Last Accessed: Apr. 2, 2024.

Otto, R. G. (1971). Effects of Salinity on the Survival and Growth of Pre-Smolt Coho Salmon (*Oncorhynchus kisutch*). *Journal of the Fisheries Research Board of Canada*, *28*(3), 343–349. https://doi.org/10.1139/f71-046 Last Accessed: Apr. 2, 2024.

Palmer, M. a., Bernhardt, E. s., Allan, J. D., Lake, P. s., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C. N., Follstad Shah, J., Galat, D. L., Loss, S. G., Goodwin, P., Hart, D. d., Hassett, B., Jenkinson, R., Kondolf, G. m., Lave, R., Meyer, J. l., … Sudduth, E. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology*, *42*(2), 208–217. https://doi.org/10.1111/j.1365-2664.2005.01004.x Last Accessed: Apr. 2, 2024.

Quinn, T.P. (2018). *The Behavior and Ecology of Pacific Salmon and Trout*. (second edition ed.). Seattle: University of Washington Press. https://muse-jhu-edu.proxy.lib.sfu.ca/book/63776/ Last Accessed: Apr. 2, 2024.

Roni, P., Beechie, T. J., Bilby, R. E., Leonetti, F. E., Pollock, M. M., & Pess, G. R. (2002). A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. *North American Journal of Fisheries Management*, *22*(1), 1–20. https://doi.org/10.1577/1548-8675(2002)022<0001:AROSRT>2.0.CO;2 Last Accessed: Apr. 2, 2024.

Ruggerone, G. T. (1992). Threespine stickleback aggregations create a potential predation refuge for sockeye salmon fry. *Canadian Journal of Zoology*, *70*(5), 1052–1056. https://doi.org/10.1139/z92-147 Last Accessed: Apr. 2, 2024.

Rutherford, J. C., Marsh, N. A., Davies, P. M., & Bunn, S. E. (2004). Effects of patchy shade on stream water temperature: How quickly do small streams heat and cool? *Marine and Freshwater Research*, *55*(8), 737–748. https://doi.org/10.1071/MF04120 Last Accessed: Apr. 2, 2024.

Sutherst, J., & Heim, C. (2017). Simms Park Refocus to Improve Side Channel Connectivity. COA-F17-F-1382. Comox Valley Project Watershed Society; Carolla Environmental Consulting. https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=52612 Last Accessed: Apr. 2, 2024.

Sutherst, J. (2018). Simms Park Side Channel Habitat Enhancement for Fish. COA-F18-F-2398. Comox Valley Watershed Society. https://a100.gov.bc.ca/pub/acat/documents/r54488/COA_F18_F_2398_1533841035686_3838848182.pdf Last Accessed: Apr. 2, 2024.

Swain, N. R., Hocking, M. D., Harding, J. N., & Reynolds, J. D. (2014). Effects of salmon on the diet and condition of stream-resident sculpins. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(4), 521–532. https://doi.org/10.1139/cjfas-2013-0159 Last Accessed: Apr. 2, 2024.

Taccogna, G. S., & Hillaby, J. (2011). Investigation of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) use of Off-channel and Mainstem Habitats in Two Upper Fraser River watersheds. *Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2848*. https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-4-2848-eng.pdf Last Accessed: Apr. 2, 2024.

