Wild Fish Conservancy
NORTHWEST
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2018 Hood Canal Juvenile Chum Salmon Nearshore Habitat Use Assessment

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Table of Acronyms

ANOVA	Analysis of Variance
CI	Confidence Interval
CPUE	Catch-Per-Unit-Effort
eDNA	Environmental Deoxyribonucleic Acid
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
GLM	Generalized Linear Model
PWD	Population Weighted Distance
SE	Standard Error
SJF	Strait of Juan de Fuca
WDFW	Washington Department of Fish and Wildlife
WFC	Wild Fish Conservancy

Acknowledgements

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In memory of James Fletcher Healy

Abstract

Habitat protection and restoration are vital to the survival and recovery of many salmonid populations in the U.S Pacific Northwest. However, conservation actions that fail to consider specific behaviors and life-history strategies demonstrated by a species or population of concern are unlikely to achieve recovery objectives. Building upon a two-year genetic study in Hood Canal, WA that developed statistical models to retrospectively assign chum salmon (*Oncorhynchus keta*) catch to genetically distinct summer and fall population groups, the non-profit Wild Fish Conservancy performed a nearshore study within Hood Canal to determine habitat preferences by chum salmon population group. Results of the study suggest that summer and fall chum salmon fry exhibit differential use of nearshore estuarine habitats within the Hood Canal that may be dependent on seasonal nearshore ecosystem conditions. Previous research has determined that cooler and less productive estuarine emergence conditions cause early emerging chum salmon juveniles—most of which are now known to be of summer run origin—to emigrate at a faster rate from Hood Canal than later emerging fall chum salmon. Differences in nearshore ecosystem conditions and subsequent impacts on emigration likely result in reduced summer chum residence time within seasonally unproductive delta habitats; this may be the cause of the relative increase in winter season use of barrier lagoon and estuary habitats observed within the Hood Canal outmigration corridor and significantly lower probabilities of chum salmon occurrence in delta habitats in comparison to later spring months. These findings demonstrate the importance of embayment habitat features (such as barrier lagoons and estuaries) to the recovery of Endangered Species Act (ESA)-listed Hood Canal summer chum salmon. Protection and restoration of embayment features will help maintain or increase shelter and feeding opportunities for juvenile chum and Chinook salmon that may seek substitute rearing habitats to seasonally unproductive or anthropogenically diminished river deltas prior to entering the North Pacific Ocean.

Background

1.1 Introduction

Habitat protection and restoration are vital to the survival and recovery of many salmonid populations in the U.S Pacific Northwest. However, conservation actions that fail to consider specific behaviors and life-history strategies demonstrated by a species or population of concern are unlikely to achieve recovery objectives (Roni and Beechie 2013). In Hood Canal, Admiralty Inlet, and the Strait of Juan de Fuca (SJF), WA, there are two sympatric chum salmon (*Oncorhynchus keta*) populations with separate life history types based on spawn timing: summer and fall. These two populations are genetically distinct enough to warrant separate Evolutionarily Significant Unit (ESUs) designations. Despite years of research documenting adult migration timing and habitat use patterns of chum salmon in Hood Canal, differences in juvenile nearshore estuarine habitat use between the two sympatric ESUs remain unknown due to the identical appearance of chum fry in the field and previously insufficient genetic identification techniques (Fresh 2006; HCCC 2014). This data gap—common to the juvenile life-history stage of seasonal salmon runs—limits the ability of resource managers to effectively prioritize habitat protection and restoration opportunities that may be critical to the recovery of Endangered Species Act (ESA)-listed summer chum salmon.

Chum salmon are a species of Pacific salmon ranging from California to the Arctic in North America and from Korea to the Arctic in Asia (Salo 1991). Chum salmon are anadromous, utilizing fluvial habitats as juveniles for a brief period after hatching from the egg, migrating to the marine environment for growth, and returning to fresh water to spawn as adults at ages 3-5. All chum are semelparous, meaning that they die after spawning. Their ability to precisely return and identify natal freshwater habitats is achieved through the process of homing, in which salmon utilize olfactory senses and memory imprinting to detect chemical cues of their stream reach of origin (Quinn 2005). Chum are the third most abundant Pacific salmon species in North America, accounting for approximately 15% of annual commercial salmon landings in the United States (NOAA 2014). They play a major role in commercial, tribal, and recreational fisheries across North America, contributing millions of dollars to U.S and Canadian economies and supporting various indigenous communities of the continent. Chum are widely considered a keystone species, shaping their surrounding ecosystem as a predator of smaller fishes and invertebrates, prey for various mammals and birds, and a substantial source of marine derived nutrients for nutrient poor watersheds and associated riparian zones (Willson and Halupka 1995).

Nearshore estuarine habitats—shallow intertidal and subtidal waters adjacent to estuarine shorelines—are critical nursery grounds for juvenile chum salmon preparing for survival in open waters of the Pacific Ocean (Salo 1991; Farley et al. 2007; Young 2009). Apart from Chinook salmon (*O. tshawytscha*), no other salmon species utilizes the estuary more extensively than juvenile chum (Salo 1991). Once emerged from the gravel as fry, chum salmon quickly migrate to shallow nearshore habitats to seek food resources for growth, adjust osmoregulatory capacity, and avoid predation (Salo 1991; Quinn 2005). During this vulnerable life-history stage, individual chum salmon fry typically occupy the estuary for a period of 1-4 weeks reaching critical size requirements for survival in the Pacific Ocean as smolts and sub-adults (Healey 1982; Whitmus 1985; Shreffler et al. 1990).

Estuarine habitat use by chum salmon depends on fish size, ecology, environmental variables, and habitat characteristics. After leaving the freshwater environment, chum salmon fry inhabit brackish, nearshore waters and feed upon abundant harpacticoid copepods and gammarid amphipods (Cooney et al. 1978; Simenstad et al. 1982). High input of organic matter from freshwater systems in combination with the presence of wetland and intertidal habitats create ideal rearing conditions as organic detritus and living plant matter are converted to forms edible and preferred by salmonid fry (Simenstad et al. 1982). Shallow, turbid, and vegetated conditions of nearshore estuarine habitats (frequently consisting of networks of eelgrass and kelp) provide shelter and protection from larger predators at a vulnerable life-history stage (Quinn 2005; Young 2009). With rapid growth and decline in the abundance of epibenthic invertebrates within the nearshore environment due to seasonal trends and fish predation, chum salmon migrate offshore to deeper and more saline estuarine waters (Simenstad and Salo 1982; Wissmar and Simenstad 1988). This commonly occurs at a size range of 45-60 mm fork length (Cooney et al. 1978; Simenstad et al. 1982). These juveniles can better escape predators and access larger, preferred neritic prey. Reaching progressively greater sizes, chum salmon migrate farther offshore and to greater depths, eventually exiting the estuarine environment for the North Pacific Ocean.

While salmonid habitat use is often explained by fish size, ecology, and the environment, individual populations of a given species frequently demonstrate diverse life-history strategies and exhibit differential use of habitats (differing or varying habitat use patterns according to circumstances or relevant factors); this contributes toward variance in growth, survival, and abundance (Quinn 2005).

Throughout time, anadromy and homing—which drive temporal and spatial isolation—have resulted in adaptation and evolution of genetically distinct populations which take advantage of unique environmental and ecological conditions to survive and co-exist with competing salmonid populations (Quinn 2005). For example, Chinook salmon exhibit a diverse array of life-history strategies and habitat use patterns that are controlled, in part, by genetics (Waples et al. 2004). “Stream-type” Chinook salmon are adapted to colder, less productive, upriver conditions of a watershed. Juveniles originating from these upriver habitats generally remain in the freshwater environment for a year prior to their migration downstream. These fish utilize the estuary minimally, exiting the nearshore for the marine environment rapidly. In contrast, “ocean-type” populations are adapted to warmer, more productive conditions at lower elevations of a watershed. Juveniles of these populations often spend only a period of weeks to a month in freshwater prior to migrating to the estuary (Narum et al. 2004). Use of nearshore estuarine habitats for “ocean-type” Chinook is extensive, with individuals residing in brackish waters for far longer than their “stream-type” counterparts as they strive to reach critical size requirements for survival at sea (Quinn 2005). These unique salmon populations, and thousands of other genetically distinct populations of Chinook, chum, sockeye (*O. nerka*), and coho (*O. kisutch*) across the North Pacific, have taken advantage of a strategic ecological niche that has enabled them to survive, adapt, evolve, and co-exist throughout varied environmental and ecological conditions—a phenomenon known as the portfolio effect (Quinn 2005; Schindler et al. 2010; Simmons et al. 2013). Within and between watersheds, genetically distinct salmon populations frequently demonstrate locally-adapted life-history strategies and differential freshwater, estuarine, and marine habitat use patterns.

In Hood Canal, Admiralty Inlet, and SJF, WA there are two seasonal ESUs of chum salmon (Tynan 1997). The summer run ESU (consisting of genetically distinct populations from Hood Canal and SJF) spawns from late-August through mid-October; the fall run ESU spawns in late October through early January. Summer chum salmon have evolved to spawn shortly after entering the freshwater environment in the lowest reaches of natal streams, where they are physically confined by low flow conditions (Koski 1975; Tynan 1997). In contrast, fall chum salmon generally spawn in higher stream reaches which become accessible in later months when flows are greater. With an earlier spawning period, summer chum gain the advantage of advanced embryonic development prior to the onset of low water temperatures and avoidance of high water levels during spawning and early incubation (Koski 1975; Tynan 1997). As a result, eggs of the summer population may hatch before the fall population, causing an earlier period of winter entry into the estuarine environment. It is hypothesized that differences in spawn timing and estuarine emergence between the two ESUs may act to expand the portfolio effect and improve overall survival for the chum species, giving the summer ESU a competitive advantage over the fall ESU in some years (and vice versa), depending on environmental conditions which impact food availability in the nearshore and survival at sea (Tynan 1997; Schindler et al. 2010).

Due to differences in spawn timing and emergence from the gravel, juvenile summer and fall chum exhibit a bi-model pattern of nearshore estuarine occupancy (Bax 1983; Tynan 1997). Nevertheless, there is considerable overlap of residency within Hood Canal and SJF for the two ESUs and they are indistinguishable, making potential distinctions in habitat use, juvenile abundance, and spatial distribution challenging to assess (Tynan 1997). While individuals from both ESUs commonly reside in the estuary for 1-4 weeks, summer chum occupy the estuary from late-December through early-May; fall chum occupy the estuary from late-February through June (Tynan 1997; WFC 2017). Although extensive research was performed from the late 1970s through the 2000s documenting estuarine residence of the chum salmon species within Hood Canal, no study to date has assessed possible differences between juvenile habitat use patterns of the two ESUs (Simenstad 1977; Bax 1983; Whitmus 1985; Todd et al. 2006; Fresh 2006; SAIC 2006; Bhuthimethee et al. 2009; HCCC 2014). Considering differences in evolutionary history, juvenile emergence timing, and nearshore ecosystem conditions, some aspects of habitat use may differ between the two ESUs (Simenstad et al. 1980; Fresh 2006).

In the mid-1990s', adult returns for the summer chum ESU dropped to all-time lows in Hood Canal and SJF, prompting concern of extinction (Tynan 1997). In this period, summer chum were extirpated from various watersheds of the region including the Dewatto River, the Tahuya River, the Skokomish River, Big Beef Creek, Finch Creek, Anderson Creek, and Chimacum Creek (Brewer et al 2005). Habitat loss, overharvest, hatchery interactions, and climatic conditions were cited as leading causes of decline (Ames et al. 2000). Emergency measures were taken to reverse the decline of the ESU including integrated hatchery supplementation, reintroduction, and harvest restrictions (Tynan 1997). With the ESA-listing of summer chum in 1999, habitat restoration and responsible hatchery management strategies were initiated to assist the recovery of the ESU (Brewer et al. 2005; NOAA 2007). Conservation hatchery efforts successfully re-established populations in the Dewatto, the Tahuya, the Skokomish, Big Beef, and Chimacum watersheds—a rare achievement in the history of hatchery management (Withler 1982).

Habitat restoration projects were undertaken in the 2000s to improve fish access and increase the quality and quantity of chum salmon spawning habitats (HCCC 2017). With the majority of planned spawning habitat restoration projects completed in the freshwater environment, attention is now being drawn toward restoration of the estuarine nearshore of Hood Canal and SJF where only 22% of historical tidal wetland habitats associated with stream-delta and spit/marsh habitat complexes remain functional, with the rest being moderately impaired, severely impaired, or lost (Todd et al. 2006). Nevertheless, major data gaps in juvenile habitat use and spatial distribution remain for the summer chum ESU throughout the entirety of their estuarine extent, limiting the ability of resource managers to effectively prioritize habitat protection and restoration opportunities specific to the recovery of summer chum (Tynan 1997; Pacific Estuarine Research Society 2004; Todd et al. 2006; NMFS 2012).

1.2 Previous Wild Fish Conservancy Research in Hood Canal

To address data gaps in juvenile chum salmon nearshore habitat use and spatial distribution, the non-profit Wild Fish Conservancy (WFC) conducted a pilot study in limited portions of the Hood Canal nearshore from 2012-2013. Primarily, this pilot study was intended to determine the feasibility of a method to genetically and statistically distinguish between juvenile summer and fall chum salmon to enable evaluation of ESU-specific habitat use and spatial distribution in the estuarine nearshore environment (WFC 2014). This study expanded upon work completed by Todd et al. (2006) which inventoried and documented many of the nearshore features that would likely be targeted for restoration or protection in the region. The results of the WFC pilot study indicated that statistical models incorporating genetic information could be constructed to retrospectively distinguish the two ESUs based upon fork length at a given time of year (WFC 2014).

Improving upon the precision of the 2012-2013 genetic modeling efforts and filling data gaps in juvenile chum salmon habitat use in understudied regions, WFC expanded the pilot study to encompass the entirety of Hood Canal and the SJF nearshore in 2016-2017. Tissue samples were collected for DNA analysis from a subsample of juvenile chum salmon specimens (n = 844) during numerically assigned bi-monthly sampling periods from January through June. Genetic analyses were performed at the Molecular Genetics Lab of Washington Department of Fish and Wildlife. Juvenile chum salmon samples were successfully assigned (n = 344) to a chum salmon genetic baseline that included summer and fall chum salmon populations from Hood Canal. Assignment tests (with a threshold 80% probability) were used to calculate likelihoods that chum salmon juveniles originated in each of the chum salmon populations in the baseline.

The chum salmon juveniles genotyped were roughly 36% summer-run (n = 129) and 58% fall-run (n = 215); three were unassigned because they had nearly equal likelihoods of coming from summer or fall run populations. The summer-run juveniles out-migrated earlier than fall-run, with summer-run peaking in the first half of March and fall-run peaking in the second half of March (Figure 1-1). Samples obtained from January to mid-February were nearly all summer chum with the exception of one genetic assignment to the fall-run during the 2nd week of February (WFC 2017).

