

INSIGHTS FOR NO NET LOSS POLICY IN PRACTICE: AN EMPIRICAL STUDY  
OF JUVENILE PACIFIC SALMON USE OF OFFSET HABITATS IN THE FRASER  
RIVER ESTUARY

By

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## Abstract

The Fraser River Estuary (FRE) provides critical habitat for juvenile Pacific salmon (*Oncorhynchus spp.*), offering shelter, transition zones, and nutritional resources during migration. To ensure no net loss of fish habitat (NNL), s. 35(2) *Fisheries Act* authorizations for the harmful alteration, destruction, or disruption of fish habitat (HADD) require that habitat loss be balanced via actions like offsetting (R.S.C., 1985, c. F-14). Few studies have quantitatively analyzed fish use of created offset habitats in the FRE, meaning the effectiveness of these marshes in supporting Pacific salmon remains uncertain. This study evaluated juvenile salmon use of offset and reference habitats in the FRE during the 2023 outmigration period. From April to July, 9,636 juvenile salmon were captured at 23 marsh sites (13 offset and 10 reference). Generalized Additive Models (GAMs) assessed salmon abundance in relation to site type (offset vs. reference) and Julian day.

Results showed reference sites supported 3.05 times more salmon per sampling occurrence ( $p < 0.001$ ). Seasonal peaks and salmon species diversity were also greater in reference sites. These results were reflected at the species-specific level, where reference sites hosted over three times more chum (*O. keta*), Chinook (*O. tshawytscha*), and sockeye salmon (*O. nerka*) than offset sites. Findings suggest that offset habitats fail to meet the expected long-term productivity standards, raising ecological, social, and economic concerns. This misalignment with NNL policy underscores the need for enhanced monitoring, improved offset design, and adherence to the mitigation hierarchy to ensure fish habitat protection policies achieve their intended ecological outcomes.

*Keywords:* no net loss (NNL), habitat offsetting, Pacific salmon (*Oncorhynchus spp.*), Fraser River Estuary, ecological monitoring,

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## 1 — Introduction

Offering shelter from predators, acting as transition zones, and providing nutritional resources, estuarine sedge marshes are of extreme importance for juvenile Pacific salmon (*Oncorhynchus spp.*) as they migrate to the ocean (Beechie et al., 1994; Levy & Northcote, 1982; Wissmar & Simenstad, 1998). In heavily altered areas like the Fraser River Estuary's (FRE) North and South Arms, few of these natural marshes persist, making preserving their function as juvenile salmon rearing habitat critical (Chalifour et al., 2019; Rosenfeld et al., 2008).

To protect Canadian fisheries, such as that of Pacific salmon, the harmful alteration, destruction, or disruption of fish habitat (HADD) is prohibited under s. 35(1) of the federal *Fisheries Act* (R.S.C., 1985, c. F-14). Where a development has the potential to result in HADD, it must first be authorized by Fisheries and Oceans Canada (DFO) under section 35(2) of the federal *Fisheries Act*. These authorizations are often contingent on offsetting measures designed to balance any loss of fish resource productive capacity, thereby ensuring there is no net loss (NNL) of fish habitat in Canada. This offsetting often means the construction of equivalent habitat to that which will be lost (DFO, 1986, 2019b). Despite the compensatory nature of Canada's past and current offsetting policies<sup>1</sup>, several studies have identified offset projects that passed compliance monitoring and were deemed properly functioning but were ultimately found to have resulted in the net loss of habitat or have not maintained productive capacity through time (Bradford et al., 2017; Harper & Quigley, 2005; Quigley & Harper, 2006b, 2006a).

Since 1986, over 100 marsh offset sites have been established throughout the FRE as a part of section 35(2) *Fisheries Act* authorizations (*BIEAP-FREMP Atlas*, 2015; Stewart et al., 2022). These have nearly all been constructed under the assumption that proxies, namely primary productivity, are appropriate surrogates to support a policy goal

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<sup>1</sup>Section 35(2) *Fisheries Act* authorizations have been made under three policy iterations to date; the 1986 Policy for the Management of Fish Habitat (effective from 1986 through 2013), the 2013 Fisheries Productivity Investment Policy (effective from 2013 to 2019), and the 2019 Fish and Fish Habitat Protection Policy (effective from 2019 to present) (DFO, 1986, 2013, 2019b).

of fisheries protection and proliferation (DFO, 2002). There are challenges, however, in determining if this policy goal is being met. Many of these offset sites were evaluated without the collection of quantitative baseline data (Adams & Williams, 2004), which limits the ability to accurately assess the efficacy of offsetting efforts accurately. While some studies exist evaluating the productivity of offset sites within the FRE (Stewart et al., 2022), very few have quantified fish use of the sites or linked fish use to primary productivity (Bradford et al., 2017). This puts into question the suitability of primary productivity as a measure for success in offset sites, especially given the *Fisheries Act*'s guiding objective to support the production of fish resources — not just the primary productivity of a habitat (DFO, 1986). While primary productivity at offset sites may reflect that found in naturally occurring habitats, offset sites may not be supporting Pacific salmon fisheries to the same extent. Urgency is drawn when it is noted that several studies over the past 20 years have pointed to a failure of offset sites to serve their purpose of supporting fisheries in the long term (Harper & Quigley, 2005; Lievesley et al., 2016; Stewart et al., 2022).

Given the lack of studies associating offset site success with primary productivity in the FRE and recent failures of projects to maintain NNL, this study seeks to address the gap in understanding if offset sites support juvenile salmon to an extent comparable to natural habitat. If findings suggest that offset sites support salmon as well as natural (unaltered) habitat, then the findings of this research will affirm that current expectations for offset sites are appropriate and facilitate the desired outcomes of DFO's NNL policies. If findings suggest that offset sites, which were deemed in compliance with offset policy guidelines, do not support salmon as well as natural habitat, then they will highlight an area where the Canadian offsetting policy has fallen short and inadvertently allowed for a net loss of suitable fish habitat. This research will contribute to a better understanding of the suitability of offset sites for supporting juvenile Pacific salmon populations in this critical estuarine environment.

## 2 — Background

### 2.1 Fraser River Estuary and Habitat loss

Covering over 17,000 hectares, the FRE has been recognized as a “globally important centre for biodiversity” (Lievesley et al., 2016). It provides crucial rearing ground for over 80 species of fish and shellfish, hosts over 300 invertebrates, and supports the highest concentration of migratory birds in Canada (B.C. Ministry of Environment, 2006).

By annual average biomass of returns, the Fraser is the greatest salmon-producing river in the world (B.C. Ministry of Environment, 2006), with its basin serving as a significant spawning ground for sockeye salmon (*Oncorhynchus nerka*), chum salmon (*Oncorhynchus keta*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*) (DFO, 1998). Each spring, juvenile Pacific salmon migrate from inland spawning waters to the Strait of Georgia. In a typical year, over 2 billion juvenile salmon will pass through the FRE, residing there for months at a time before migrating into the ocean (B.C. Ministry of Environment, 2006). Serving as a place to feed, grow, and adapt to oceanic conditions, residency in estuarine marshes is of extreme importance for juvenile salmon survival (Beechie et al., 1994; Levy & Northcote, 1982; Wissmar & Simenstad, 1998).

Since the early 1900s, the FRE has been heavily altered and anthropogenic pressures, such as urbanization and industrial activity, have caused significant degradation and fragmentation of the estuary’s natural environment (Finn et al., 2021). Estuaries are naturally vulnerable to disturbances and cover only 2.3% of British Columbia’s (B.C.) coast (B.C. Ministry of Environment, 2006). To date, over 85% of marsh habitat has been lost or isolated from the FRE (Finn et al., 2021). Since 1986, when the first offsetting policy (DFO, 1986) brought into law s. 35(2) of the *Fisheries Act* (1985), any new projects resulting in the harmful alteration, degradation, or destruction of fish habitat (HADD) have required offsetting to balance the loss of habitat with alternative gain. Given the extent of habitat loss to date, it is crucial to understand if these offsetting projects are working effectively. In heavily altered areas like Lower

Fraser Estuary’s North and South Arms, where few sedge marshes persist, the function of remaining natural and offset habitat is critical for sustaining juvenile Pacific salmon populations (Chalifour et al., 2019; Rosenfeld et al., 2008).