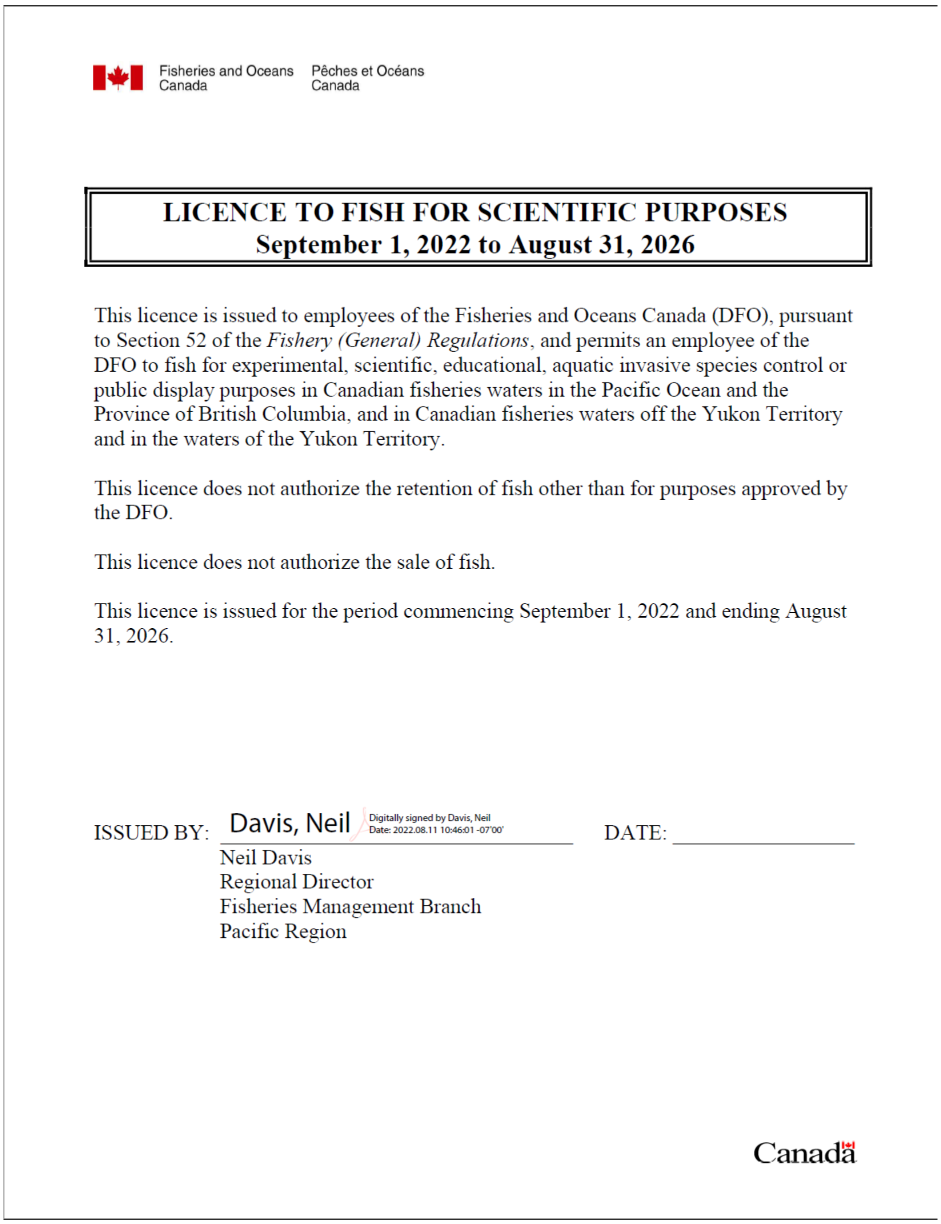
Tryon, L. (2011). Investigation of Restoration and Protection Options for Juvenile Salmonids in the Courtenay Estuary. Lake Trail Environmental Consulting. https://projectwatershed.ca/wp-content/uploads/2016/11/Juvenile_Salmonids_Courtenay_Estuary_2011.pdf Last Accessed: Apr. 2, 2024.

Whitmore, C. M., Warren, C. E., & Doudoroff, P. (1960). Avoidance Reactions of Salmonid and Centrarchid Fishes to Low Oxygen Concentrations. *Transactions of the American Fisheries Society*, *89*(1), 17–26. https://doi.org/10.1577/1548-8659(1960)89[17:AROSAC]2.0.CO;2 Last Accessed: Apr. 2, 2024.