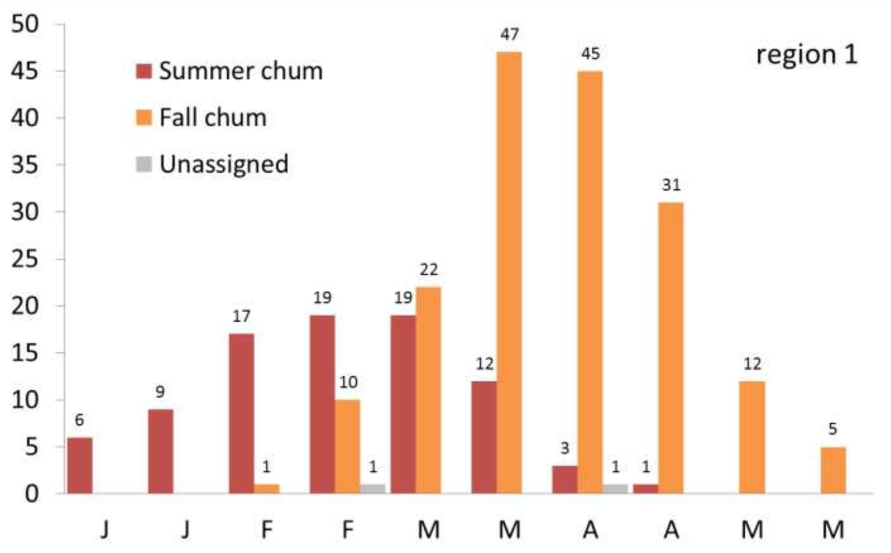

Figure 1-1. Histogram showing the number of summer-run and fall-run chum salmon juveniles genotyped per sampling period in Hood Canal (region 1). The unassigned juveniles were equally likely to be summer or fall-run.

The results of the genetic assignments were used to develop Bayesian logistic regressions to estimate the probability of juvenile chum being from summer or fall populations based upon fork length and bi-monthly period of sampling January through May (Figure 1-2). Chum salmon juveniles captured in the estuary from bi-monthly sampling period 1 (beginning of January) to the beginning of sampling period 4 (mid-February) appeared to be overwhelmingly of summer-run origin (WFC 2017; Small et al. 2017; Frierson et al. 2017). After mid-February, the likelihood of classification to the summer run was driven by fork-length, with larger sized chum having a greater likelihood of summer-run classification than those of the smaller size-class. Overall, these modeling results (incorporating data gathered by Frierson et al. (2017) from WDFW) provided a means to use capture date and fork length to retrospectively classify juvenile chum salmon catch in the Hood Canal nearshore environment, therefore enabling evaluation of differential habitat use preferences and spatial distribution between chum salmon ESUs. While focusing primarily on genetic tissue collection from 2016-2017, evaluation of habitat use at a coarse-scale suggested chum salmon preference for pocket-like estuaries and deltas relative to barrier and bluff backed beaches in both 2016 and 2017 (Figure 1-3).

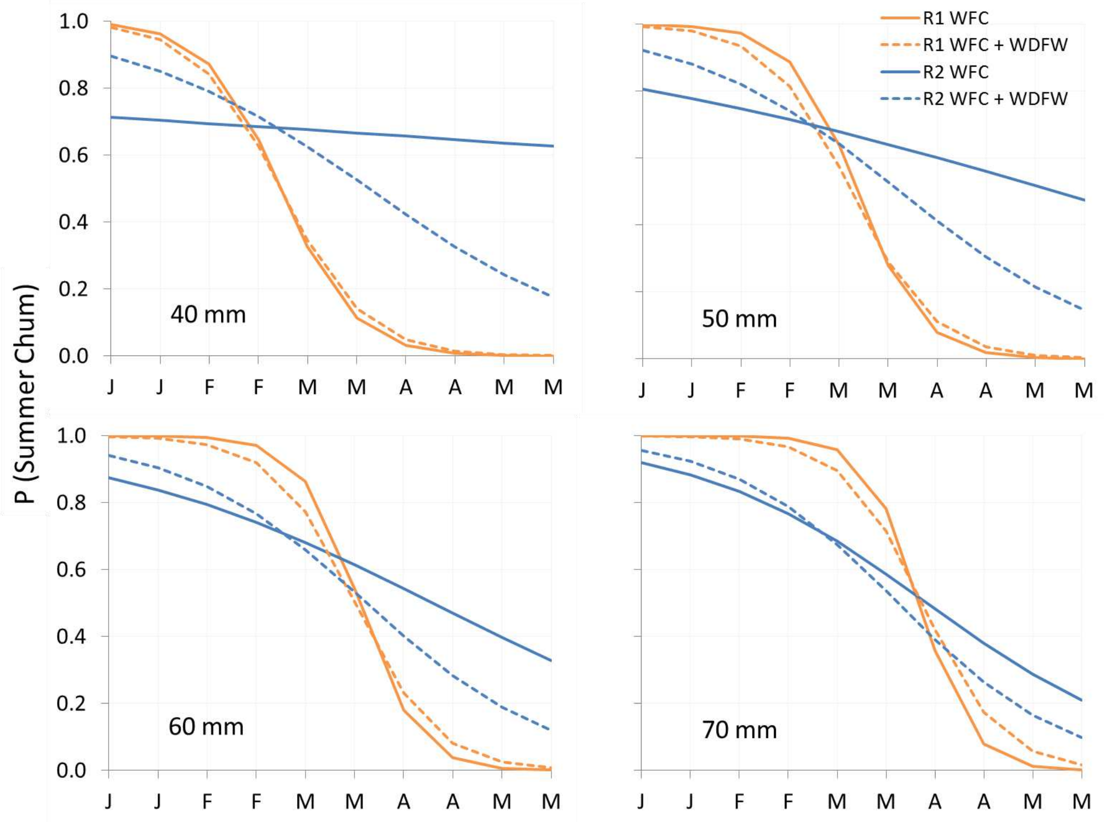

Figure 1-2. Posterior modes of the probabilities of assignment to a summer chum population for fork lengths of 40, 50, 60, and 70 mm for region 1 (Hood Canal), region 2 (Admiralty Inlet and SJF), and data set (WFC 2017; WFC + WDFW 2017).

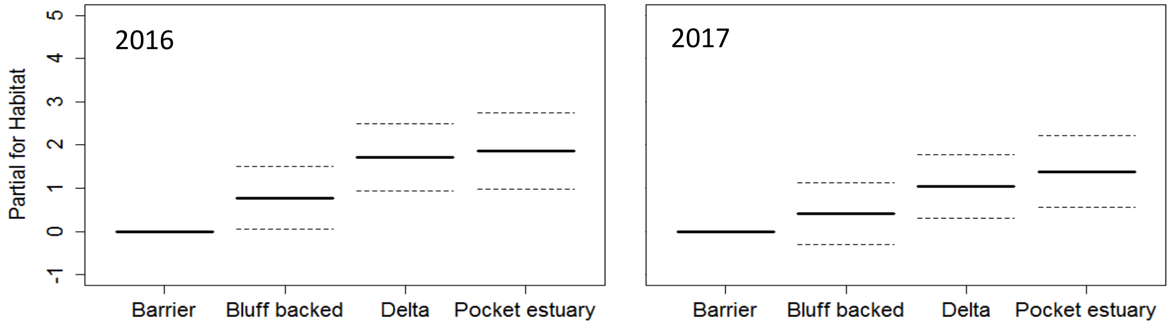

Figure 1-3. Log normalized density (fish per hectare) of chum salmon ± SE for habitat covariates throughout Hood Canal, 2016 and 2017.

1.3 Objectives

To better distinguish habitat use preferences by summer and fall chum salmon in the nearshore estuarine environment, WFC conducted an intensive nearshore habitat use assessment study focusing on the Dabob Bay region of Hood Canal during the juvenile outmigration in 2018. Specifically, objectives were to identify the habitat and environmental variables that best explain juvenile summer and fall chum salmon relative abundance and occurrence in the nearshore. Through weekly beach seine sampling to capture juvenile chum salmon at eight distinct shoreline types within three subregions, chum salmon were counted and measured (fork length (mm)). Catch was speciated and retrospectively assigned to summer and fall ESUs based upon WFC's Bayesian regression modeling (WFC 2017). Utilizing generalized linear models (GLM), WFC strived to answer the following questions:

1) Do summer chum exhibit habitat preference within the Hood Canal nearshore environment?

2) Do summer chum demonstrate equivalent use of nearshore habitats relative to fall chum?

3) What environmental and habitat variables best explain relative abundance and occurrence of summer and fall chum salmon in the nearshore estuarine environment?

Answering these three questions addresses fundamental data gaps about salmon use of nearshore habitats that may improve the effectiveness of habitat protection and restoration efforts.

1.4 Research Hypotheses

Null-Hypotheses

- H_{01}) Summer chum relative abundance and occurrence is statistically equivalent amongst shoreline types at the 0.05 significance level.
- H_{02}) Environmental and habitat variables do not explain relative abundance of summer and fall chum salmon at the 0.05 significance level ($\beta x_i = 0$).

Alternative Hypotheses

- H_{a1}) Summer chum relative abundance and occurrence differs amongst shoreline types at the 0.05 significance level, indicating habitat use preferences.
- H_{a2}) Environmental and habitat variables explain relative abundance of summer and fall chum salmon at the 0.05 significance level ($\beta x_i \neq 0$).

Methods

2.1 Study Region in 2018

Carved by glacial processes at the tail end of the Pleistocene, Hood Canal is a narrow fjord extending approximately 100 kilometers at the westernmost reach of the Puget Sound in Washington State. The waterway divides the Olympic and Kitsap peninsulas with over 385 square kilometers of surface area and 21 cubic kilometers of water. Stretching southwest from its entrance near Tala Point, Hood Canal changes course abruptly to the northeast at Union for its final 20 kilometers; the fjord eventually ends in Lynch Cove. Hood Canal is a drainage for numerous freshwater sources from the Olympic Mountains including the Skokomish, Dosewallips, Duckabush, Big Quilcene, and Hamma Hamma rivers. In addition, many smaller rivers and streams—including Stavis Creek and Big Beef Creek—flow westerly from the Kitsap Peninsula making Hood Canal an important estuary for a number of wild salmonid stocks.

To better understand habitat preferences of summer chum salmon, WFC’s 2018 Hood Canal nearshore assessment study focused on the Dabob Bay region of Hood Canal. This study area (Figure 2-1) was selected for two important reasons: 1) it is the most productive sub-region of Hood Canal for summer chum salmon (providing sufficient sample size to assess habitat use preferences); and 2) it hosts the greatest diversity of habitat in a small and accessible area. Dabob Bay includes three major rivers with the greatest returns of summer chum: the Big Quilcene River, the Dosewallips River, and the Duckabush River. The selected study region also hosts a variety of smaller natal and non-natal systems such as Anderson Creek, Big Beef Creek, Fulton Creek, Stavis Creek, Tarboo Creek, and the Little Quilcene River. Selection of this diverse, yet confined study region provided a means to control for a variety of environmental and ecological factors that may be relevant but challenging to quantify over a broader study area (including basin to basin differences in egg-smolt survival, disease, and predatory effects).

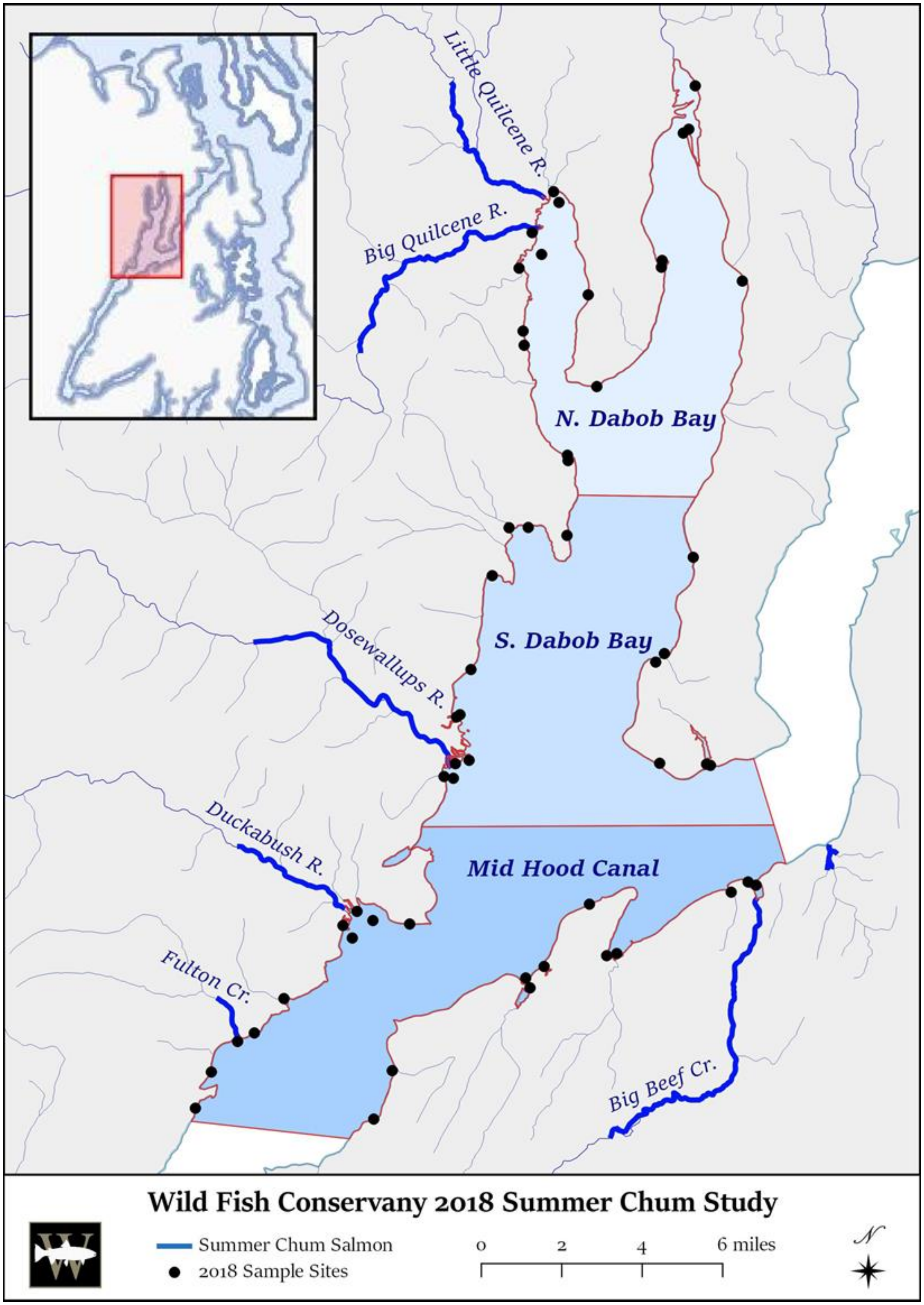

Figure 2-1. Study region, subregions, and sampling sites for the 2018 Hood Canal chum salmon habitat use assessment project.