## **2.2 Importance of Pacific Salmon**

### ***2.2.1 Ecological Importance of Salmon***

Pacific Salmon are a foundation species, sensu Angelini et al. (2011), heavily influencing regional and local biodiversity and contributing to ecosystem dynamics (Pacific Salmon Foundation [PSF], 2011). Their anadromous life history helps nutrients cycle from the ocean and upriver, making salmon an essential part of the nutrient budget for riparian ecosystems (Stanek et al., 2017). As all Pacific salmon species are semelparous, dying shortly after spawning, adult salmon carcasses remain along streams and other spawning areas where they are consumed by a variety of species — including wolves, bears, and various birds — which transport these nutrients away from the water, where they contribute to the biomass of inland ecosystems (Stanek et al., 2017). This transportation of marine-derived nutrients and carbon to freshwater lakes and rivers has been linked to elevated riparian tree species diversity, aquatic invertebrate abundance, and fish production (Naiman et al., 2002). A decline in Pacific salmon populations can, therefore, affect entire ecosystems, both aquatic and terrestrial (PSF, 2011).

### ***2.2.2 Sociocultural Significance of Pacific Salmon***

A poll of over 2000 B.C. residents found that 86% of adults are deeply concerned about the state of wild Pacific salmon (PSF, 2021). Salmon have been a part of the lives of people in the Pacific Northwest for time immemorial (PSF, 2011). A deep interconnectedness can be observed in the many First Nations that identify as “salmon people” for the significant role Pacific salmon have played in shaping their culture and diets and the centrality of salmon to their histories, identities, and futures (*CRITFC*, 2020). Indigenous fishing opportunities and fish-based knowledge systems are tied to the health of these stocks (Reid et al., 2022). Salmon are fundamental to the sociocultural systems of many Indigenous peoples (Cisneros-Montemayor & Ota, 2017), so their loss

would mean more than just the loss of a food or economic resource — it would also mean the loss of teachings, knowledge, relations, and identity.

### ***2.2.3 Economic Value of Pacific Salmon***

B.C.'s Pacific salmon fishery has accounted for ~13% of the province's landed value of wild seafood over the past 10 years (B.C. Salmon Marketing Council, 2024). Following hake, sockeye and chum salmon were B.C.'s most widely exported seafood species in 2018, respectively reaching 23 and 22 global markets (Government of British Columbia, 2018). From 2016 through 2018, B.C.'s wild-caught Pacific salmon generated a wholesale value of \$200.2 million to \$235.8 million per year (Government of British Columbia, 2018). As a resource, B.C.'s Pacific salmon fishery creates and supports over 6000 jobs yearly, while supplier industries generate an additional 3000-3100 (Counterpoint Consulting, 2014).

Beyond the fishery, salmon-related tourism is a significant contributor to B.C.'s economy. Recreational anglers, primarily drawn by salmon fishing, spend approximately \$550 million annually on sport fishing in the province (PSF, 2011). Additionally, hundreds of thousands of tourists visit hatcheries, fish ladders and other built structures and travel to observe the annual salmon runs, further boosting local economies (Counterpoint Consulting, 2014).

### ***2.2.4 Canada's Stance on Salmon Habitat Protection***

The government of Canada recognizes that maintaining the productive capacity of Pacific salmon and their habitat is essential, as indicated by the 1998 policy shift where conservation was established as the primary focus of the fishery's management (DFO, 1998). DFO, therefore, links harvest and stock management for Pacific salmon with conservation and habitat preservation (DFO, 2005). Since 2005, DFO has operated under the assumption that declines in productive capacity of habitat is the highest likelihood of loss for the species (DFO, 2005).

## **2.3 NNL Policy and Habitat Offsetting**

Fisheries and Oceans Canada (DFO) uses the principle of No Net Loss (NNL) as a guide when authorizing the harmful alteration, disruption, or destruction of fish habitat

(HADD) under section 35(2) of the *Fisheries Act* (1985). When proposed projects will impact fish or fish habitat, authorization is granted under the condition that offsetting measures be carried out to balance any loss of fish resource productive capacity, with the goal of ensuring there is no net loss of fish habitat (NNL) in terms of area or quality. Offsetting can involve replacing or enhancing natural habitat through habitat construction or enriching fish production through artificial means (DFO, 1986, 2019b).

Every policy guiding offsetting has been rooted in the objective of supporting the production of fish resources for all Canadians for generations to come (DFO, 1986, 2013, 2019b). DFO emphasizes following the internationally accepted hierarchy of “avoid, mitigate, offset” to protect biodiversity (DFO, 2019b). This process prioritizes *avoiding* harm, which can be achieved by moving a project’s location (and is supported by the general prohibition against HADD under s. 35(1) of the *Fisheries Act*), *mitigating* impacts on wildlife throughout development, and finally *offsetting* impacts as a last resort. However, human populations in coastal and riparian areas are the fastest growing in the world (Creel, 2003), and development along the FRE is integral to key industries in Canada, such as logging, mining, and transportation (Fraser River Estuary Management Plan [FREMP], 2003). Beyond industry, these areas are highly sought after for personal and touristic developments (FREMP, 2003). Globally, coastal estuarine areas face high demand for development, necessitating offsetting to accommodate growth while attempting to maintain and protect biodiversity. Given development pressures, investigating the success and effectiveness of offsetting projects in achieving their goals remains a priority. Understanding whether the tools enabling development while maintaining biodiversity are functioning as intended is essential.

Over the years, fish habitat offsetting in Canada has been directed by several different policies and guidelines. Many of the offset sites sampled in this research throughout the FRE were constructed under the guidelines of the 2013 *Fisheries Productivity Improvement Policy: A Proponent’s Guide* (DFO, 2013). The 2013 policy’s fourth Principle dictates that “offsets should strive to generate self-sustaining benefits to fisheries productivity. The offset benefits to the fisheries should last at least as long as the

impacts from the development project.” Therefore, in the case of projects where there is a permanent loss of habitat, offsets are expected to last indefinitely.

Similar requirements can be found in its succeeding policy, the 2019 *Policy for applying measures to offset adverse effects on fish and fish habitat under the Fisheries Act* and the preceding 1986 *Policy for the Management of Fish Habitat* (DFO, 1986, 2019b). Despite these evolving policy iterations, very little has substantively changed regarding the practitioner guidelines for offsetting as they pertain to compliance monitoring and monitoring metrics.

## **2.4 Offsetting in Practice**

In theory, if executed properly, offset policies should maintain overall biodiversity and ecosystem function while allowing human development and activity. Per the 2019 guidelines, during the planning phase of offsetting, proponents will characterize any projected death of fish or HADD, select the measures to offset, establish monitoring measures, and submit their plan to DFO for review (DFO, 2019b). While a wide range of ecological monitoring metrics are accepted, the monitoring of fish habitat offset projects has typically focused on measuring primary productivity rather than fish use of the new or enhanced habitat (Fisheries and Oceans Canada (DFO), 2002). After the compliance monitoring period — often lasting five years — is complete, the proponent has fulfilled their duty and no longer bears responsibility for the site (DFO, 2019b). However, it remains uncertain whether offset projects are achieving the objective of being self-sustaining and supporting fisheries in the long term, particularly for juvenile salmon in the FRE.