Willson, M. F., & Halupka, K. C. (1995). Anadromous Fish as Keystone Species in Vertebrate Communities. *Conservation Biology*, *9*(3), 489–497. https://www.jstor.org/stable/2386604 Last Accessed: Apr. 2, 2024.

Appendix A.

Scientific Permit



Fisheries and Oceans Canada | Pêches et Océans Canada

LICENCE TO FISH FOR SCIENTIFIC PURPOSES
September 1, 2022 to August 31, 2026

This licence is issued to employees of the Fisheries and Oceans Canada (DFO), pursuant to Section 52 of the *Fishery (General) Regulations*, and permits an employee of the DFO to fish for experimental, scientific, educational, aquatic invasive species control or public display purposes in Canadian fisheries waters in the Pacific Ocean and the Province of British Columbia, and in Canadian fisheries waters off the Yukon Territory and in the waters of the Yukon Territory.

This licence does not authorize the retention of fish other than for purposes approved by the DFO.

This licence does not authorize the sale of fish.

This licence is issued for the period commencing September 1, 2022 and ending August 31, 2026.

ISSUED BY: Davis, Neil Digitally signed by Davis, Neil Date: 2022.08.11 10:46:01 -07'00' DATE: ____________

Neil Davis
Regional Director
Fisheries Management Branch
Pacific Region

Canadä

Figure A.1: Copy of DFO Community Advisor Jacob Melville's scientific permit utilized by The Project Watershed Sampling Team during this project for sampling fish.

Appendix B.

Indicative photos of Juvenile Salmon

Figure B.1: Indicative Photos of chinook circled in red. All juvenile salmon matching identification descriptions and looking like the fish pictured above were identified as chinook. Descriptions: *Parr marks regular in height, straddle lateral line, and longer than vertical diameter of the fry's eye. Colorless anal fin. Adipose fin has clear center.* (Godwin & Krkosek, 2022)