2.2 Stratifying Variables

Pacific salmonid populations have evolved to take advantage of specific niches in time and space which maximize survival and fitness over generations (Quinn 2005). As a result, juvenile salmonid nearshore habitat use frequently varies with time, space, and habitat type (Zhang and Beamish 2000; Beamer et al. 2003). Similar to the work of Beamer et al. (2012), the following stratifying variables were selected for use within WFC's nearshore assessment of Dabob Bay:

Time

The sampling period was informed by prior literature documenting the early emergence of summer chum salmon from the gravel in the month of December and results of WFC's genetic analysis which indicated that summer chum mostly exit the nearshore environment by mid-April (Tynan 1996; Small 2016; WFC 2017). As a result, sampling occurred on a weekly basis from January through April of 2018 to capture the seasonal curve from absence to presence, and again to absence for the summer chum stock.

Space

Three subregions were defined within the study area to reflect logical geographic separations amongst spawning populations and hypothesized migration pathways (Figure 2-1). Each subregion represents a unique and complete subset of nearshore habitat within the study region. The North Dabob Bay subregion is fed by the Big Quilcene River, the Little Quilcene River, and Tarboo Creek; South Dabob Bay is fed by the Dosewallips River and Spencer Creek; the mid Hood Canal subregion is fed by the Duckabush River, Big Beef Creek, Stavis Creek, and Fulton Creek (Figure 2-1).

Habitat-type

The shoreline types assessed in this study are closely linked in geomorphology and hydrology with habitat features tending to show strong interdependence (McBride et al. 2009, Beamer and Fresh 2012). The groupings are similar to those defined by Shipman (2008) with minor modifications to reflect key habitat components within Hood Canal that may be relevant to juvenile salmonid use. Of twelve Shipman (2008) habitat types defined throughout Puget Sound, this study focused on the following eight based upon the presence of each habitat type within the study region, access, and logistical constraints:

- **Bluff Backed Beach** – Open shorelines where the upland rises directly landward of the beach forming both high, steep cliffs, as well as more gentle slopes. They are formed as eroding shoreline advances into upland areas developing an erosional platform that underlies the beach with a low-tide terrace.

- **Barrier Beach** – Open beaches which are formed by the transport and deposition of sand and gravel seaward of the original coastline. They consist of a relatively continuous ridge of sand and gravel rising a small distance above high tide. Barriers often form across embayments in the coastline, at distinct bends in the shoreline, or where sediment transported alongshore converges from two directions.

- **Pocket Beach** – Open beaches which are typically compartmentalized between rocky headlands and promontories. They are primarily comprised of coarse sediment. This shore form is generally oriented perpendicular to the major direction of wave approach (swash-aligned).

- **Barrier Lagoon** - Tidal embayments that lack a significant freshwater source such as a perennial stream.

- **Barrier Estuary** – Estuarine embayments with a significant freshwater source which are partially isolated from open marine water by a barrier beach and with tidal exchange occurring through a narrow entrance channel (Shipman 2008).

- **River Delta Channel** - A distributary or blind channel through a delta's alluvial fan.

- **River Delta Alluvial Fan** - The shallow fan of a delta formed by deposition of sediment carried by a large river system; often characterized by fine sediments.

- **Stream Delta Alluvial Fan** - The shallow fan of a delta formed by deposition of sediment carried by a small river or stream system.

2.3 Field Protocol

Sample sites were selected to encompass the range of nearshore habitat types present in Hood Canal and based on logistical considerations (Figure 2-1). Of the 8 selected habitat units, 56 total sites (7 of each habitat unit) were designated within the study region. Contingent upon weather conditions, approximately 4-6 representations of each habitat unit were sampled weekly through a stratified-random design. At each site, four samples were gathered to account for set-to-set variation in catch. Sets occurred at least 20 m apart from one another within a habitat unit and at least 10 min apart in time. A small mesh beach seine was used in this study to sample all nearshore habitats. The seine was 80 ft. (24.4 m) long by 6 ft. (1.8m) deep and constructed with 1/8 in. (0.3 cm) knotless nylon mesh (Figure 2-2). All sets were performed in "round haul" fashion by fixing one end of the net on the beach, with the rest of the net deployed from a floating tub that was pulled while wading along the shoreline. Standardizing sampling effort through use of only one size of beach seine likely reduced calibration error and attenuation biases that may be encountered from common beach seining methods previously employed in Puget Sound where two separate sizes of seine were generally employed (Simenstad 1977; Bax 1983; Whitmus 1985; WFC 2007; Beamer et al. 2012). Furthermore, use of the smaller seine helped to focus the study effort on a smaller size class of fish, controlling for well-known effects of fish size on habitat use patterns (Healey 1982; Salo 1991; Quinn 2005).

During each sampling event, all fish brought to hand were enumerated and identified to species (Figure 2-3). For Chinook and coho salmon, a determination of hatchery vs. wild origin was made based on the presence of an adipose fin (hatchery-origin chum salmon are not ad-clipped prior to release and cannot be distinguished from wild chum in the field). The first 40 individuals of chum and 20 individuals of other salmonid and forage fish species captured at a site were measured for fork length, enabling retrospective chum salmon ESU classification by date of capture and length (WFC 2017). Data for following continuous and categorical variables were collected at each site visited on a weekly basis: water temperature (ºC; Extech), salinity (ppt; Extech), tide stage (ebb, flood, high-water, low-water), tide height (m), max depth sampled (m), substrate composition (silt, sand, gravel, cobble, bedrock), presence of oyster beds and % coverage, vegetation and % coverage, presence of drifting vegetation (none, present), and wave action (<1 ft., > 1 ft.).

Figure 2-2. Beach seine set performed in January 2018 in the Hood Canal nearshore.

Figure 2-3. Chinook salmon (left) and chum salmon (right) brought to hand by beach seine.

2.4 Sampling Effort

A total of 2,042 beach seine sets were completed at 56 different sites over the four-month study period. The number sets performed within each of the 3 subregions was fairly uniform but varied based on factors such as logistics and access. At the conclusion of the study, 651 sets were performed in the North Dabob Bay subregion, 639 in South Dabob Bay, and 752 in Mid Hood Canal. The number of sets performed at each shoreline type was nearly equivalent by the conclusion of the study (Table 2-1). Similarly, the number of sets performed each week remained fairly consistent throughout the study period, but varied somewhat as a result of foul weather (Table 2-2).

Table 2-1. Number of beach seine sets performed by shoreline type.

Shoreline Type	**# of Sets**
Barrier Beach	255
Barrier Estuary	255
Barrier Lagoon	254
Bluff Backed Beach	262
River Delta Channel	254
River Delta Fan	264
Stream Delta Fan	255
Pocket Beach	243
Total	2042

Table 2-2. Number of beach seine sets performed during each sampling week.

Week	Month	# of Sets
1	Jan	159
2	Jan	104
3	Jan	131
4	Jan	162
5	Feb	168
6	Feb	140
7	Feb	156
8	Feb	163
9	Mar	156
10	Mar	160

11	Mar	159
12	Mar	156
13	Apr	139
14	Apr	89
Total	--	2042

2.5 Retrospective ESU Classification

Chum salmon catch from 2018 was retrospectively classified to summer and fall ESUs based upon fork length and date of capture. WFC's Bayesian regression modeling results were used to inform ESU assignment (Table 1-1). There are obvious limitations to this approach given that each year exhibits unique weather conditions that may accelerate or slow egg incubation and emergence of chum salmon juveniles. As a result, genetic and fork length modeling from prior years may not represent data from other years; only genetic data from every individual during the same year of capture can resolve this uncertainty. Nevertheless, the best available information was used to roughly classify catch to each seasonal population group. Chum salmon data from the first two weeks of March were mostly excluded from the analysis due to the consistency of chum salmon fork length encountered (approximately 40 mm) and the uncertainty of population group assignment for the 40 mm size-class at that specific period of time. Generally, catch of chum salmon fry prior to the end of February was classified as the summer run while catch after mid-March was classified as fall run. Despite the limitations of this approach, uncertainty and attenuation bias in ESU classification (primarily during the periods of late-February and late-March) only has potential to make differences in habitat preference by ESU seem less distinctive; therefore, results of this ESU-specific analysis should be viewed as conservative estimates of habitat preference.

2.6 Statistical Analysis for Nearshore Abundance and Occurrence

Abundance Modeling

Generalized linear modeling (GLM) through the R-platform was used to evaluate the effects of shoreline type on relative chum salmon abundance and to determine the covariates that best explain catch-per-unit-effort (CPUE) within the Hood Canal nearshore environment as a function of space, time, and environmental characteristics (addressing H_{01} and H_{02}) (Kutner et al.

2004). Chum Salmon CPUE represented the response variable. The Poisson distribution (log-link) was used to account for skewness of the data and anticipated multiplicative effects (Mullahy 1986). The backwards-elimination/deletion approach was employed to select the most parsimonious model (Burnham and Anderson 1998). All t-value modeling results were adjusted by the scale parameter to reduce bias from potential overdispersion; coefficients were backtransformed and standard error adjusted utilizing the delta method (Kutner et al. 2004). Spatial, habitat, environmental, and temporal covariates considered for relative abundance analyses are listed in Table 2-3, with interactions between seasonal ESU classification and shoreline type considered for confirmation of seasonal habitat preferences. Significance was determined at the $\alpha \leq 0.05$ level (two-tailed). Barrier beach habitat was used as the base condition (the condition to which other habitats were compared to assess potential differences in use) for input of shoreline type into all GLM models. Association of each covariate with the response variable (positive or negative) was evaluated independently of the regression model on a single-factor basis.

Table 2-3. Descriptors of covariates used in GLM modeling to explain relative abundance and occurrence.

Covariate	**Unit of Measure**	**Description**
Adjacent Vegetation	Categorical	Less than or greater than 25% vegetative cover within a 25 m radius of the beach seine set.
Maximum Sampling Depth	m	Maximum depth sampled at a given site.
Oyster Bed Presence	Categorical	Less than or greater than 25% oyster bed cover within the beach seine set.
Population Weighted Distance	Numerical	Sum of all spawning populations in Hood Canal weighted by the distance of the populations from each sampling site.
Salinity	ppt	Salinity measured one meter below the water surface.

Sampling Week	Week	Week of sampling beginning on the 2nd week of January 2018.
Shoreline Type	Categorical	Estuarine shoreline type (adapted and modified from PSNERP).
Subregion	Categorical	Unique subset of nearshore habitat within the study region based upon salmonid ecology.
Substrate Composition	Categorical	Substrate mixture within the beach seine set (silt, silt/sand, sand, sand/gravel, gravel, gravel/cobble, or cobble).
Tidal Stage	Categorical	Tide stage (ebb, flood, slack) during sampling.
Tide Height	m	Height of tide during sampling.
Vegetation	Categorical	Less than or greater than 25% vegetative cover within the beach seine set.
Water Temperature	ºC	Water temperature measured one meter below the water surface.
Wave Action	Categorical	Less than or greater than 1 ft wave action during the sampling event.

Table 2-3 presents a spatial variable called "population-weighted distance" which was calculated for each study site. This variable describes the distance of a given study site to the natal rivers weighted by the number of summer chum or pink salmon spawning in that basin. This variable utilizes salmon spawners during the prior year as a proxy for the number of juveniles outmigrating during the year of study. The weighted distance of each basin was summed to create a unique value for each study site using the following equation

$$Population\ Weighted\ Distance = \sum all\ sources\ (\frac{P}{D})$$

where D represents the distance of the estuary entrance point to a study site and P represents the abundance of summer chum or pink salmon spawners attributed to an estuary entrance point. For fall chum salmon, this spatial variable was not considered due to significant production of hatchery juveniles which would bias analysis of the data.

Single-Factor Habitat Use and Subregion Analyses

To support GLM relative abundance results and present findings in a more traditional and simplistic manner, chum salmon relative abundance was assessed on a single factor basis by subregion and shoreline type (addressing H_{01}). Abundance by shoreline type and subregion were evaluated separately by species and ESU (informed by results of Bayesian logistic regression modeling based upon genetics, fork length, and date) (WFC 2017). For these single factor analyses, salmon catch was log (x+1) transformed to account for anticipated multiplicative effects and reduce the effects of skew and unequal variance across groups. One-way ANOVA analyses were conducted through GLM in the R-platform (Kutner et al. 2004). These basic analyses were used for other salmonid stocks given that stock-specific abundances were significant enough to warrant such analyses. In all cases, relative abundance was utilized as a proxy for habitat preference, making the assumption that species abundance represents importance to that species.

Occurance and Temporal Habitat Use Modeling

GLM models were constructed through the R-platform to model the probability of detecting chum or pink salmon in Hood Canal nearshore environment as a function of subregion, habitat, and time (addressing H_{01}); models were also developed to determine the primary factors explaining occurrence (Table 2-3) (Kutner et al. 2004). For chum salmon, presence or absence in each set represented the response variable. For pink salmon, set catch was summed for each site visited to provide sufficient successes and failures to enable binary modeling; as a result, the response variable for pink salmon represented presence or absence at a given site. The binomial distribution (logit-link) was used to account for the binary nature of the data (Mullahy 1986). The backwards-elimination/deletion approach was employed to select the most parsimonious model (Burnham and Anderson 1998). All t-value modeling results were adjusted by the scale parameter to reduce bias from potential overdispersion; coefficients were back-transformed and standard error adjusted utilizing the delta method (Kutner et al. 2004). For these binary analyses, significance was determined at the $\alpha \leq 0.05$ level (two-tailed). Association of each covariate with the response variable (positive or negative) was evaluated independently of the regression model on a single-factor basis.

Results

3.1 Chum Salmon (Pooled Summer and Fall Life-Histories)

Total Catch

Over the course of the 2018 study, 102,642 chum salmon fry were captured and released from 2,042 beach seine sets performed. Juvenile chum were present in small numbers in the nearshore environment on the first day of sampling on January 9, suggesting that entrance into the estuary had occurred shortly before initiation of the study. The log transformation of weekly catch (Figure 3-1) was at a minimum during the first week of sampling in early January (Mean = 0.341, CI ($0.081 \leq \widehat{Catch} \leq 0.601$) = 0.95)) and peaked during the final week of sampling (week 14) in mid-April (Mean = 4.281, (CI ($3.933 \leq \widehat{Catch} \leq 4.629$) = 0.95)). As in prior years of sampling, chum salmon catch likely would have declined at the end of April and further into the spring season with the conclusion of the wild chum emergence and hatchery releases.