### ***2.4.2 Disconnects Between Compliance Monitoring Metrics and Goals***

There is a disconnect between offset site monitoring metrics and goals because proxies are usually used. As noted above, compliance monitoring often focuses on primary productivity rather than actual fish use of offset sites (DFO, 2002). The current *Fish Habitat Policy Statement* (2019) outlines how, for projects likely to cause large-scale impacts on habitat quality or quantity, only area-based productivity metrics and productivity components related to fish life cycles, such as primary productivity, must be

measured. For sites that will experience “relatively small” habitat quality impacts, only qualitative documentation is required (DFO, 2019a). While studies exist evaluating the productivity of completed offset sites within the Lower Fraser (Stewart et al., 2022), very few have quantified fish use or linked the two (Bradford et al., 2017). Bradford et al.’s (2017) literature review identified only five studies monitoring offset works that quantitatively assessed fish abundance. Among those, two could not formally analyze the data collected, and one focused on fish use immediately following construction, before habitat maturation or compliance monitoring completion. Given that primary productivity is often used as a proxy for fish productivity in offset projects, the lack of studies linking the two is a notable gap. This highlights that the assumption that productivity is an appropriate compliance monitoring metric must be questioned.

## **2.5 Focus of Study**

Offset projects throughout the FRE are expected to have been established with nursery and rearing habitat for juvenile salmon in mind. This study aims to address the gap in understanding whether offset sites throughout the FRE are serving their purpose as equivalent habitats for juvenile salmon. By analyzing juvenile salmon use of offset sites in relation to reference (unaltered) habitat, this study will explore whether these offset projects are fulfilling the intended outcome to balance HADD or if they are falling short in terms of supporting fish productivity as well as natural habitat does.

## 3 — Materials and Methods

### 3.1 Study Design

This research seeks to determine if offset sites in the FRE are functioning as juvenile salmon habitat through a study of fish abundance at a series of previously constructed offset sites, as well as at unaltered (reference) habitats. If juvenile salmon abundance at offset sites is greater than or equal to abundance at reference sites, this will indicate that offset sites are potentially serving their purpose to sustain juvenile salmon populations as if no HADD had occurred. Such an outcome would demonstrate progress toward the underlying objective of the 1985 *Federal Fisheries Act* and the associated fish habitat offsetting policies of 1986, 2013, and 2019 to sustain the production of fishery resources for future generations.

If that is the case, then the findings of this research will affirm that current expectations for offset sites are appropriate and facilitate the desired outcomes of current strategies for attaining no net loss of fish habitat. However, if juvenile salmon abundance at offset sites is lower than that at reference sites, then it will be determined that offset sites may not support juvenile salmon as well as natural habitat, highlighting an area where the habitat protection policies are falling short and are inadvertently facilitating a net loss of salmon habitat in the FRE.

### 3.2 Data Collection

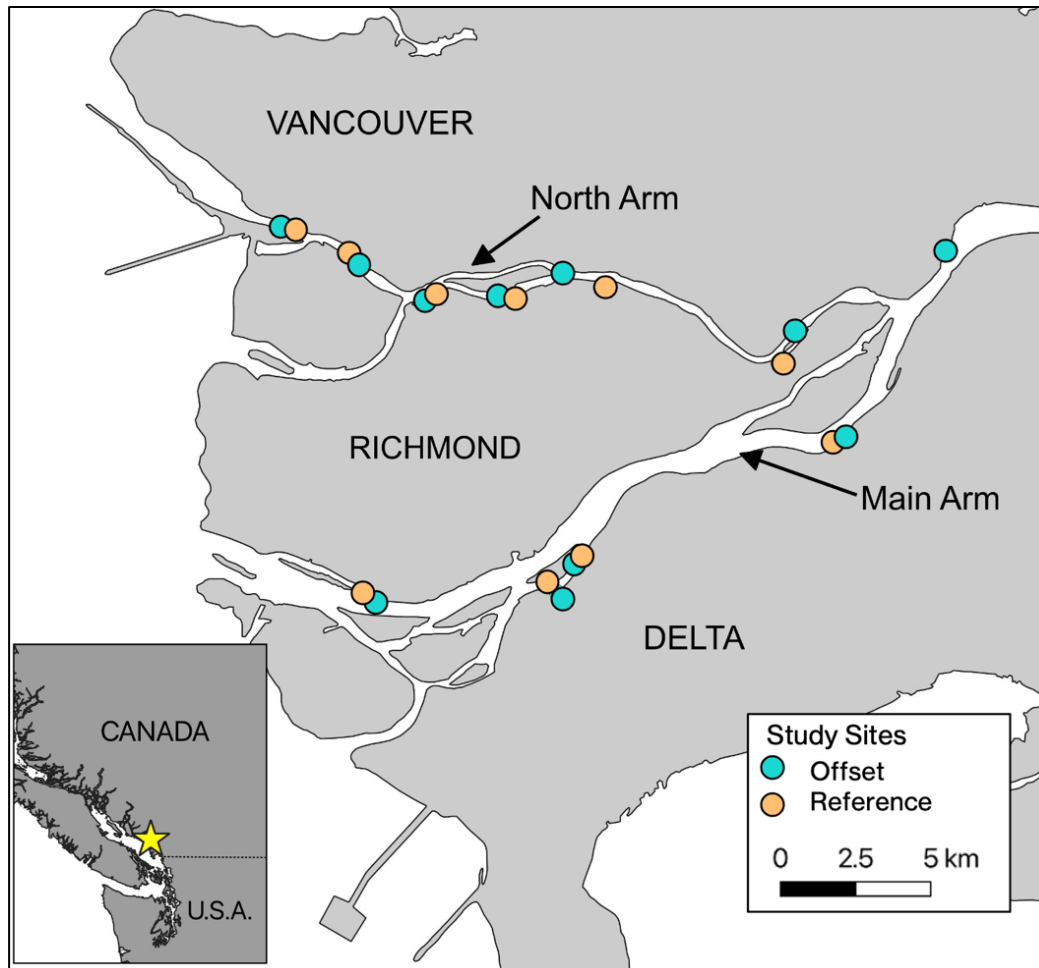
Data used in this study was part of a dataset collected by Raincoast Conservation Foundation's Lower Fraser Salmon Program team. Offset and reference sites were sampled throughout the 2023 juvenile salmon outmigration period (from April through July). Sites were visited roughly bi-weekly, though the schedule was not consistent due to accessibility issues with the timing of tides. The research team employed beach seining (20 m length x 2 m depth with 1.5 m deep bag) to capture juvenile salmon at 23 marshes spanning the lower Fraser Estuary. Sampling was timed to occur within three hours of a high tide when sites are inundated. Beach seines were deployed manually, with individuals dragging the net typically for 20 even paces per set, representing ~20 meters.

Three non-overlapping sets of beach seines were conducted during each sampling instance. After each set was concluded, the research team released fish from the submerged bag one by one, counting and identifying the salmon species captured (such as Chinook, coho, sockeye, or chum salmon) as they did. The landings of the three sets were summed to culminate one sampling occurrence. Due to the two-year spawning cycle of Fraser pink salmon, with runs occurring only in odd years (Grant & Pestal, 2009), no juvenile pinks were present in the 2023 sample year, excluding them from this study.

### **3.3 Study Sites**

The 23 study sites highlighted in Figure 1 are dispersed throughout the North, Middle and South Arms of the inner Fraser estuary. Offset sites provide broad spatial coverage across the estuary's gradient and habitat types, from its oceanic to riverine boundaries. All offset sites sampled were past their 5-year period of compliance monitoring. Having completed this monitoring period means it has been demonstrated that they should independently maintain productivity into the future as self-sustaining habitats.

Reference sites were chosen based on being as unmodified as possible in recent history, for their proximity to offset sites, for their similarity to adjacent offset sites in terms of size and considering practical considerations regarding access. In total, data was collected at 13 offset sites and 10 reference sites throughout the 2023 juvenile salmon outmigration period.