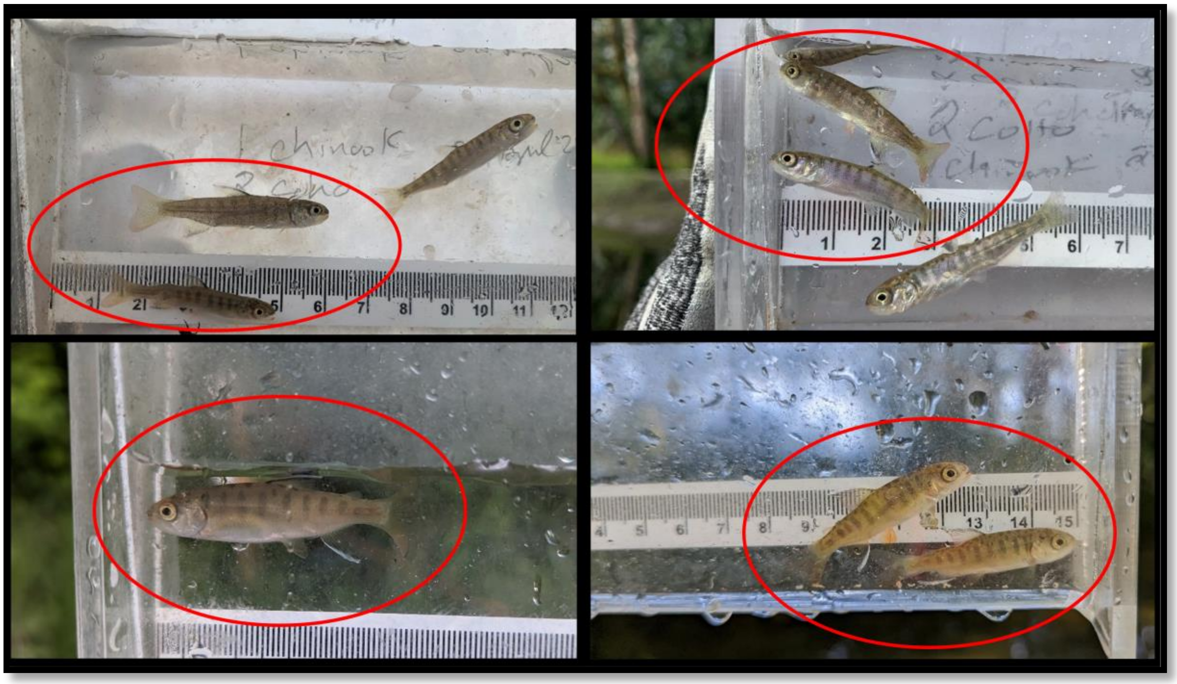


Figure B.2: Indicative Photos of coho circled in red. All juvenile salmon matching identification descriptions and looking like the fish pictured above were identified as coho. Descriptions: *Parr marks regular in height and straddling lateral line. Most parr marks are longer than vertical diameter of fry's eye. Dorsal fin and anal fin both have white leading edge. The anal fin is sickle shaped.* (Godwin & Krkosek, 2022)

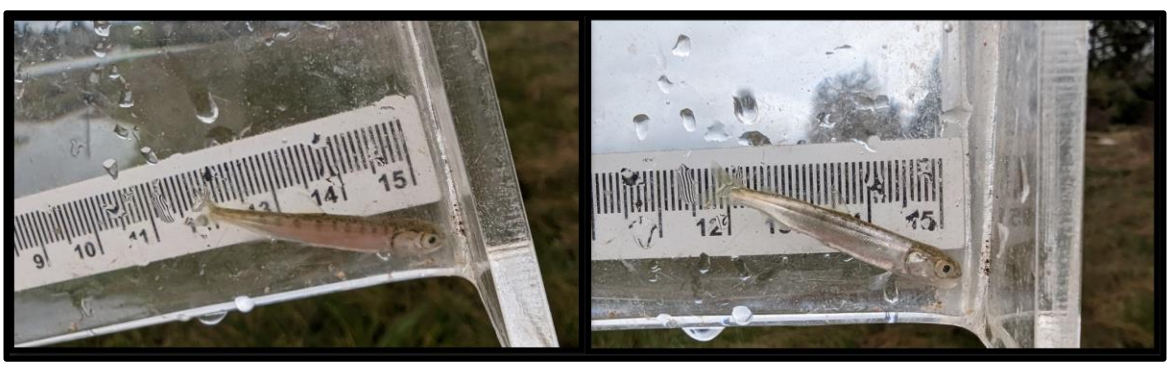


Figure B.3: Indicative Photos of chum. All juvenile salmon matching identification descriptions and looking like the fish pictured above were identified as chum. Descriptions: *Parr marks are shorter than the vertical diameter of the eye and are mostly above the lateral line. Colorless anal and adipose fin.* (Godwin & Krkosek, 2022)