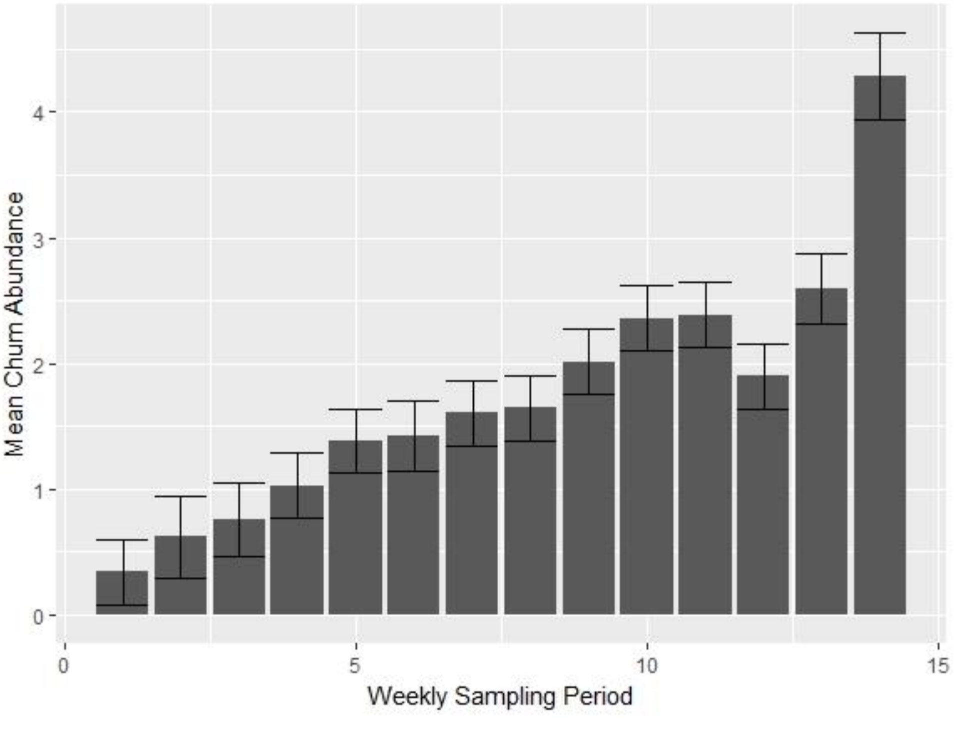

Figure 3-1. Mean log transformed chum salmon catch by week and the 95% confidence interval.

Mean fork length increased slightly throughout the study period from 37.59 mm ($\widehat{SE}$ = 0.24) in week 1 (early-January) to 41.79 mm ($\widehat{SE}$ = 0.067) during week 14 (late-April), but remained relatively consistent (Min = 26 mm; Max = 72 mm). Consistency in fork lengths observed throughout the study indicates that the data collection methodology was effective primarily for summer and fall chum salmon fry in the nearshore (Figure 3-2). This suggests that the effects of fish size on habitat use have mostly been controlled for through the study design and sampling methodology.

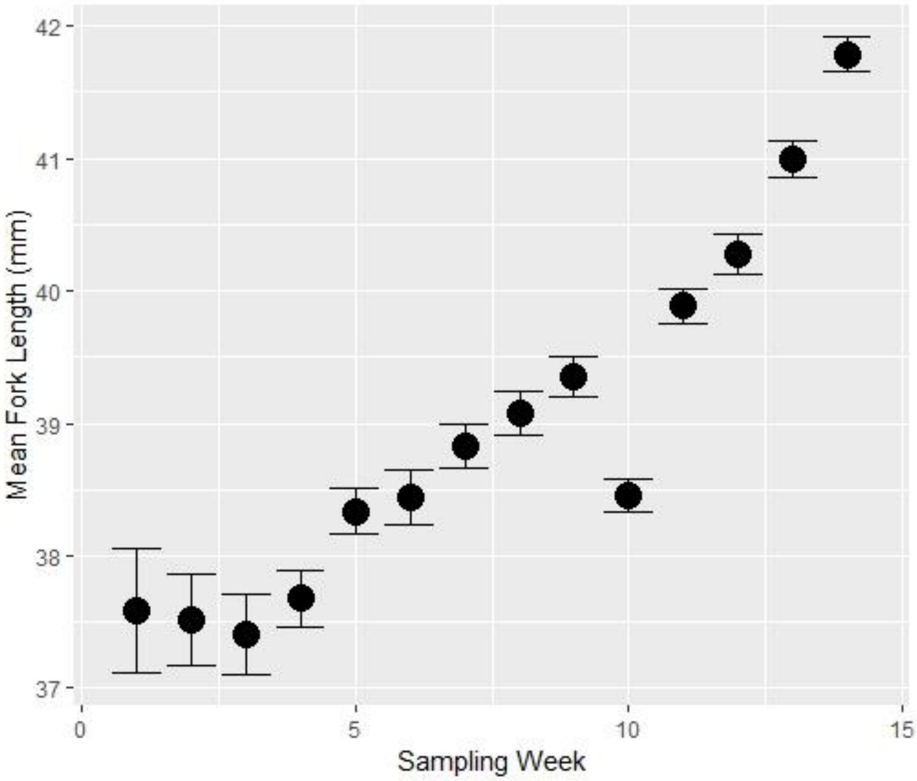

Figure 3-2. Mean chum salmon fork length (mm) by week and the 95% confidence interval.

Sub-Regional Relative Abundance Analysis

Chum salmon catch varied by sub-region on a single factor basis ($P\ (|F_{2,2039}| \geq 4.579) = 0.010$) (Figure 3-3). Log transformed catch was greatest in north Dabob Bay (Mean = 1.813, CI

($1.670 \leq \widehat{Catch} \leq 1.957$) = 0.95)), followed by south Dabob Bay (Mean = 1.748, CI ($1.603 \leq \widehat{Catch} \leq 1.893$) = 0.95)), and mid-Hood Canal (Mean = 1.527, CI ($1.393 \leq \widehat{Catch} \leq 1.661$) = 0.95)). Chum salmon relative abundances are shown at a site-specific level throughout the study region in Figure 3-4.

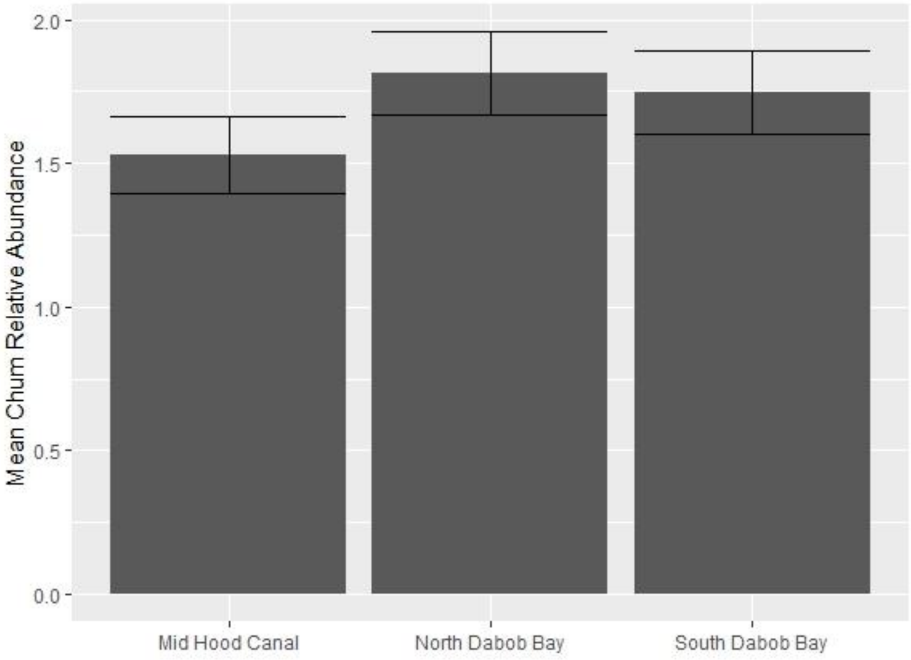

Figure 3-3. Mean log transformed chum salmon catch by sub-region and the 95% confidence interval.

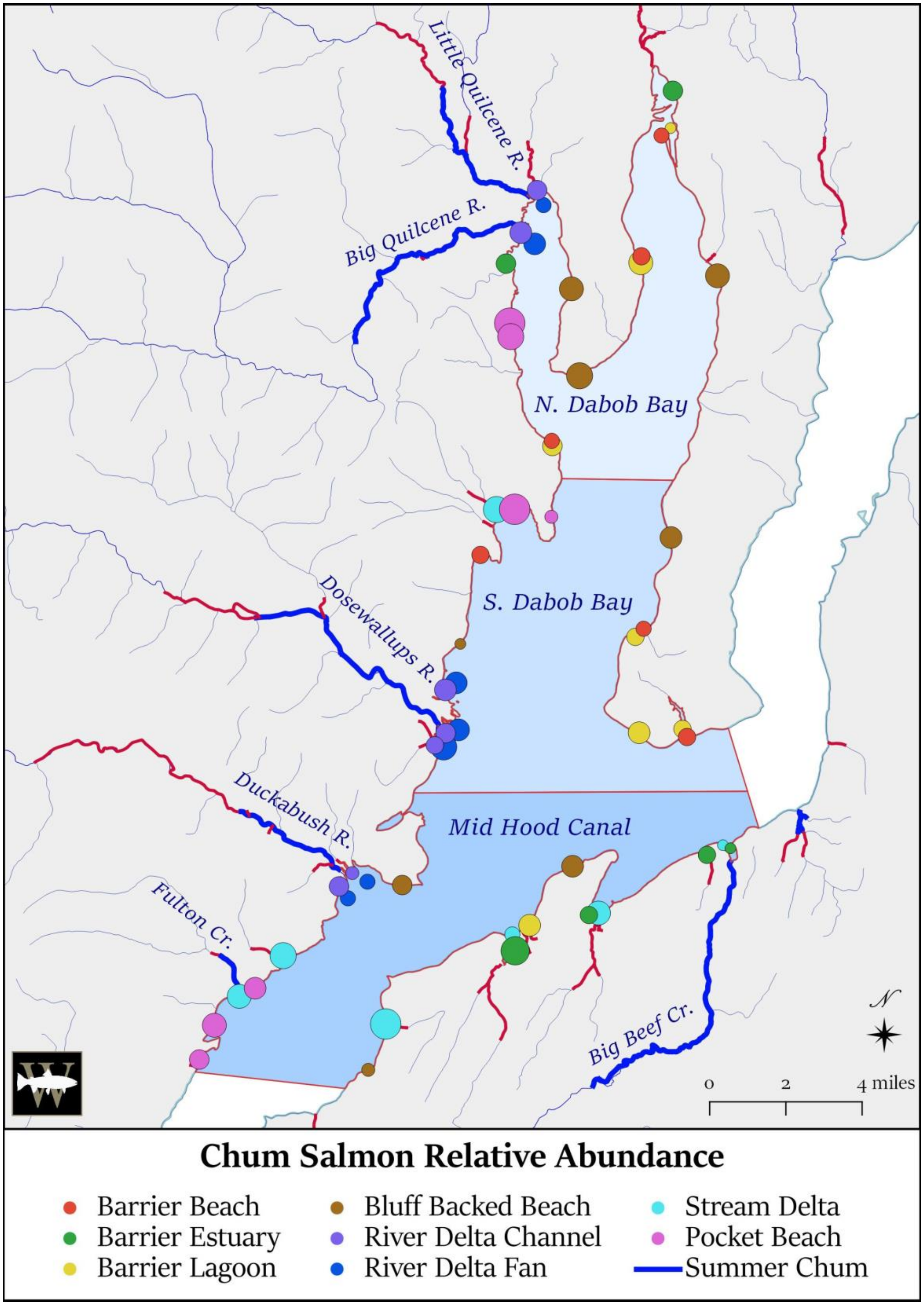

Figure 3-4. Mean log transformed chum salmon relative abundance is represented by plot size at each site sampled within the study region.

Single-Factor Habitat Use Analysis

Analyzed through one-way ANOVA, the chum salmon species exhibited statistically significant habitat preferences ($P\ (|F| \geq 10.091) < 0.001$). Chum salmon relative abundance (Figure 3-5) was greatest in pocket beach habitats ($P\ (|t| \geq 7.660) < 0.001$, Mean = 2.434, (CI ($2.202 \leq \widehat{Catch} \leq 2.666$) = 0.95)), followed by barrier lagoons ($P\ (|t| \geq 4.631) < 0.001$, Mean = 1.924, (CI ($1.696 \leq \widehat{Catch} \leq 2.151$) = 0.95)), bluff backed beaches ($P\ (|t| \geq 3.451) < 0.001$, Mean = 1.726, (CI ($1.502 \leq \widehat{Catch} \leq 1.950$) = 0.95)), and stream deltas ($P\ (|t| \geq 3.221) = 0.001$, Mean = 1.692, (CI ($1.465 \leq \widehat{Catch} \leq 1.919$) = 0.95)). Relative abundance was lowest at the base condition, barrier beach habitat (Mean = 1.165, (CI ($0.938 \leq \widehat{Catch} \leq 1.392$) = 0.95)).

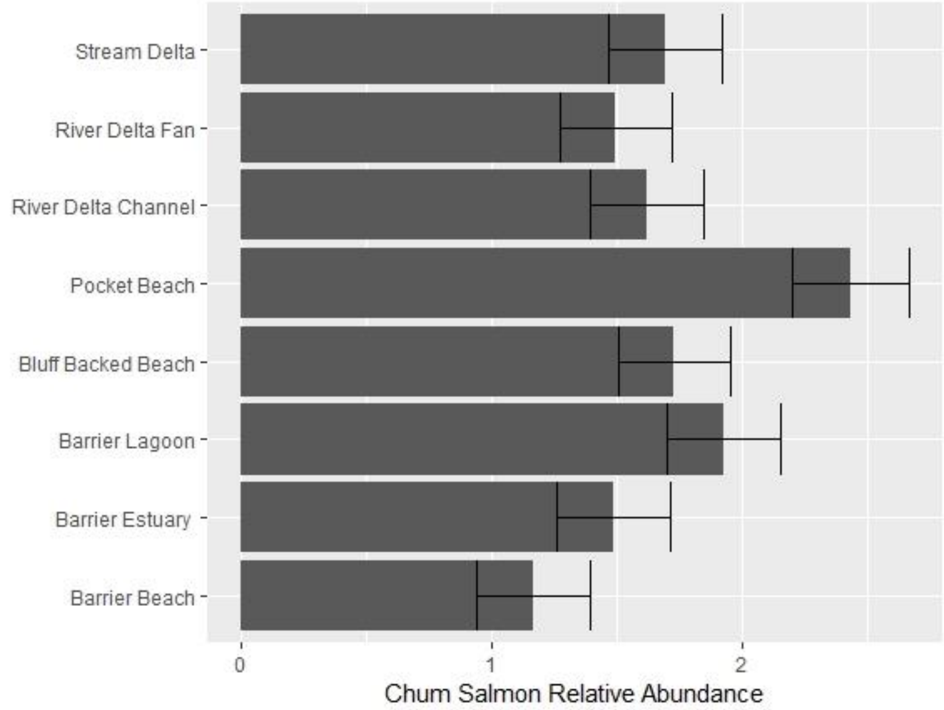

Figure 3-5. Mean log transformed chum salmon relative abundance at each shoreline type and the 95% confidence interval.