**Figure 1.** 2023 Study Sites sampled for juvenile Pacific salmon presence throughout Fraser River Estuary (FRE).

*Note.* The locations of fish habitat offset sites (blue) and reference sites (orange) sampled for juvenile Pacific salmon presence throughout the Fraser River Estuary (FRE) during the 2023 juvenile Pacific salmon migration are identified.

### 3.4 Statistical Analysis

#### 3.4.1 Relationship Between Salmon Abundance, Site Type, and Time

Data was grouped by site type (offset or reference), salmon species (coho, Chinook, sockeye, or chum), and Julian day. A Generalized Additive Model (GAM) was used to model the relationships between total salmon count per sampling occurrence at offset versus reference sites through time. Though Poisson family GAMs are often used

for count data (Zuur et al., 2009), the high variability of salmon counts in this dataset meant that the variance was often larger than the mean. To handle this overdispersion, a negative binomial family model with a logarithmic link function was instead used to predict salmon counts based on the site type variable (Zuur et al., 2009). Acknowledging the dynamic nature of salmon migrations and that the relationship between Julian day and salmon count is known to be non-linear, Julian day was selected as the smooth term. This enabled the model to adapt to changes in the response variable (salmon count) over time without imposing a strict functional form. Using Julian day as the smooth term also acknowledged the seasonal patterns expected during salmon migration and how they might influence outputs (hence the high variability). Once the log coefficient for reference sites was identified, the relationship between salmon count at reference sites and offset sites could be identified. Negative binomial, logarithmic link GAMs were also generated at the species-specific level for Chinook, sockeye, and chum salmon. Coho salmon-specific patterns in offset site use were not analyzed, as Raincoast's sampling over the past decade has shown consistently low catch rates for juvenile coho in the FRE (Dave Scott, personal communication, October 2024).

### ***3.4.2 Observational Trends in Abundance Through Time***

Scatter plots were also created to aid in highlighting trends through visual analysis. These included plots displaying total juvenile salmon, Chinook, sockeye, and chum salmon catches per sampling instance over time.

### ***3.4.3 Statistical Analysis Software***

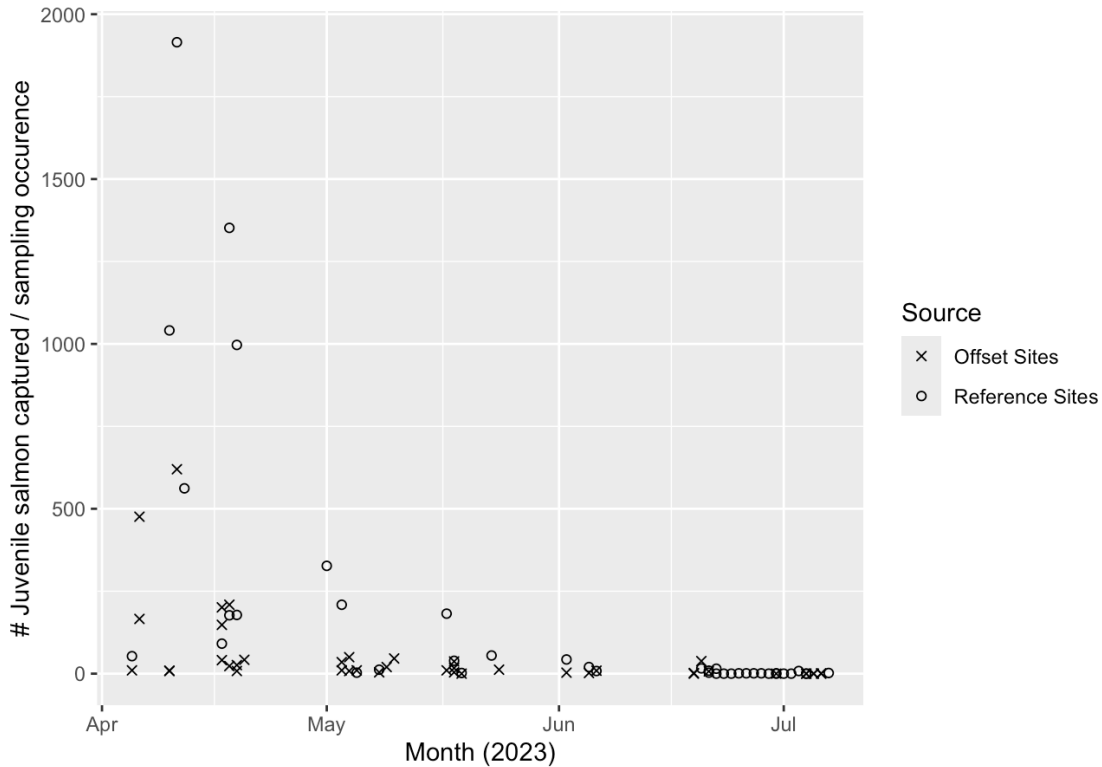
All statistical analyses were completed using R Statistical Software (v4.2.1; R Core Team, 2022). GAMs and GAM plots were generated using the mgcv R package (Wood, 2004), while all other plots were generated with the ggplot2 R package (Wickham, 2016).

## 4 — Results

### 4.1 Overall Trends in Abundance

#### 4.1.1 *Observational Trends*

From April through July 2023, 9,636 juvenile Pacific salmon were caught over the course of 82 sampling occurrences. For both reference and offset sites, juvenile salmon captured per sampling occurrence peaked in mid-April and then gradually decreased from May through July for both reference and offset sites (Figure 2), a trend consistent with juvenile salmon migratory patterns previously observed in the FRE (Scott et al., 2024). Across the entire outmigration period, reference sites consistently hosted more juvenile salmon than offset sites, with the most pronounced difference observed in the peak migratory months of April and May (Figure 2). Notably, there were several sampling events at reference sites where over 1,000 juvenile salmon were captured in individual sampling occurrences. The capture rates at offset sites, on the other hand, only surpassed 500 juvenile salmon per sampling occurrence once. The peak in juvenile salmon abundance occurred on the same day (April 11) for both reference and offset site types at two spatially proximate locations: GBR (reference) and GBC (offset). However, significantly more juvenile salmon were caught at the reference site (1,915) than at the offset site (620).



**Figure 2.** Total juvenile salmon captures at Fraser River Estuary fish habitat offset and reference sites throughout the 2023 outmigration period.

*Note.* Total juvenile Pacific salmon captures per sampling occurrence (three beach sein sets) is shown at offset (x) and reference (o) sites. Points represent the sum of chum salmon, Chinook salmon, sockeye salmon, and coho salmon caught per sampling occurrence at each site type.

Overall, when considering whether offset sites provide equivalent habitat value to juvenile salmon as the reference sites they emulate, Figure 2 shows how reference sites consistently supported higher salmon captures across the outmigration period.

#### 4.1.2 Statistical Analysis of Total Juvenile Salmon Capture Data

The results of the Generalized Additive Model (GAM) relating total juvenile salmon count/sampling occurrence with site type and Julian day reinforce the observed trends. Table 1 shows that both the site type and Julian day had significant effects on salmon counts. The parametric coefficient for reference sites of 1.1141 ( $p = 0.0004$ ) indicates that total juvenile Pacific salmon caught per sampling occurrence was

approximately 3.05 times higher at reference sites compared to offset sites. This highly significant result reinforces the observational data, indicating that offset sites were less effective as reference sites in supporting juvenile salmon.