Appendix C. QQ Plots for Testing ANOVA Assumptions

Salmon

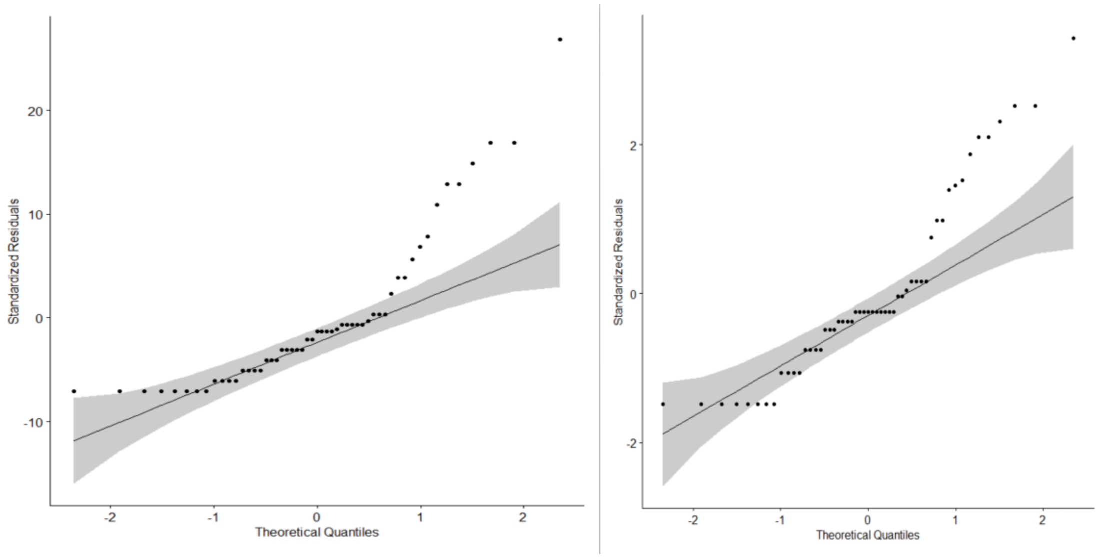


Figure C.1: QQ plots showing the lack of homogeneity of variances for the juvenile salmon count data. Original data (left) compared to square root transformed data (right) reveals that using a square root transformation did not create homogenous variances.

Non-Salmon Species

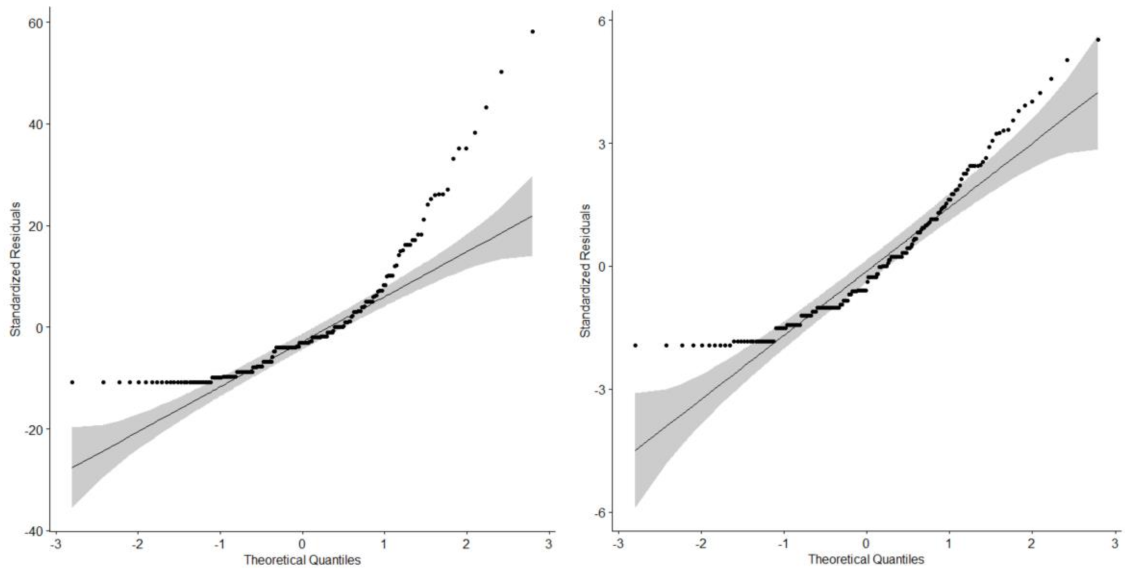


Figure C.2: QQ plots showing the lack of homogeneity of variances for the non-salmon fish count data. Original data (left) compared to square root transformed data (right) reveals that using a square root transformation did not create homogenous variances.