Occurrence Modeling

To explain occurrence of chum salmon fry in the Hood Canal nearshore environment, multiple GLM regression (Binomial, logit-link) was used for the sets performed (n = 2042) throughout the 2018 study period. Considering the covariates listed in Table 2-3 (with the exception of population weighted distance due to the mixed natural/hatchery origin of this species in Hood Canal), the following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Occurrence} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{Depth}) + \beta_3\,(\text{Tide Height}) + \beta_4\,(\text{factor(Shoreline Type)}) + \varepsilon$$

Modeling through the R-platform, week was the greatest predictor of chum salmon occurrence ($P\ (|F_{1,2029}| \geq 138.087) < 0.001$), followed by shoreline type ($P\ (|F_{7,2029}| \geq 5.001) < 0.001$), depth ($P\ (|F_{1,2029}| \geq 6.717) = 0.010$), and tide height ($P\ (|F_{1,2029}| \geq 4.674) = 0.031$) (Table 3-1). Of the assessed shoreline types, pocket beach ($P\ (|t| \geq 4.632) < 0.001$) and barrier lagoon habitats ($P\ (|t| \geq 3.560) < 0.001$) had significant impacts on chum salmon occurrence at the $P \leq 0.05$ level relative to the base condition (barrier beach).

Table 3-1. Summary of factors from the multiple regression model used to explain occurrence of juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	*P*-value	*F*-value
Week	0.000	138.087
Shoreline Type	0.000	5.001
Depth	0.010	6.717
Tide Height	0.031	4.674

Relative Abundance Modeling

Multiple GLM regression (Poisson, log-link) was used to explain relative abundance of chum salmon fry in the Hood Canal nearshore environment for the sets performed in 2018. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Catch} = \beta_0 + \beta_1 \text{(Week)} + \beta_2 \text{(Depth)} + \beta_3 \text{(factor(Tidal Stage))} + \beta_4 \text{(Salinity)} + \beta_5 \text{(Temperature)} + \beta_6 \text{(factor(Substrate))} + \beta_7 \text{(factor(Shoreline Type))} + \beta_8 \text{(factor(Subregion))} + \varepsilon$$

Week (P ($|F_{1,1857}| \geq 178.529$) < 0.001), depth ($P$ ($|F_{1,1857}| \geq 14.812$) < 0.001), tidal stage (P ($|F_{2,1857}| \geq 17.884$) < 0.001), salinity (P ($|F_{1,1857}| \geq 3.830$) = 0.050), temperature (P ($|F_{1,1857}| \geq 65.802$) < 0.001), substrate (P ($|F_{6,1857}| \geq 10.894$) < 0.001), shoreline type (P ($|F_{7,1857}| \geq 36.856$) < 0.001), and subregion (P ($|F_{2,1857}| \geq 20.698$) < 0.001) all explained relative abundance of juvenile chum fry catch in the nearshore environment. Each partial regression coefficient is described in order of statistical significance in Table 3-2. Of the covariates considered through the backwards-elimination/deletion approach, only substrate (cobble) (P ($|t| \geq 1.353$) = 0.176), substrate (silt/sand) (P ($|t| \geq -1.191$) = 0.234), substrate (sand) (P ($|t| \geq -0.898$) = 0.370), and sub-region (Dabob South) (P ($|t| \geq 0.397$) = 0.692) were insignificant at the $P \leq 0.05$ significance level through last-entry analysis. Overall, these results indicate that juvenile chum salmon fry relative abundance in the nearshore environment is influenced by space, time, habitat, and a suite of environmental variables.

Table 3-2. Summary of covariates from the multiple regression model used to explain relative abundance of juvenile chum salmon fry in the nearshore, ranked by P-value for last entry into the model.

Independent Variable	***P*-value**	***t*-value**	**Coefficient**	$\widehat{SE}$
Week	0.000	11.896	1.276	0.026
Shoreline Type (Pocket Beach)	0.000	11.289	16.728	4.174
Shoreline Type (Stream Delta)	0.000	9.154	10.755	2.791
Temperature	0.000	8.140	1.313	0.044
Shoreline Type (Bluff Backed Beach)	0.000	7.426	6.589	1.673
Shoreline Type (Barrier Estuary)	0.000	7.131	7.491	2.116
Substrate (Gravel)	0.000	5.803	2.554	0.413
Shoreline Type (Delta Fan)	0.000	5.481	4.250	1.122
Tidal Stage (Flood)	0.000	-4.782	0.646	0.059
Sub-Region (Mid-Hood Canal)	0.000	-4.771	0.573	0.067
Shoreline Type (Barrier Lagoon)	0.000	4.534	3.394	0.915
Substrate (Gravel/Cobble)	0.000	4.504	2.366	0.452
Intercept Term	0.000	-4.494	0.140	0.061

Shoreline Type (Delta Channel)	0.000	4.319	3.644	1.091
Depth	0.000	-3.834	0.775	0.052
Substrate (Sand/Gravel)	0.024	2.246	1.394	0.206
Tidal Stage (Slack)	0.046	1.990	1.249	0.140
Salinity	0.048	-1.976	0.986	0.007
Substrate (Cobble)	0.176	1.353	1.372	0.320
Substrate (Silt/Sand)	0.234	-1.191	0.777	0.164
Substrate (Sand)	0.370	-0.898	0.790	0.207
Sub-Region (Dabob South)	0.692	0.397	1.045	0.117

Temporal Habitat Use Modeling

Modeling the probability of detecting chum salmon fry in the Hood Canal nearshore environment based upon habitat and time, the covariates week, shoreline type, subregion, and all interaction terms were considered in a multiple GLM regression (Binomial, logit-link) for the sets performed. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Probability\ of\ Detection} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{factor(Shoreline Type)}) + \beta_3\,(\text{Week}):(\text{factor(Shoreline Type)}) + \varepsilon$$

Of the considered covariates, week ($P\ (|F_{1,2041}| \geq 7.630) = 0.006$), shoreline type ($P\ (|F_{7,2041}| \geq 6.235) < 0.001$), and the interaction between week and shoreline type ($P\ (|F_{7,2041}| \geq 4.589) < 0.001$) explained the probability of detecting juvenile chum fry catch in the nearshore environment. Each partial regression coefficient is described in order of statistical significance in Table 3-3. Figures 3-6 through 3-11 show the probability of detecting juvenile chum fry in each of the studied habitat types relative to the barrier beach control on a set by set basis; intercept and slope treatment effects are shown at the $P \leq 0.10$ significance level. Note that barrier estuaries demonstrated no significant treatment effect on slope or intercept relative to the barrier beach control. Since the probability of detection in barrier estuaries mirrors that of barrier beaches, no additional figure is provided. Overall, these results indicate that the probability of detecting juvenile chum salmon fry in the nearshore environment is influenced significantly by shoreline type and time of year. The data suggest that habitat preferences may be exhibited by seasonal ESU.

Table 3-3. Summary of covariates from the multiple regression model used to explain presence and absence of juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Independent Variable	***P*-value**	***t*-value**	**Coefficient**	$\widehat{SE}$
week:factor(psnrp.classification)delta fan	0.000	4.231	1.311	0.084
Shoreline Type (Delta Fan)	0.000	-3.467	0.173	0.088
Week	0.003	2.715	1.107	0.041
Shoreline Type (Pocket Beach)	0.011	2.276	2.746	1.219
Intercept Term	0.016	-2.151	0.513	0.159
week:factor(psnrp.classification)bluff backed beach	0.019	2.086	1.124	0.063
week:factor(psnrp.classification)delta channel	0.035	1.818	1.108	0.062
Shoreline Type (Barrier Lagoon)	0.053	1.615	2.056	0.918
week:factor(psnrp.classification)midsize delta	0.065	1.516	1.088	0.061
Shoreline Type (Bluff Backed Beach)	0.125	-1.152	0.599	0.266
Shoreline Type (Barrier Estuary)	0.234	0.726	1.377	0.607
Shoreline Type (Delta Channel)	0.278	-0.588	0.769	0.344
Shoreline Type (Midsize Delta)	0.338	-0.419	0.830	0.369
week:factor(psnrp.classification)pocket beach	0.354	-0.373	0.979	0.054
week:factor(psnrp.classification)barrier estuary	0.360	0.358	1.019	0.055
week:factor(psnrp.classification)barrier lagoon	0.597	0.245	1.014	0.056

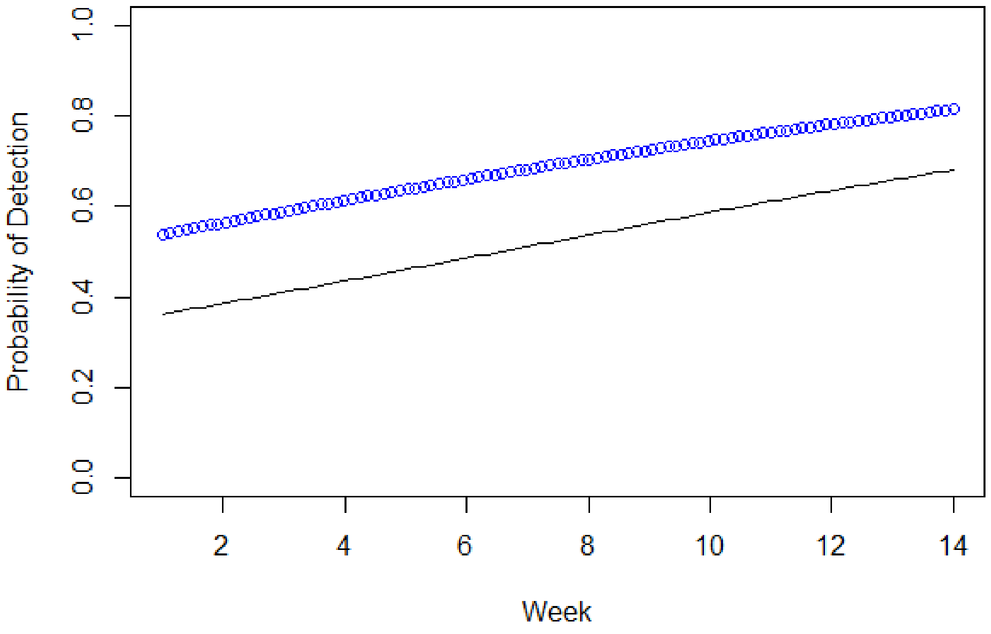

Figure 3-6. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. barrier lagoons (treatment, blue points).

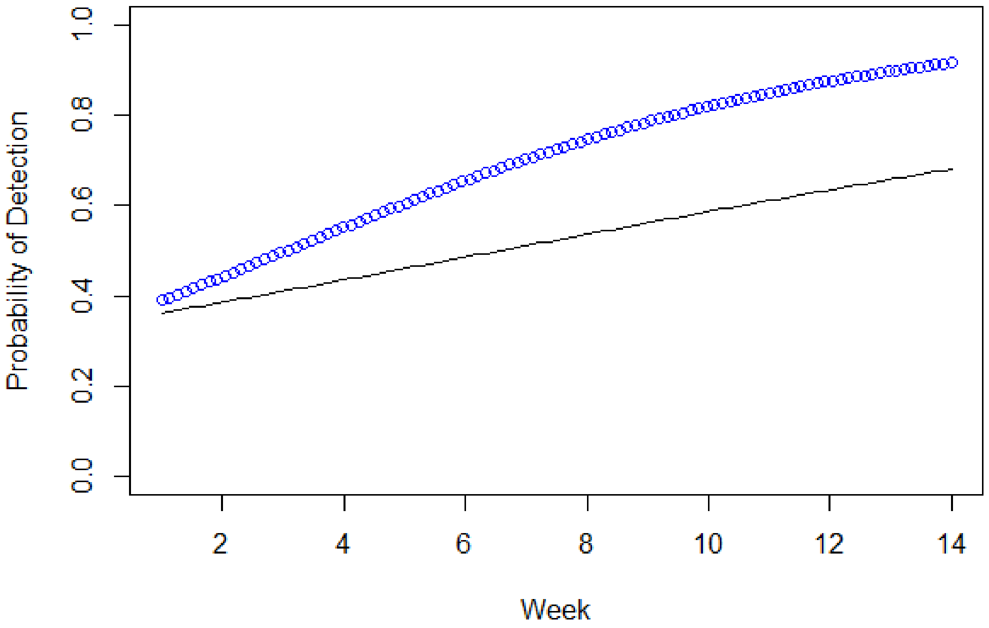

Figure 3-7. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. bluff backed beaches (treatment, blue points).

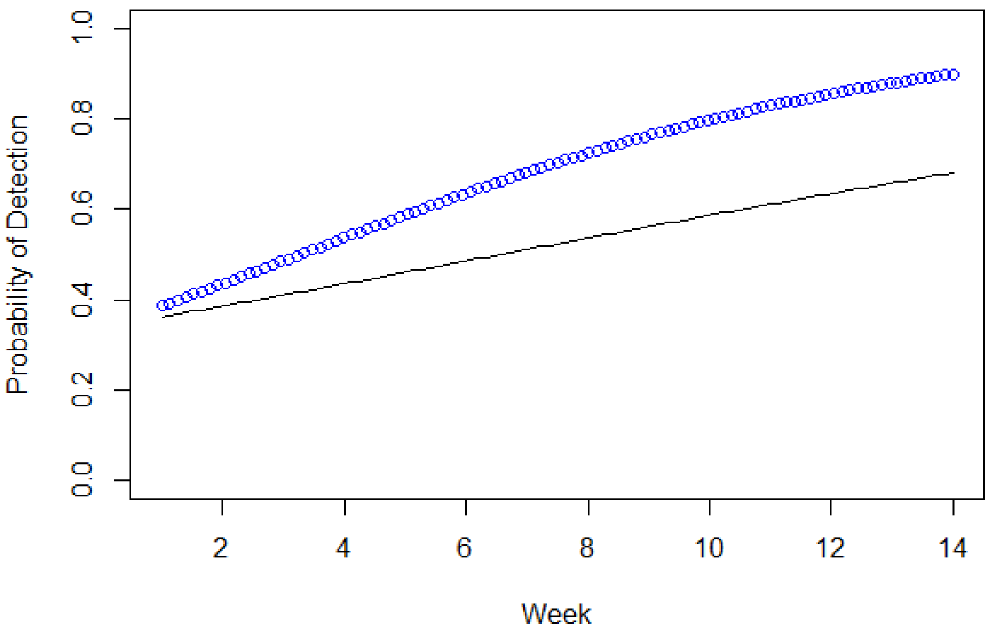

Figure 3-8. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. delta channels (treatment, blue points).