**Table 1.** *Relationship Between the Number of Juvenile Salmon Captured per Sampling occurrence, Site Type (Reference or Offset) and Julian Day.*

adjusted R-square:	0.375	deviance explained:	66.2	
parametric coefficients				
	estimate	std.error	statistic	<i>p</i> .value
source: Reference Sites	1.1141	0.3153	3.5337	0.0004
Approximate significance of smooth terms				
	edf	ref.df	Chi-sq stat.	<i>p</i> .value
smooth term: Julian day	3.4542	4.2905	173.1415	<2E-12

*Note.* Results from the General Additive Model (GAM) predicting the number of total juvenile salmon caught per sampling instance based on site type (reference or offset) and Julian day are summarized.

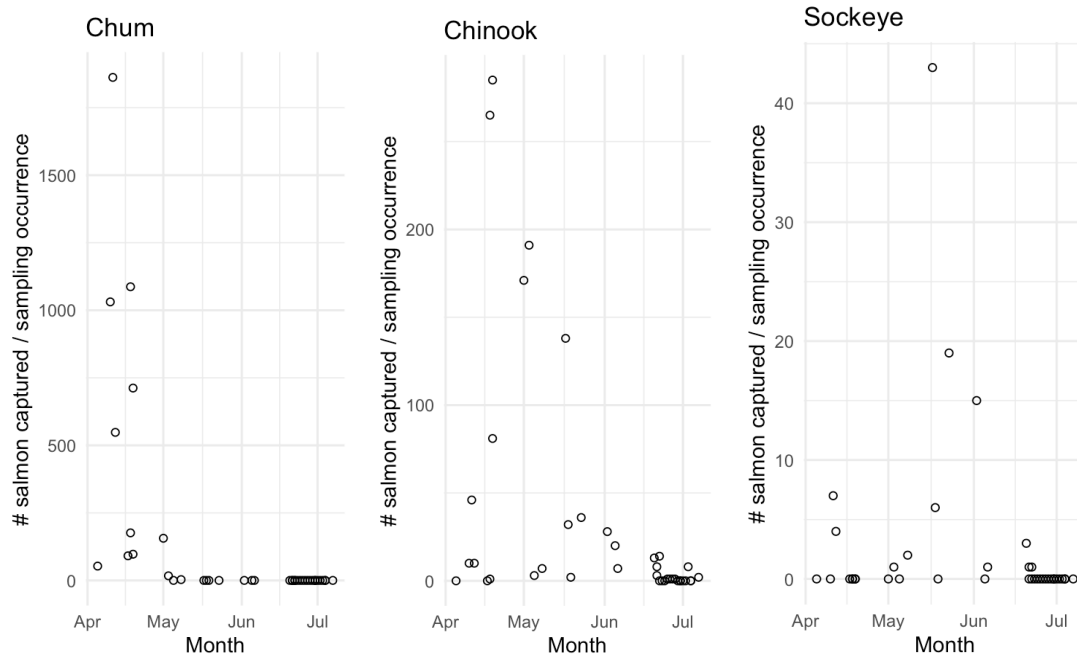
The model explains 66.2% of deviance, indicating that the model effectively captures the relationship between site type, sample timing (Julian day) and juvenile salmon abundance. The effective degrees of freedom (*edf*) of 3.45 for Julian day reflects a complex, non-linear relationship between salmon counts and time, which is common in the case of ecological abundance data (Heit et al., 2024).

The Chi-square statistic of 173 with a highly significant *p*-value ( $<2E-16$ ) indicates that the smooth term (Julian day) is a significant predictor for the model. Additionally, the adjusted R-squared ( $R^2$ ) value suggests that 37.5% of the variation in salmon counts is explained by the model, which is reasonable given the typically high variability of ecological count data (Heit et al., 2024; Zuur et al., 2009).

## **4.2 Salmon species-specific Results**

### ***4.2.1 Comparing Temporal and Site-type use Patterns Among Salmon Species***

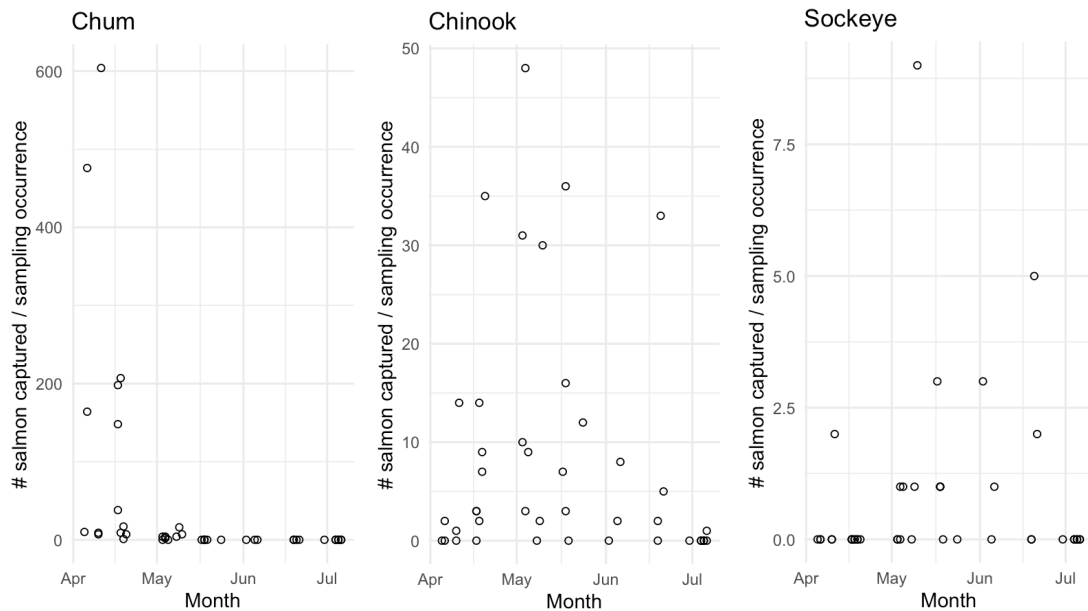
Chum were the most abundant salmon species captured across both site types. At reference sites, juvenile chum salmon captures peaked in mid-April, followed by a sharp decline through May, and relatively low numbers through June before dropping to zero in July (Figure 3). Juvenile Chinook salmon showed a similar peak in mid-April, but their decline was much more gradual, continuing from May through June. Coho captures were minimal, with only three recorded at reference sites during the season, resulting in the decision to exclude them from species-specific statistical analysis. While juvenile sockeye captures were more frequent than juvenile coho captures, they were infrequent relative to chum and Chinook, and peaked later, in mid-May (Figure 3). In reference sites, the seasonal trend in juvenile salmon abundance was most pronounced for chum salmon, followed by coho and sockeye.



**Figure 3.** Juvenile Pacific salmon caught per sampling occurrence at reference sites by species (2023).

*Note.* Captures per sampling occurrence (three beach sein sets) by Pacific salmon species (chum, Chinook, and sockeye) at reference sites (o) are shown. It is important to note the different y-axis scales, which were changed from species to species to capture seasonal trends.

Relative to reference sites, offset sites had fewer chum salmon overall, but they still had the highest capture rate of any Pacific salmon species (Figure 4). Chinook were less abundant, and their presence was more consistent across the season, showing a gradual decrease rather than a sharp decline.