Salinity Data

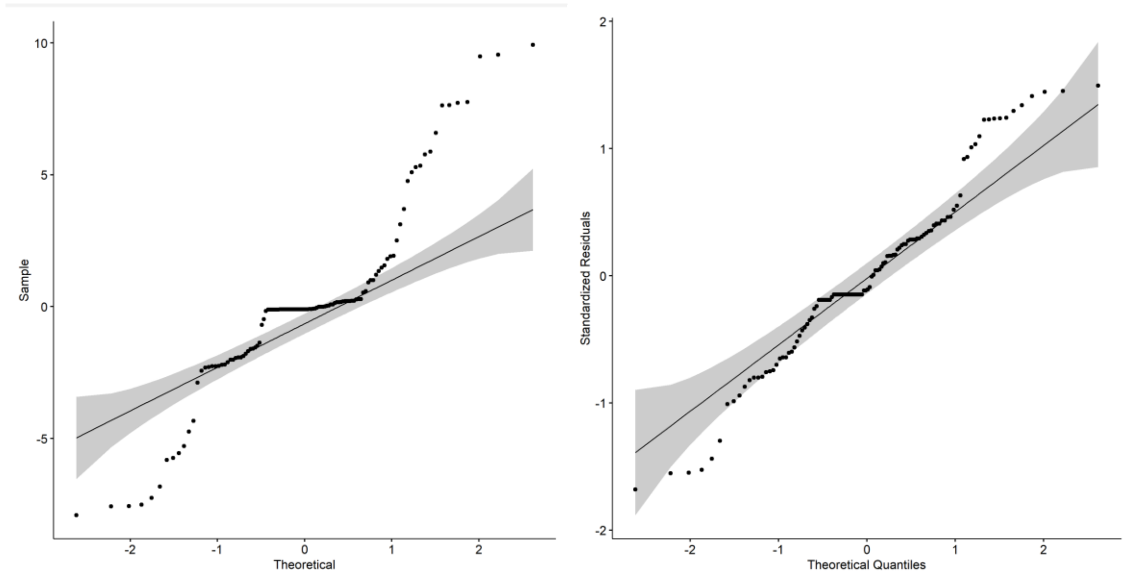


Figure C.3: QQ plots showing the lack of homogeneity of variances for the salinity data. Original data (left) compared to square root transformed data (right) reveals that using a square root transformation did not create homogenous variances.

Shade Data

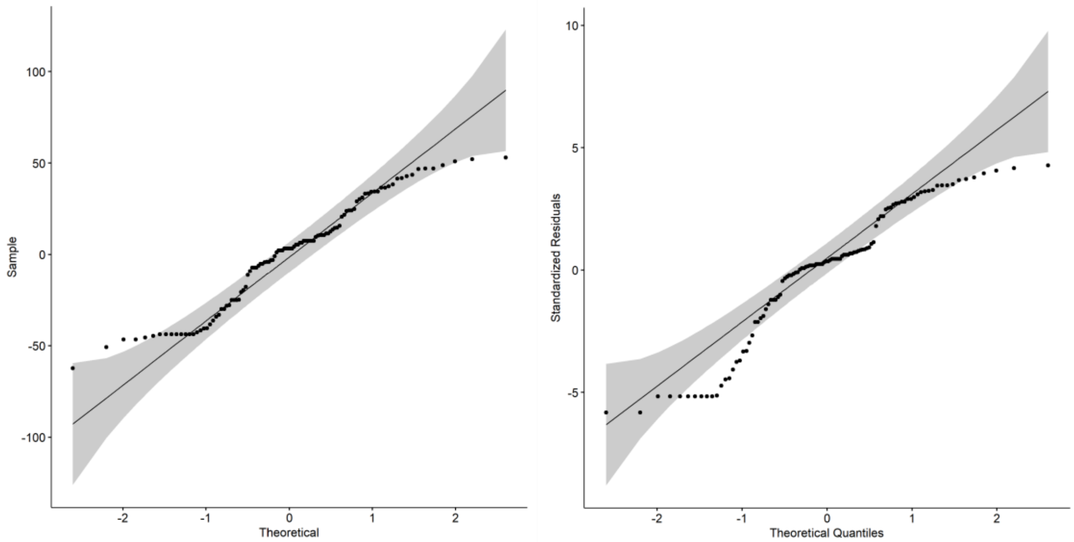


Figure C.4: QQ plots showing the lack of homogeneity of variances for the shade data. Original data (left) was close to homogeneity with a few outliers when compared to square root transformed data (right) reveals that using a square root transformation did not create homogenous variances.