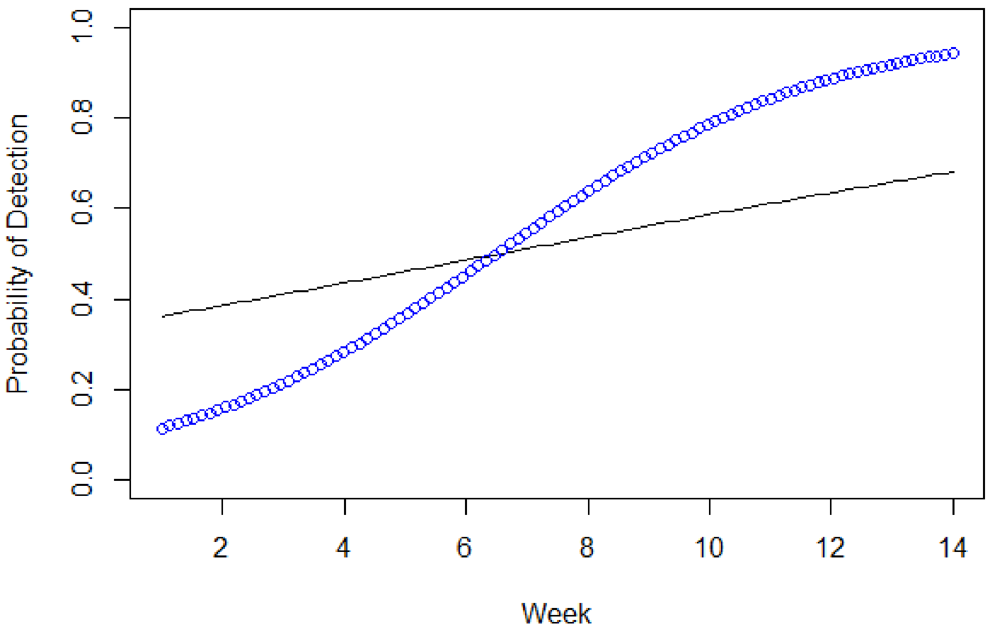

Figure 3-9. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. delta fans (treatment, blue points).

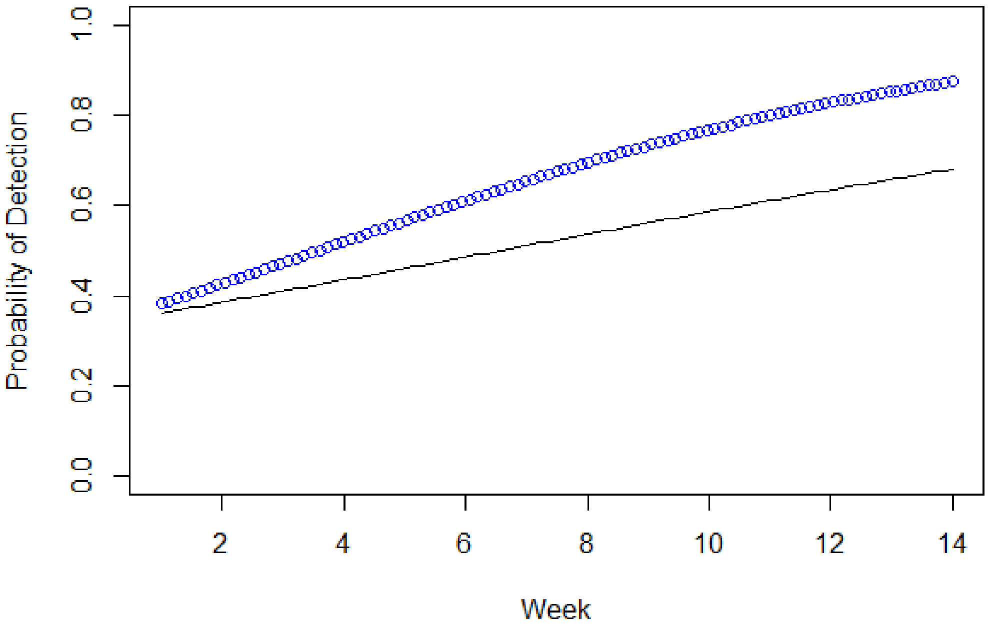

Figure 3-10. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. mid-size deltas (treatment, blue points).

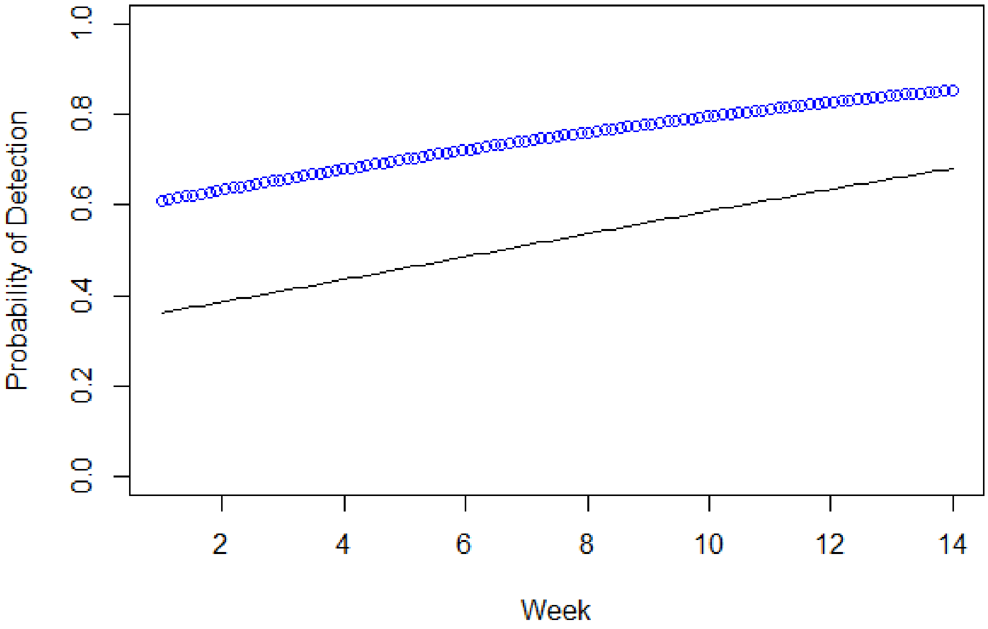

Figure 3-11. Probability of detecting juvenile chum fry at barrier beaches (control, black line) vs. pocket beaches (treatment, blue points).

Habitat and Life-History Interactions

To investigate differences in habitat use by chum salmon population group, seasonal classification (summer or fall) and the interaction between seasonal classification and shoreline type were used as independent variables to explain occurrence of pooled chum salmon fry through multiple GLM regression (Binomial, logit-link). The following model was selected:

$$\widehat{Occurrence} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{factor(Shoreline Type)} + \beta_3\,(\text{factor(Seasonal Classification)}$$
$$+\ \beta_4\,(\text{factor(Shoreline Type)):factor(Seasonal Classification)} + \varepsilon$$

All selected variables were significant at the $P \leq 0.05$ level, indicating that there were differential habitat use preferences by seasonal chum salmon ESU. Week was the greatest predictor of chum salmon occurrence ($P\ (|F_{1,2041}| \geq 92.913) < 0.001$), followed by seasonal classification ($P\ (|F_{2,2041}| \geq 13.361) < 0.001$), and shoreline type ($P\ (|F_{7,2041}| \geq 5.736) = 0.001$). Most importantly, there was a significant interaction effect between shoreline type and seasonal classification ($P\ (|F_{14,2041}| \geq 3.056) < 0.001$) while holding all else constant; this suggests that habitat use preferences differ on a stock-specific level (Table 3-4). For the summer classification, pocket beach ($P\ (|t| \geq 3.968) < 0.001$), barrier lagoon ($P\ (|t| \geq 2.720) = 0.006$), and barrier estuary ($P\ (|t| \geq 1.740) = 0.081$) habitats exhibited the most significant effects on occurrence over that of the barrier beach base condition. The most significant interactions existed between the fall classification and river delta fan ($P\ (|t| \geq 3.677) < 0.001$), river delta channel ($P\ (|t| \geq 2.081) = 0.038$), bluff backed beach ($P\ (|t| \geq 1.727) = 0.084$), and stream delta habitats ($P\ (|t| \geq 1.695) = 0.089$).

Table 3-4. Summary of factors from the multiple regression model used to explain occurrence of juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	***P*-value**	***F*-value**
Week	0.000	92.913
Shoreline Type	0.000	5.736
Seasonal Classification	0.000	13.361
Shoreline Type : Seasonal Classification	0.000	3.056

Similarly, significant interactions held true when analyzing pooled summer and fall chum fry relative abundance with the same set of variables through multiple GLM regression (Poisson, log-link). The following model was selected to explain relative abundance:

$$\widehat{Catch} = \beta_0 + \beta_1 (\text{Week}) + \beta_2 (\text{factor(Shoreline Type)} + \beta_3 (\text{factor(Seasonal Classification)} + \beta_4 (\text{factor(Shoreline Type)):factor(Seasonal Classification)} + \varepsilon$$

Week (P ($|F_{1,1031}| \geq 363.709$) < 0.001), seasonal classification (P ($|F_{2,2041}| \geq 7.380$) < 0.001), shoreline type (P ($|F_{7,2041}| \geq 5.987$) = 0.001), and the interaction effect between shoreline type and seasonal classification (P ($|F_{14,2041}| \geq 7.194$) < 0.001) proved significant in explaining relative abundance, adding further evidence to the argument for habitat preference by seasonal ESU (Table 3-5). As for occurrence, pocket beach (P ($|t| \geq 3.985$) < 0.001), barrier lagoon (P ($|t| \geq 2.881$) = 0.004), and barrier estuary (P ($|t| \geq 1.764$) = 0.077) habitats exhibited the most significant effects on abundance relative to the barrier beach base condition for the summer classification. Significant interactions existed between the fall classification and stream delta fan (P ($|t| \geq 3.032$) = 0.002) and river delta fan habitats (P ($|t| \geq 2.174$) = 0.029).

Table 3-5. Summary of factors from the multiple regression model used to explain occurrence of juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	***P*-value**	***F*-value**
Week	0.000	363.709
Shoreline Type	0.000	5.987
Seasonal Classification	0.000	7.380
Shoreline Type : Seasonal Classification	0.000	7.194

3.2 Summer Chum Salmon

Single-Factor Habitat Use Analysis

Given that the probability of detecting juvenile chum salmon fry in the nearshore environment is influenced by shoreline type and time of year (in terms of both slope and intercept effects) (Figures 3-6 - 3-11) and significant interaction effects were documented between seasonal classification and shoreline type, there appears to be differential use of nearshore estuarine habitats by summer and fall chum salmon. Utilizing WFC Bayesian modeling results distinguishing summer from fall chum salmon juveniles by fork length and time of year (WFC 2017), ANOVA analysis on a single-factor basis confirms distinct habitat preferences by ESU. Overall, summer chum salmon exhibited statistically significant habitat preferences ($P\ (|F_{7,1116}| \geq 8.960) < 0.001$) and a greater affinity for barrier lagoon ($P\ (|t| \geq 3.946) < 0.001$) and barrier estuary habitats ($P\ (|t| \geq 2.330) = 0.020$) relative to fall chum salmon. Furthermore, summer chum appeared to prefer delta habitats to a much lesser extent than fall chum salmon, with relative abundance at all delta habitats statistically equivalent to that of the base condition (barrier beach habitat) at the $P < 0.05$ level. Summer chum salmon relative abundance (Figure 3-12) was greatest in pocket beach habitats (Mean = 1.762, (CI ($1.528 \leq \widehat{Catch} \leq 1.997$) = 0.95)), followed by barrier lagoons (Mean = 1.458, (CI ($1.221 \leq \widehat{Catch} \leq 1.694$) = 0.95)), barrier estuaries (Mean = 1.184, (CI ($0.949 \leq \widehat{Catch} \leq 1.418$) = 0.95)), and bluff backed beaches (Mean = 1.066, (CI ($0.844 \leq \widehat{Catch} \leq 1.288$) = 0.95)). Relative abundance of summer chum salmon was lowest at delta fans (Mean = 0.667, (CI ($0.439 \leq \widehat{Catch} \leq 0.895$) = 0.95)) and barrier beaches (Mean = 0.793, (CI ($0.562 \leq \widehat{Catch} \leq 1.024$) = 0.95)).

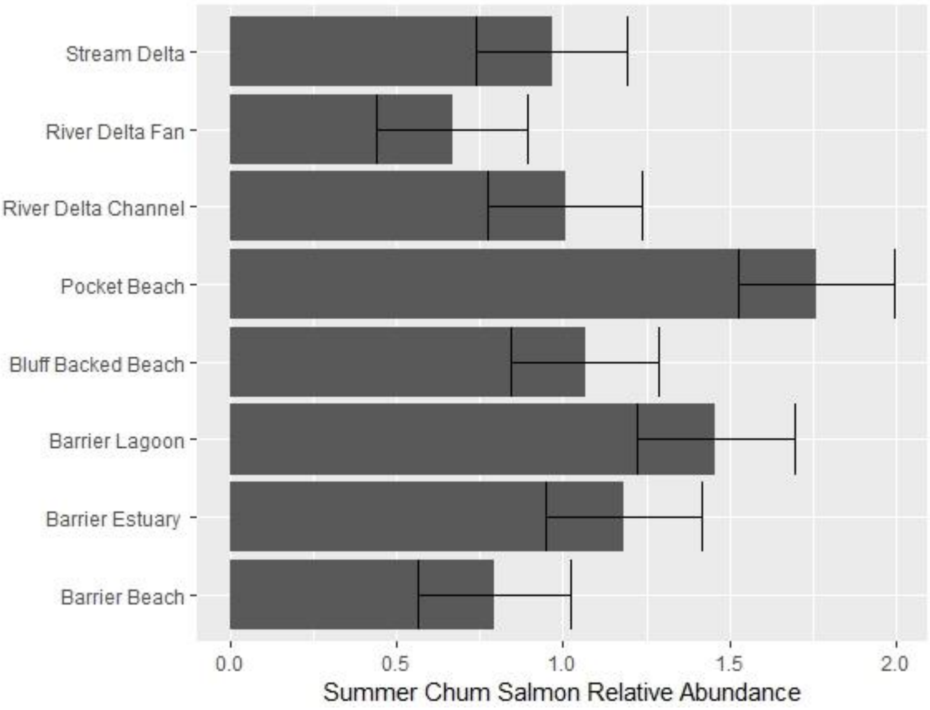

Figure 3-12. Mean log transformed summer chum salmon relative abundance at each shoreline type and the 95% confidence interval.