**Figure 4.** Juvenile Pacific salmon caught per sampling occurrence at offset sites by species (2023).

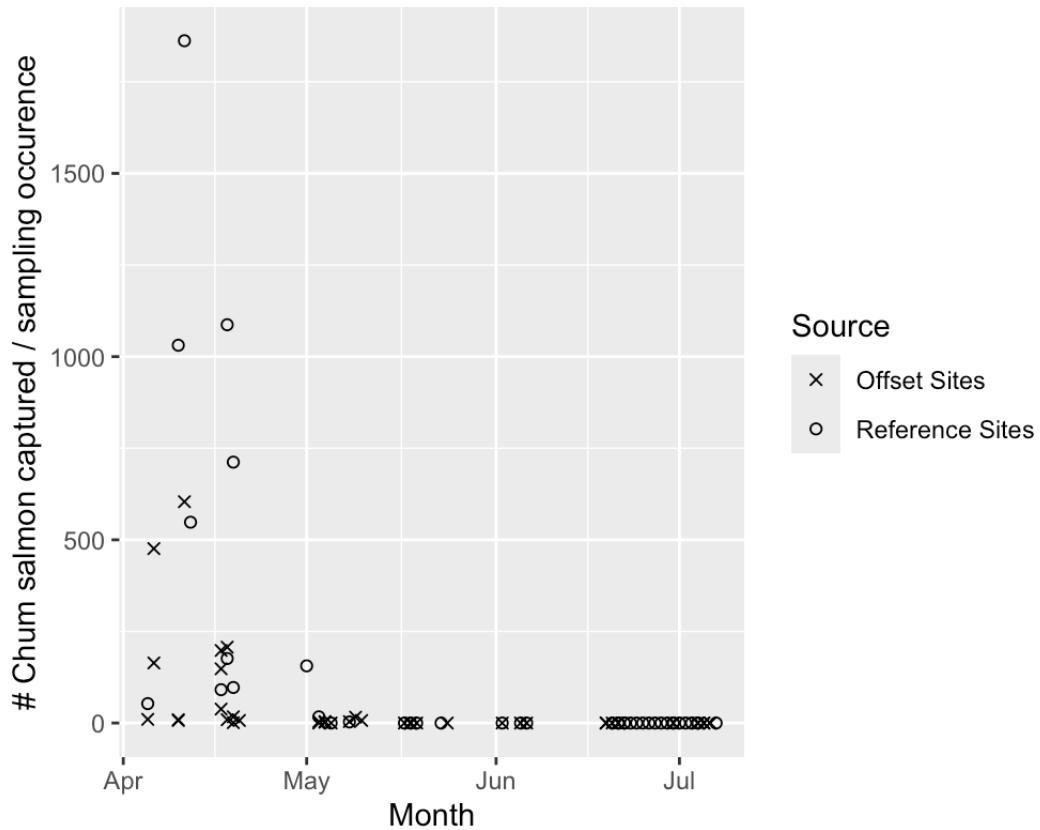
*Note.* Captures per sampling occurrence by Pacific salmon species (chum, Chinook, and sockeye) at offset sites are shown. It is important to note the different y-axis scales, which were changed from species to species to capture seasonal trends.

It is clear from Figures 3 and 4 that for both site types, Chinook and coho salmon drove the overall trends in juvenile Pacific salmon captures. They were the main contributors to the large early-season peaks observed in Figure 2, with a marked decline in abundance over time, particularly at reference sites (Figure 3). In offset sites, seasonal trends were present (Figure 4), though less pronounced than at reference sites for chum and Chinook, and almost unobservable for sockeye (Figure 3). This may indicate that reference sites are more effective in supporting multiple Pacific salmon species as juveniles pass through the estuary.

#### **4.2.2 Chum Salmon use of Offset and Reference Sites**

Observational trends for chum salmon resembled those of total juvenile salmon abundance. Of the 9,636 juvenile salmon captured, 7,765 (80.6%) were chum, underscoring their contribution to overall trends. At both site types, juvenile chum

abundance peaked in early to mid-April before dropping significantly throughout the second half of the month. Capture rates were low through May, before dropping to around zero in June and July (Figure 5). While they were present in the estuary, juvenile chum count remained higher at reference sites than at offset sites.



**Figure 5.** Juvenile chum salmon captures at FRE offset and reference sites throughout 2023 outmigration period.

*Note.* Juvenile chum salmon captures per sampling occurrence (three beach sein sets) is shown at offset (x) and reference (o) sites.

Results of the GAM predicting juvenile chum salmon abundance per sampling occurrence at offset vs. reference sites (Table 2) further support the observed trends in figure 5. The model explained 88.1% of deviance (adjusted  $R^2 = 0.493$ ). Site type (reference or offset) was a significant predictor (log-transformed estimate = 1.35, std. error = 0.28,  $p = 0.005$ ), indicating that reference sites hosted, on average, 3.9 times more juvenile salmon per sampling instance. Additionally, Julian Day exhibited a strong non-linear relationship with salmon abundance, as indicated by the smooth term ( $edf = 3.03$ ,  $\chi^2 = 81.19$ ,  $p < 0.001$ ), reinforcing model fit (Table 2).

**Table 2.** Relationship Between Juvenile Chum Salmon Abundance, Site Type (Reference or Offset) and Julian Day

adjusted R-square:	0.493	% deviance explained:	88.1	
parametric coefficients				
	estimate	std.error	statistic	p.value
source: Reference Sites	1.3475	0.4827	2.7916	0.0052
Approximate significance of smooth terms				
	edf	ref.df	Chi-sq stat.	p.value
smooth term: Julian day	3.0343	3.6027	81.1916	<2E-16

*Note.* Summary of results from the General Additive Model (GAM) predicting the number of juvenile chum salmon caught per sampling instance based on site type (reference or offset) and Julian day



The GAM predicting the number of juvenile Chinook salmon caught per sampling instance based on site type (reference or offset) and Julian day (summarized in Table 3) explained 47% of the deviance in salmon counts, with an adjusted R-square of 0.313. The parametric coefficient for reference sites was 1.3050 (p-value = 0.0005), indicating that reference sites hosted 3.96 times more juvenile Chinook salmon than offset sites. The smooth term for Julian day had an effective degree of freedom (edf) of 4.60, and the Chi-square statistic was 60.22 ( $p < 2E-16$ ), indicating a significant non-linear relationship between juvenile Chinook abundance and the time in the migration period.

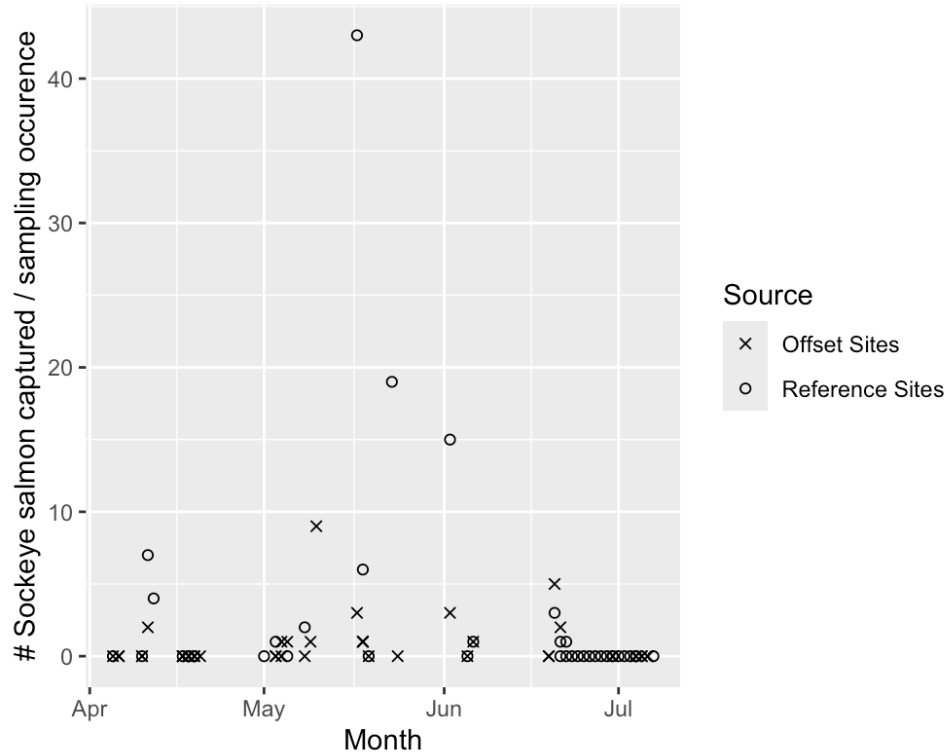
**Table 3.** *Relationship Between Juvenile Chinook Salmon Abundance, Site Type (Reference or Offset) and Julian Day*

adjusted R-square:	0.313	% deviance explained:	47	
parametric coefficients				
	estimate	std.error	statistic	p.value
source: Reference Sites	1.3050	0.3724	3.5047	0.0005
Approximate significance of smooth terms				
	edf	ref.df	Chi-sq stat.	p.value
smooth term: Julian day	4.6036	5.5943	60.2226	<2E-16

*Note.* Summary of results from the General Additive Model (GAM) predicting the number of juvenile Chinook salmon caught per sampling occurrence (three beach sein sets) based on site type (reference or offset) and Julian day.