Appendix D.

Extra Data Tables

Table D.1: Total salmon count by date and site.

Date	Location	Total Salmon Count
11-Apr-23	Hollyhock Flats	1
12-Apr-23	Airpark Lagoon	12
13-Apr-23	Simms Creek	19
24-Apr-23	Simms Creek	121
25-Apr-23	Airpark Lagoon	2
26-Apr-23	Hollyhock Flats	2
08-May-23	Simms Creek	45
09-May-23	Airpark Lagoon	1
10-May-23	Hollyhock Flats	11
23-May-23	Simms Creek	86
24-May-23	Airpark Lagoon	0
25-May-23	Hollyhock Flats	0
06-Jun-23	Simms Creek	27
07-Jun-23	Airpark Lagoon	0
08-Jun-23	Hollyhock Flats	0
19-Jun-23	Simms Creek	10
20-Jun-23	Airpark Lagoon	0
21-Jun-23	Hollyhock Flats	0
05-Jul-23	Hollyhock Flats	0
06-Jul-23	Simms Creek	0
07-Jul-23	Airpark Lagoon	0

Table D.2: Average water temperature and maximum water temperature in degrees Celsius by site and date.

Date	Site	Average Water Temperature (°C)	Maximum Water Temperature (°C)
24-Apr-23	Simms Creek	5.98	6.29
25-Apr-23	Airpark Lagoon	9.21	10.15
26-Apr-23	Hollyhock Flats	8.09	8.60
08-May-23	Simms Creek	8.56	8.65
09-May-23	Airpark Lagoon	10.19	10.80
10-May-23	Hollyhock Flats	11.37	11.68
23-May-23	Simms Creek	11.37	11.43
24-May-23	Airpark Lagoon	15.49	16.33
25-May-23	Hollyhock Flats	13.90	14.48
06-Jun-23	Simms Creek	15.76	15.89
07-Jun-23	Airpark Lagoon	19.43	20.26
08-Jun-23	Hollyhock Flats	17.80	18.50
19-Jun-23	Simms Creek	15.77	15.96
20-Jun-23	Airpark Lagoon	16.27	17.38
21-Jun-23	Hollyhock Flats	17.70	17.96
05-Jul-23	Hollyhock Flats	20.71	20.93
06-Jul-23	Simms Creek	21.13	21.50
07-Jul-23	Airpark Lagoon	21.43	22.23

Table D.3: Average DO concentration and Maximum DO concentration by site and date.

Date	Site	Average DO (PPM)	Maximum DO (PPM)
24-Apr-23	Simms Creek	10.53	10.15
25-Apr-23	Airpark Lagoon	9.22	8.74
26-Apr-23	Hollyhock Flats	9.35	7.68
08-May-23	Simms Creek	9.48	8.56
09-May-23	Airpark Lagoon	8.62	8.42
10-May-23	Hollyhock Flats	7.41	7.15
23-May-23	Simms Creek	7.72	7.57
24-May-23	Airpark Lagoon	6.41	5.96
25-May-23	Hollyhock Flats	6.93	6.54
06-Jun-23	Simms Creek	6.48	6.43
07-Jun-23	Airpark Lagoon	4.89	3.70
08-Jun-23	Hollyhock Flats	5.49	5.11
19-Jun-23	Simms Creek	6.41	5.50
20-Jun-23	Airpark Lagoon	6.55	5.85
21-Jun-23	Hollyhock Flats	5.31	4.56
05-Jul-23	Hollyhock Flats	5.51	4.79
06-Jul-23	Simms Creek	6.59	6.46
07-Jul-23	Airpark Lagoon	5.64	4.80