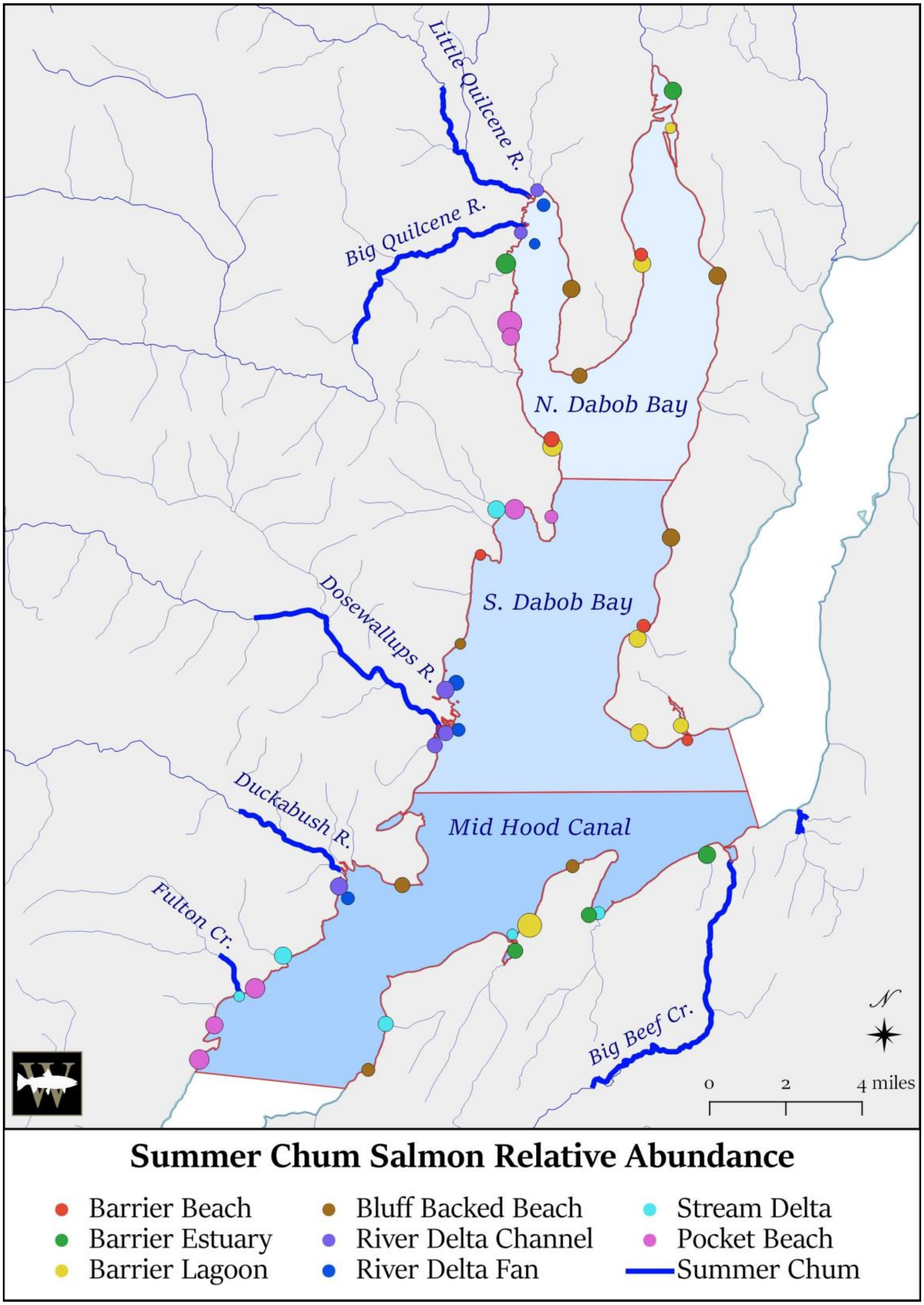
Little Quilcene R.
Big Quilcene R.
N. Dabob Bay
S. Dabob Bay
Dosewallups R.
Duckabush R.
Mid Hood Canal
Fulton Cr.
Big Beef Cr.
N
0
2
4 miles
Summer Chum Salmon Relative Abundance
● Barrier Beach
● Barrier Estuary
● Barrier Lagoon
● Bluff Backed Beach
● River Delta Channel
● River Delta Fan
● Stream Delta
● Pocket Beach
— Summer Chum

Figure 3-13. Mean log transformed summer chum salmon relative abundance is represented by plot size at each site sampled within the study region.

Occurrence Modeling

Occurrence of summer chum salmon fry was analyzed through multiple GLM regression (Binomial, logit-link) for the sets performed during the 2018 study. Population weighted distance was considered for this primarily natural origin ESU. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Occurrence} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{Depth}) + \beta_3\,(\text{Temperature}) + \beta_4\,(\text{factor(Shoreline Type)}) + \varepsilon$$

Surprisingly, population weighted distance was not a significant factor in explaining the dependent variable. Week was the greatest predictor of summer chum salmon occurrence ($P\ (|F_{1,1107}| \geq 82.631) < 0.001$), followed by shoreline type ($P\ (|F_{7,1107}| \geq 6.153) < 0.001$), temperature ($P\ (|F_{1,1107}| \geq 10.525) = 0.001$), and depth ($P\ (|F_{1,1107}| \geq 7.401) = 0.007$) (Table 3-6). Of the assessed shoreline types, pocket beach ($P\ (|t| \geq 4.344) < 0.001$), barrier lagoon ($P\ (|t| \geq 2.747) = 0.006$), barrier estuary ($P\ (|t| \geq 1.955) = 0.050$), and delta fan habitats ($P\ (|t| \geq -1.888) = 0.059$) had the most significant impacts on summer chum occurrence relative to the base condition (barrier beach). These results lend further evidence of the summer chum salmon habitat preferences identified from single factor ANOVA analysis and the relative abundance results presented in Figure 3-12.

Table 3-6. Summary of factors from the multiple regression model used to explain occurrence of juvenile summer chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	*P*-value	*F*-value
Week	0.000	82.631
Shoreline Type	0.000	6.153
Temperature	0.001	10.525
Depth	0.007	7.401

Relative Abundance Modeling

Multiple GLM regression (Poisson, log-link) was used to explain relative abundance of summer chum salmon fry in the Hood Canal nearshore environment for the sets performed. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Catch} = \beta_0 + \beta_1 \text{(Week)} + \beta_2 \text{(factor(Tidal Stage))} + \beta_3 \text{(Salinity)} + \beta_4 \text{(Temperature)}$$
$$+ \beta_5 \text{(factor(Substrate))} + \beta_6 \text{(factor(Shoreline Type))} + \beta_7 \text{(factor(Subregion))} + \varepsilon$$

Once again, the population weighted distance spatial variable was insignificant. Week ($P (|F_{1,1031}| \geq 114.883) < 0.001$), tidal stage ($P (|F_{2,1031}| \geq 10.636) < 0.001$), salinity ($P (|F_{1,1031}| \geq 6.199) = 0.013$), temperature ($P (|F_{1,1031}| \geq 35.130) < 0.001$), substrate ($P (|F_{6,1031}| \geq 5.523) < 0.001$), shoreline type ($P (|F_{7,1031}| \geq 24.374) < 0.001$), and subregion ($P (|F_{2,1031}| \geq 7.951) < 0.001$) all explained variation in juvenile summer chum fry relative abundance in the nearshore environment. Each partial regression coefficient is described in order of statistical significance in Table 3-7. Of all considered habitat types, only river delta habitats demonstrated no significant impact on summer chum relative abundance.

Table 3-7. Summary of covariates from the multiple regression model used to explain relative abundance of juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Independent Variable	***P*-value**	***t*-value**	**Coefficient**	$\widehat{SE}$
Week	0.000	10.124	1.366	0.042
Shoreline Type (Pocket Beach)	0.000	8.647	9.498	2.472
Temperature	0.000	5.578	1.408	0.086
Shoreline Type (Barrier Lagoon)	0.000	4.914	4.316	1.284
Sub-Region (Mid-Hood Canal)	0.000	-3.851	0.575	0.082
Shoreline Type (Barrier Estuary)	0.000	3.698	3.285	1.056
Shoreline Type (Bluff Backed Beach)	0.000	3.658	2.844	0.812
Tidal Stage (Slack)	0.002	3.151	1.702	0.287

Substrate (Silt/Sand)	0.002	2.994	1.924	0.420
Shoreline Type (Midsize Delta)	0.008	2.663	2.260	0.692
Sub-Region (Dabob South)	0.010	-2.609	0.687	0.098
Intercept Term	0.010	-2.600	0.189	0.121
Salinity	0.010	-2.554	0.968	0.012
Tidal Stage (Flood)	0.024	-2.265	0.757	0.092
Shoreline Type (Delta Channel)	0.110	1.644	1.758	0.603
Substrate (Cobble)	0.112	-1.579	0.364	0.232
Substrate (Gravel/Cobble)	0.182	-1.335	0.703	0.185
Substrate (Sand/Gravel)	0.184	-1.330	0.764	0.154
Substrate (Gravel)	0.384	0.873	1.228	0.289
Substrate (Sand)	0.438	-0.775	0.808	0.221
Shoreline Type (Delta Fan)	0.988	-0.014	0.995	0.353

3.3 Fall Chum Salmon

Single-Factor Habitat Use Analysis

Similar to summer chum salmon, fall chum salmon exhibited statistically significant habitat preferences (P ($|F_{7,611}| \geq 4.689$) < 0.001) (Figure 3-14). However, habitat preferences differed from that of the summer run with delta shoreline types experiencing far greater use. ANOVA analysis revealed that the fall chum salmon exhibited the greatest preference for stream delta alluvial fans (P ($|t| \geq 4.741$) < 0.001, Mean = 3.141, (CI ($2.638 \leq \widehat{Catch} \leq 3.644$) = 0.95)), followed by pocket beaches (P ($|t| \geq 4.115$) < 0.001, Mean = 2.920, (CI ($2.417 \leq \widehat{Catch} \leq 3.424$) = 0.95)), delta channels (P ($|t| \geq 3.897$) < 0.001, Mean = 2.802, (CI ($2.328 \leq \widehat{Catch} \leq 3.276$) = 0.95)), bluff backed beaches (P ($|t| \geq 3.798$) < 0.001, Mean = 2.776, (CI ($2.296 \leq \widehat{Catch} \leq 3.257$) = 0.95)), and delta fan habitats (P ($|t| \geq 3.575$) < 0.001, Mean = 2.693, (CI ($2.218 \leq \widehat{Catch} \leq 3.167$) = 0.95)) (Figure 3-14). Relative abundance was lowest at barrier beach (Mean = 1.472, (CI ($0.998 \leq \widehat{Catch} \leq 1.946$) = 0.95)), barrier estuary (P ($|t| \geq 1.959$) = 0.051, Mean = 2.142, (CI ($1.665 \leq \widehat{Catch} \leq 2.619$) = 0.95)), and barrier lagoon habitats (P ($|t| \geq 2.703$) = 0.007, Mean = 2.394, (CI ($1.920 \leq \widehat{Catch} \leq 2.868$) = 0.95)).

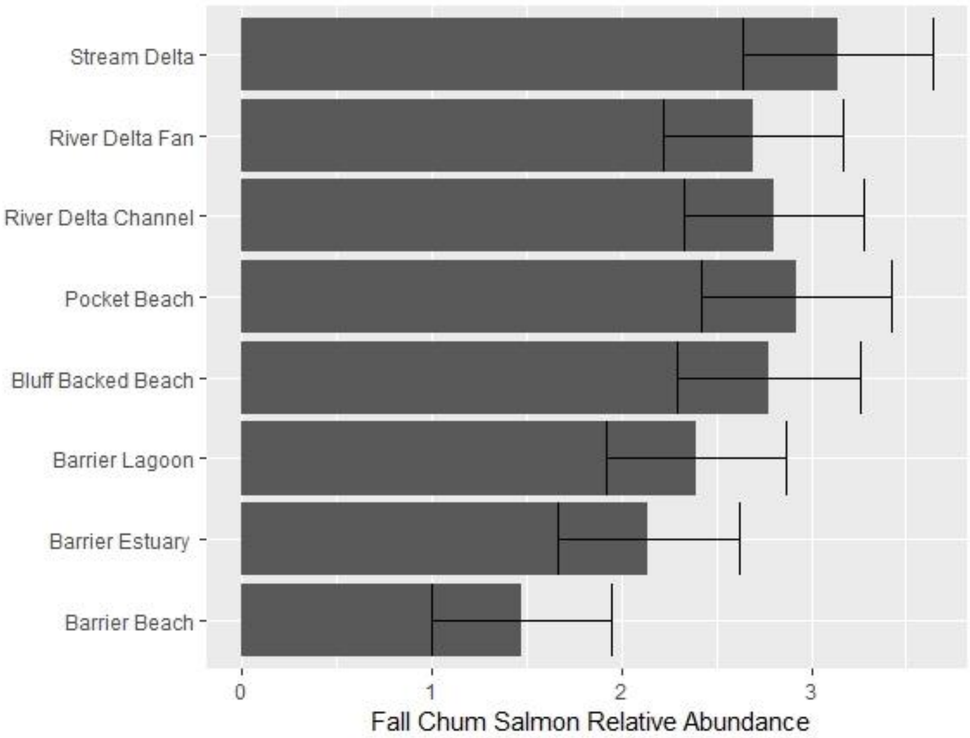

Figure 3-14. Mean log transformed fall chum salmon relative abundance at each shoreline type and the 95% confidence interval.

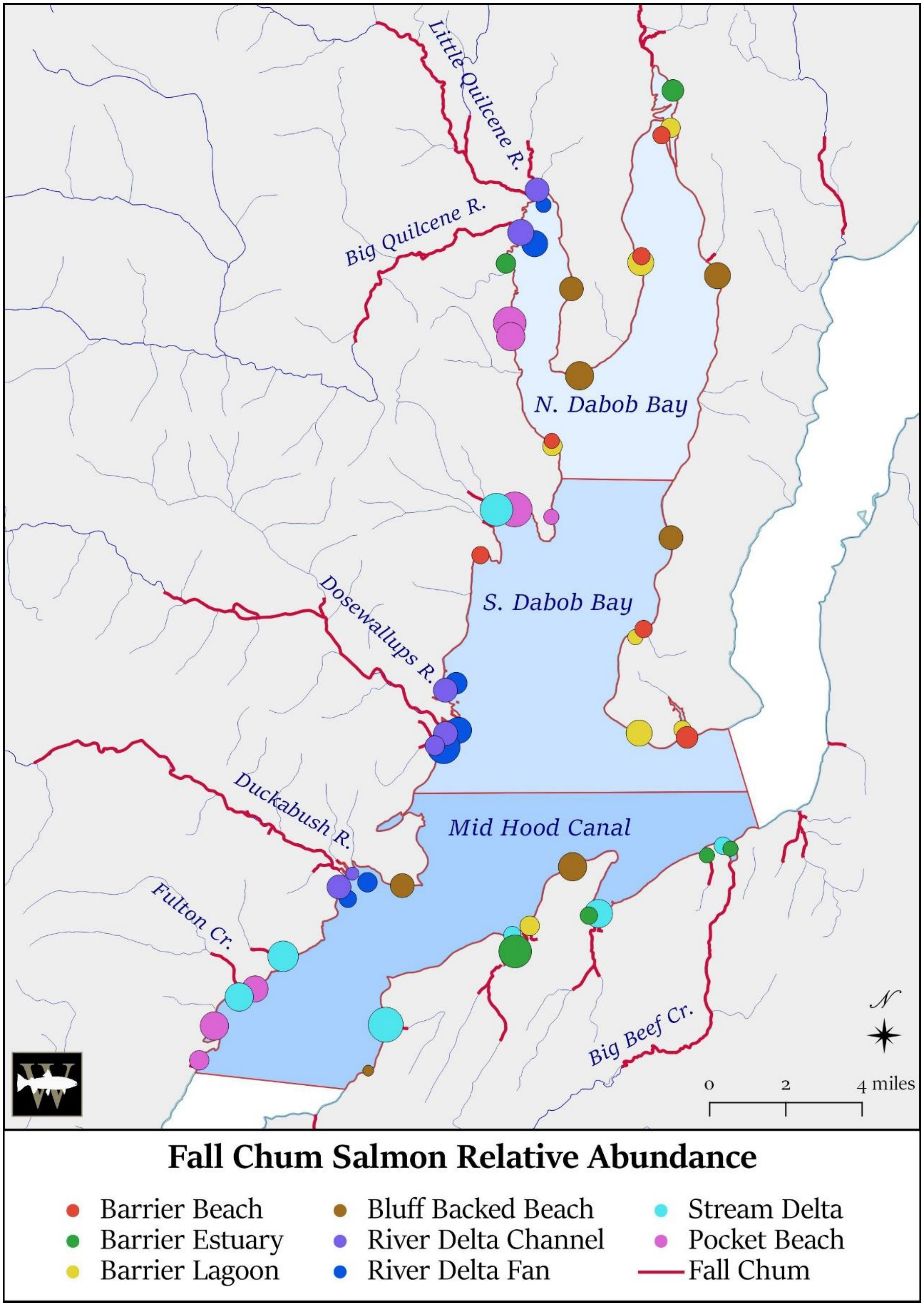

Figure 3-15. Mean log transformed chum salmon relative abundance is represented by plot size at each site sampled within the study region.