#### 4.2.4 Sockeye Salmon use of Offset and Reference Sites

Juvenile sockeye salmon were captured from April into mid-July, with a small, late-season peak in captures in mid-May (Figure 7). This peak at reference sites was over four times the peak in counts at offset sites.



**Figure 7.** Juvenile sockeye salmon captures at FRE offset and reference sites throughout the 2023 outmigration period.

*Note.* Summary of results from the General Additive Model (GAM) predicting the number of juvenile sockeye salmon caught per sampling occurrence (three beach sein sets) based on Site Type (reference or offset) and Julian Day

The Generalized Additive Model (GAM) predicting the number of juvenile sockeye salmon caught per sampling instance based on site type (reference or offset) and Julian day explained 66.6% of the deviance, with an adjusted R-square of 0.293 (Table 4). The parametric coefficient for reference sites was 1.1415 (p-value = 0.0302), indicating that reference sites hosted 3.1 times more juvenile sockeye than offset sites. The smooth term for Julian day had an effective degree of freedom (edf) of 6.90, and the Chi-square statistic was 23.94 (p-value = 0.0012), indicating a significant non-linear relationship between juvenile sockeye abundance and time of year.

**Table 4.** *Relationship Between Juvenile Sockeye Salmon Abundance, Site Type (Reference or Offset) and Julian Day*

adjusted R-square:	0.293	% deviance explained:	66.6	
parametric coefficients				
	estimate	std.error	statistic	p.value
source: Reference Sites	1.1415	0.5265	2.1680	0.0302
Approximate significance of smooth terms				
	edf	ref.df	Chi-sq stat.	p.value
smooth term: Julian day	6.9041	7.7011	23.9437	0.0012

*Note.* Summary of results from the General Additive Model (GAM) predicting the number of juvenile sockeye salmon caught per sampling instance (three beach sein sets) based on site type (reference or offset) and Julian day

#### ***4.2.5 Coho Salmon use of Offset and Reference Sites***

Only four coho salmon were caught throughout the 2023 outmigration season, so statistical analysis of juvenile coho habitat use through time and by site type (reference or offset) was not possible. Of the four coho salmon captured, three were caught at reference sites between mid-May and June, and one was caught at an offset site in early May. The Raincoast team notes that such low capture rates for coho salmon have been standard in the inner estuary over the past few years (Dave Scott, personal communication, October 2024).

## 5 – Discussion

### 5.1 Comparing Juvenile Salmon Presence in Offset and Reference Sites

#### 5.1.1 Summary of Key Findings

Findings consistently pointed to the advantage of reference sites over offset sites in supporting juvenile salmon. Figure 2 shows a clear trend of more salmon being captured at reference sites, particularly during the peak migration months of April and May. Chum and Chinook were the most consistently captured species, driving this trend. This pattern remained for the entire 2023 outmigration season. The GAM analysis further quantifies this, indicating that reference sites host 3.05 times more juvenile salmon than offset sites on any given day during the outmigration period. This was reflected at the species-specific level as well, where there were over three times as many chum, Chinook and sockeye salmon at reference sites than at offset sites. Statistical analysis pointed to a very significant relationship between site type and time during the migratory period, confirming that both influence salmon abundance. There was a spike and slow decline in salmon captures in both site types, reflecting expected migratory patterns. This effect was much more pronounced at reference sites, where juvenile salmon captures were consistently higher, and where there was greater diversity in salmon species present.

#### 5.1.2 Misalignment with Expected Productivity

Highlighted in Figure 2, the significantly higher juvenile salmon counts found at reference sites relative to offset sites suggest that offset sites may be less suitable for supporting large numbers of salmon, particularly during peak migration. DFO authorization of these offsets, however, would have assumed that the created habitat would be of equal or greater value to the surrounding natural habitat. These findings contradict DFO's policy provisions regarding offset sites, which would assume sites perpetuated desired productivity levels through time, indicating that policy goals are not being met. Two potential explanations are present. These sites either 1) never supported the fish they were assumed to as a result of the proxy metrics being used to deem a site

properly functioning being inappropriate, or 2) sites functioned effectively upon completion but failed over time.

## **5.2 Effectiveness of Offsetting Policy and NNL**

### ***5.2.1 The Role of Offsetting in Maintaining NNL***

In the case of the FRE, while offset sites may serve some purpose and lessen the overall loss of juvenile salmon habitat, they may not be functioning equivalent to reference habitats. The significantly higher abundance of juvenile Pacific salmon at reference sites, with 3.05 times more compared to offset sites, suggests that in the absence of natural habitat, offset habitats alone would not have the capacity to support the yearly influx of juvenile salmon to the FRE. This finding aligns with concerns from previous studies that offsetting policy in Canada may not be ensuring no net loss of quality fish habitat.

A 2005 review of documentation for 124 HADD/offset authorizations revealed inconsistencies in compliance monitoring procedures (Harper & Quigley, 2005). This meant NNL could only be confirmed in 17 of the 124 sites. In 30 sites, compensation ratios (area of habitat gained:habitat lost) post-construction were already less than 1:1 (Harper & Quigley, 2005). In situ investigations have had similar results; in 2006, in their assessment of 16 offset sites across the country that had completed compliance monitoring, Quigley and Harper found that over 60% of projects resulted in the net loss of habitat, averaging mean offset ratios of 0.7:1 (Quigley & Harper, 2006b). That same year, the pair proposed that Canada's offset-based NNL policies were, at best, only slowing the rate of habitat loss and in no way preventing it (Quigley & Harper, 2006a).

The discrepancy in juvenile Pacific salmon abundance observed at offset and reference sites in this study raises similar concerns; while offsetting may have mitigated habitat loss in the FRE over the past 38 years, it may not have been effective in maintaining NNL. The findings of this study highlight the inability of offset sites to be self-sustaining of Pacific salmon populations through time, undermining Canada's efforts to achieve NNL of fish habitat per the *Fisheries Act*.

### ***5.2.2 Long-term Sustainability of Offset Sites***

Canadian offset policies have always emphasized that offset sites must be self-sustaining over time, yet the findings of this study challenge the assumption that these sites maintain fishery productive capacity in the long term. The disparity in the number of juvenile salmon hosted at reference and offset sites highlights the failure of offset sites to sustain productivity levels that are comparable to those of natural habitats in the long term. While the frequency of juvenile salmon observed at both site types reflected expected migratory patterns — a peak in captures in mid-April followed by a rapid decline in May before a gradual decline throughout the summer — the peak was far more pronounced at reference sites for chum, Chinook, and sockeye salmon. Offset sites consistently supported fewer juvenile salmon and exhibited lower salmon species diversity throughout the migratory period.

The results of this study suggest that offset sites are not achieving the long-term ecological functionality required and assumed by policy. Contributing factors may include inadequate habitat design or failure to account for site-specific environmental variables (i.e. salinity, plant diversity and composition substrate type, dissolved oxygen) (Adams & Williams, 2004; Lievesley et al., 2016). Additionally, declines in productivity post-compliance monitoring may be exacerbated by the lack of long-term maintenance mechanisms or structural resilience. (Lievesley et al., 2016; Stewart et al., 2022). These results suggest that the current offsetting policies, which assume the self-sustainability of offset sites after initial compliance monitoring, are inadequate for ensuring the long-term ecological function required to maintain fish populations. A more comprehensive adaptive management approach is needed to address the changing environmental conditions and ecological processes that influence salmon populations over time

The findings of this study echo Lievesley et al. (Lievesley et al., 2016), who identified the short five-year standard duration of compliance monitoring and the absence of adaptive management frameworks as key limitations in offsetting practices in Canada. In the absence of long-term adaptive management, there is no requirement or for practitioners to address declines in functionality or productivity once the five-year window of compliance monitoring is complete. This creates a gap in ensuring long-term sustainability and a barrier to predicting such with any certainty. The document referred

to proponents to outline steps in assessing habitat offset activities emphasizes that it may take years or decades before biotic change is evident, necessitating that some monitoring programs should extend longer than 10 years (Smokorowski et al., 2015), and yet a standard five years is all that is prescribed. Zedler and Callaway (1999) warn that only in low-stress systems might a monitoring period of 5-10 years be appropriate and suggest that restoration sites meant to reach functional equivalency of species-rich systems may require monitoring for 20-100 years before high-certainty predictions of the long-term sustainability of a site can be made. This study supports these arguments. The consistently lower abundance and diversity of juvenile salmon at offset sites, as observed throughout the 2023 outmigration season, points to the failure of these sites to meet the productivity levels expected by the policies which directed their construction and approval. The current five-year compliance monitoring standard is too short to assess with certainty whether offset sites will be self-sustaining and capable of supporting fisheries in the long term, as it fails to capture important long-term changes that may occur as sites mature and fully establish, as evidenced by the lower salmon counts observed at these sites. The inability of offset sites to sustain desired juvenile salmon productivity underscores broader policy concerns, particularly with the lack of post-compliance monitoring and adaptive management.

These findings highlight the importance of improving offset site design and monitoring to better support fish productivity. Until offsetting can be made more effective in supporting juvenile salmon productivity, the significant disparity in salmon abundance at offset versus reference sites in this study further underscores the need for DFO to enforce the hierarchy of “avoid, mitigate, offset” (DFO, 2019b). Out of an abundance of caution, it will be crucial to avoid and mitigate harm and thus preserve the remaining natural habitats that robustly support juvenile salmon populations. There is a need to re-examine the length and scope of compliance monitoring, as well as to incorporate management strategies that ensure offset sites can respond to ecological changes over time. Addressing these issues will require policy adjustments to better align offset practices with their intended role in supporting fisheries productivity over time.

## **5.3 Recommendations and Next Steps**

### ***5.3.1 Considering Cumulative Habitat Loss in Future HADD Authorizations***

When granting future *Fisheries Act* s. 35(2) authorizations for HADD in the FRE, DFO should consider that over the past 38 years, a net loss of suitable juvenile Pacific salmon habitat may have occurred despite the offsets implemented to balance past HADD authorizations. The significant discrepancy observed between juvenile Pacific salmon abundance at offset and reference sites indicates that offset efforts in the FRE have fallen short in supporting fish productivity as well as natural habitat would. A precautionary approach should be adopted until further research can clarify the cause of offset site underperformance or failure. Until improvements are made to offset design and monitoring practices, DFO should consider slowing authorizations where unintended cumulative habitat loss of rearing habitat may be impacting salmon populations. This approach would help ensure that offsetting measures do not inadvertently perpetuate the decline in habitat quality or quantity for juvenile Pacific salmon.

### ***5.3.2 Offsetting Should Remain a Last Resort***

Given that offset sites are not performing as well as natural juvenile salmon rearing habitat, it is critical that DFO continue to enforce the hierarchy of measures outlined in the 2019 *Policy for applying measures to offset adverse effects on fish and fish habitat under the Fisheries Act* — to “avoid, mitigate and offset” (DFO, 2019b). DFO should continue to emphasize the steps to avoid adverse effects on fish and fish habitat and to mitigate the extent of adverse effects of an undertaking or activity. The significant difference between juvenile salmon abundance at offset and reference sites in the FRE underscores the value of avoiding and mitigating impacts on the remaining natural spaces.

### ***5.3.3 Identifying when Productivity Deficits Arise at Mature Offset Sites Through Quantitative Fish Abundance Monitoring***

To better understand and address deficits in productivity at mature offset sites, further research is needed to determine whether these shortcomings develop over time, following the completion of compliance monitoring, or if they result from misaligned

proxy metrics allowing sites to pass monitoring when they are not functioning at full capacity. This can be approached through two complementary strategies: reevaluating the suitability of proxy metrics via research conducted in situ and extending the requirement for quantitative fish abundance monitoring during compliance for projects with large-scale impacts—if not for all projects.

Such data collection could be carried out by proponents to reduce the burden on DFO while expanding the availability of critical data. Extended compliance monitoring periods could also help capture long-term changes in fish use and productivity, offering insights into whether declines result from deficiencies in offset design, or over time due to insufficient maintenance or resilience to sustain productivity. Together, these steps are essential for improving the success of offset habitats in supporting juvenile Pacific salmon and other key fisheries.

#### ***5.3.4 Further Research is Needed to Understand what Parameters are Making Offset sites less Desirable/Suitable for Juvenile Pacific Salmon.***

Future research will be key to establishing better guidelines for the development of offset projects that can better support juvenile Pacific salmon and other key fisheries during their residency in the FRE. These studies should aim to identify features of established offset sites and natural habitats that successfully support high population densities and the differences between the sites which are more or less successful. Achieving this will require comprehensive environmental monitoring of parameters critical to juvenile salmon lifecycles, including but not limited to benthic activity, water temperature, dissolved oxygen, sediment composition, vegetation type and cover, and overall biodiversity (Lievesley et al., 2016).

#### ***5.3.5 Broadening Research***

There may be other areas where NNL is not being maintained in other waterways, unknowingly hindering the productivity of other fisheries. Comparing quantitative fish abundance in other locations across the country is warranted, especially in areas with high concentrations of sites that were established to offset large-scale impacts where quantitative fish population monitoring would not have been required to demonstrate policy compliance.

## 6 — Conclusion

The findings of this study underline the need for a reevaluation of habitat offsetting practices, particularly in the FRE, where offset sites have failed to support juvenile Pacific salmon to the same degree as natural habitat. This failure to meet expectations challenges the effectiveness of current and past habitat offset policies in Canada to ensure no net loss of productivity in juvenile salmon nursery habitat in the long term.

In light of the study's findings, it is essential for future policies to take into account the inadvertent cumulative habitat loss that may have occurred despite offsetting efforts over the past four decades. Moving forward, habitat offsetting should continue to be a last resort, ensuring that the first step focuses on avoiding and mitigating impacts on fish and fish habitats. Additionally, more in-depth monitoring, including quantitative fish abundance assessments, will be crucial for identifying when productivity deficits emerge at mature and maturing offset sites. Research should also be directed toward understanding the specific environmental factors making offset sites more or less suitable for juvenile Pacific salmon, which will be key to refining offset design and management. Finally, expanding research into other regions will help identify broader patterns of habitat loss and offset ineffectiveness should they exist, enabling the development of more robust strategies for supporting fish populations across Canada's aquatic ecosystems.

Ensuring that offsetting policies deliver on their promises is not just an ecological imperative but a cultural, societal, and economic one. As noted by the Pacific Salmon Foundation (2011), Pacific salmon are foundational to the health of ecosystems, the identities of Indigenous peoples, and the vitality of local economies. Effective management of salmon habitat, including improved offsetting practices, will be essential for maintaining these interconnected systems for generations to come.

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