Occurrence Modeling

Occurrence of fall chum salmon fry was analyzed through multiple GLM regression (Binomial, logit-link) for the sets performed. For reasons previously discussed, population weighted distance was not considered for this mixed natural-origin/hatchery-origin ESU. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Occurrence} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{Tide Height}) + \beta_3\,(\text{Salinity}) + \varepsilon$$

In contrast with summer chum salmon, shoreline type was not a significant factor in explaining occurrence of fall chum salmon. Furthermore, week was not the strongest predictor of occurrence. Salinity proved the most significant factor in explaining fall chum salmon occurrence ($P\ (|F_{1,598}| \geq 13.754) < 0.001$, association = negative), followed by tide height ($P\ (|F_{1,598}| \geq 10.098) = 0.002$, association = positive) and week ($P\ (|F_{1,598}| \geq 4.889) = 0.027$) (Table 3-8). Nevertheless, had sampling continued through the completion of the entire fall chum outmigration, it seems likely that week would have been the predominant factor explaining occurrence of fall chum salmon.

Table 3-8. Summary of factors from the multiple regression model used to explain occurrence of juvenile fall chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	*P*-value	*F*-value
Salinity	0.000	13.754
Tide Height	0.002	10.098
Week	0.027	4.889

Relative Abundance Modeling

Multiple GLM regression (Poisson, log-link) was used to explain relative abundance of fall chum salmon fry in the Hood Canal nearshore environment for the sets performed. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Catch} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{Tide Height}) + \beta_3\,(\text{factor(Tidal Stage)}) + \beta_4\,(\text{Temperature}) + \beta_5\,(\text{factor(Substrate)}) + \beta_6\,(\text{factor(Shoreline Type)}) + \beta_7\,(\text{factor(Subregion)}) + \varepsilon$$

Week ($P\ (|F_{1,594}| \geq 50.519) < 0.001$), tide height ($P\ (|F_{1,594}| \geq 34.934) < 0.001$), tidal stage ($P\ (|F_{2,594}| \geq 11.502) < 0.001$), temperature ($P\ (|F_{1,594}| \geq 17.436) < 0.001$), substrate ($P\ (|F_{6,594}| \geq 8.410) < 0.001$), shoreline type ($P\ (|F_{7,594}| \geq 17.331) < 0.001$), and subregion ($P\ (|F_{2,594}| \geq 9.673) < 0.001$) all explained relative abundance of juvenile fall chum fry catch in the nearshore environment. Each partial regression coefficient is described in order of statistical significance in Table 3-9. The habitats most significant in explaining relative fall chum abundance were stream delta alluvial fans, barrier estuaries, and pocket beaches. Associations between habitat and relative abundance can only be determined on a single factor basis (see Figure 3-14).

Table 3-9. Summary of covariates from the multiple regression model used to explain relative abundance of fall juvenile chum salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Independent Variable	***P*-value**	***t*-value**	**Coefficient**	$\widehat{SE}$
Shoreline Type (Stream Delta)	0.000	7.552	35.140	5.596
Week	0.000	6.858	1.712	0.045
Intercept Term	0.000	-6.566	0.001	0.001
Shoreline Type (Barrier Estuary)	0.000	6.173	26.706	4.801
Tide Height	0.000	-5.817	0.833	0.008
Shoreline Type (Pocket Beach)	0.000	5.734	14.122	2.203
Shoreline Type (Bluff Backed Beach)	0.000	5.028	10.724	1.709
Shoreline Type (River Delta Fan)	0.000	4.975	10.847	1.756
Substrate (Gravel)	0.000	4.642	3.963	0.397
Shoreline Type (River Delta Channel)	0.000	4.473	11.246	2.055
Temperature	0.000	4.177	1.282	0.025
Tidal Stage (Flood)	0.000	-3.678	0.556	0.029
Substrate (Gravel/Cobble)	0.000	3.650	3.778	0.464
Shoreline Type (Barrier Lagoon)	0.004	2.828	4.369	0.769
Sub-Region (Dabob South)	0.010	2.595	1.729	0.123
Substrate (Sand/Gravel)	0.012	2.527	2.015	0.188
Substrate (Silt/Sand)	0.036	-2.107	0.377	0.058
Tidal Stage (Slack)	0.070	1.819	1.455	0.101
Substrate (Cobble)	0.148	1.445	1.745	0.227
Sub-Region (Mid-Hood Canal)	0.226	-1.213	0.771	0.055
Substrate (Sand)	0.320	-0.993	0.596	0.104

3.4 Pink Salmon

Total Catch

During the 2018 study, 3,244 pink salmon fry were captured and released. Juvenile pink salmon were documented in the estuary for the first time on January 12, 2018. The log transformation of weekly catch (Figure 3-16) was at a minimum during the first week of sampling in early January (Mean = 0.004, CI $(0.000 \leq \widehat{Catch} \leq 0.086) = 0.95)$) and peaked during the final week of sampling (week 14) in mid-April (Mean = 1.544, (CI $(1.434 \leq \widehat{Catch} \leq 1.653) = 0.95)$)). Due to low numbers of pink salmon encountered in the nearshore environment in 2018, total catch from each set performed at a site on a given date was summed to enable multiple GLM regression modeling for occurrence; however, numbers of pink salmon encountered at each site still proved too few to enable effective relative abundance modeling.

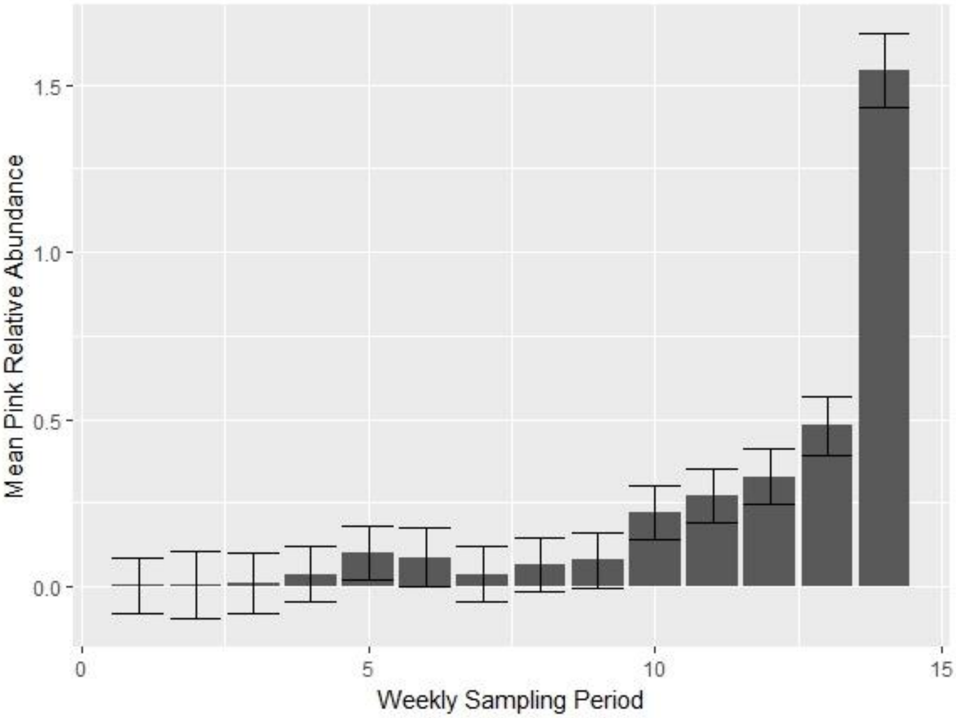

Figure 3-16. Mean log transformed pink salmon catch by week and the 95% confidence interval.

Mean pink salmon fork length remained relatively consistent throughout the study period (Figure 3-15), increasing slightly from 34.00 mm (SE = 2.76) in week 1 (early-January) to 36.91

mm ($\widehat{SE}$ = 0.12) during week 14 (late-April) (Min = 25 mm; Max = 65 mm). Consistency in fork lengths observed throughout the study indicates that the data collection methodology was effective primarily for pink salmon fry (Figure 3-17).

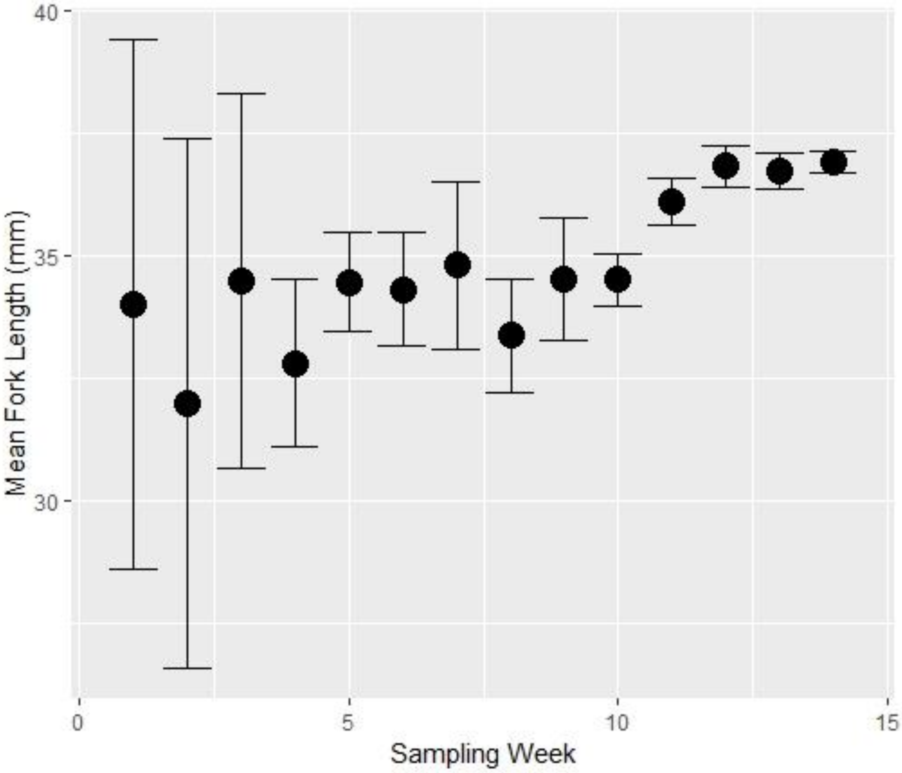

Figure 3-17. Mean pink salmon fork length by week and the 95% confidence interval.

Sub-Regional Relative Abundance Analysis

Pink salmon catch varied by sub-region on a single factor basis (P ($|F_{2,2039}| \geq 4.845$) = 0.008) (Figure 3-18). Log transformed catch was greatest in north Dabob Bay (Mean = 0.227, CI ($0.181 \leq \widehat{Catch} \leq 0.275$) = 0.95)), followed by south Dabob Bay (Mean = 0.230, CI ($0.182 \leq \widehat{Catch} \leq 0.277$) = 0.95)), and mid-Hood Canal (Mean = 0.141, CI ($0.097 \leq \widehat{Catch} \leq 0.185$) = 0.95)). Pink salmon relative abundance is shown at a site-specific level throughout the study region in Figure 3-19.

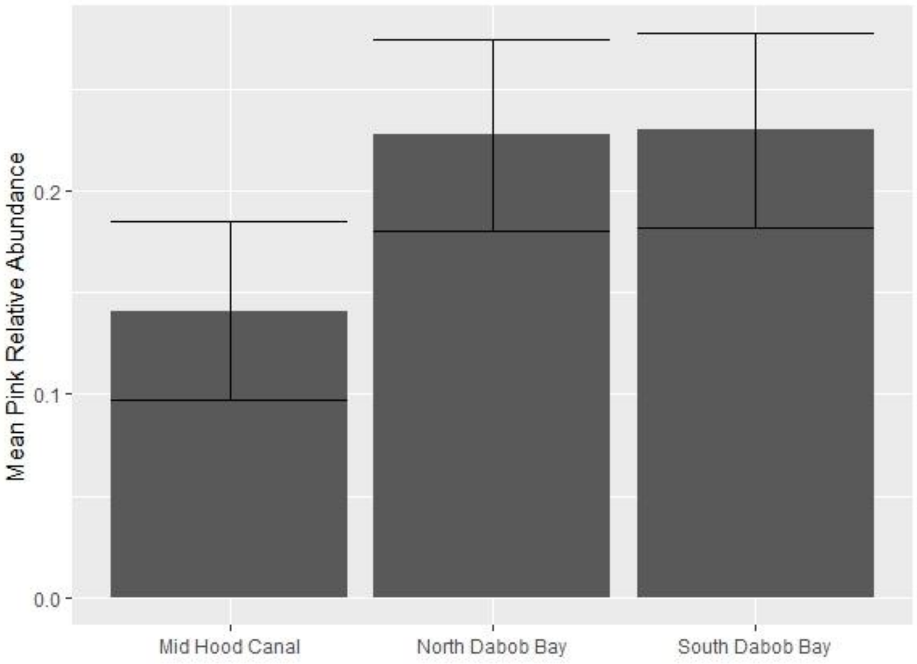

Figure 3-18. Mean log transformed pink salmon catch by sub-region and the 95% confidence interval.

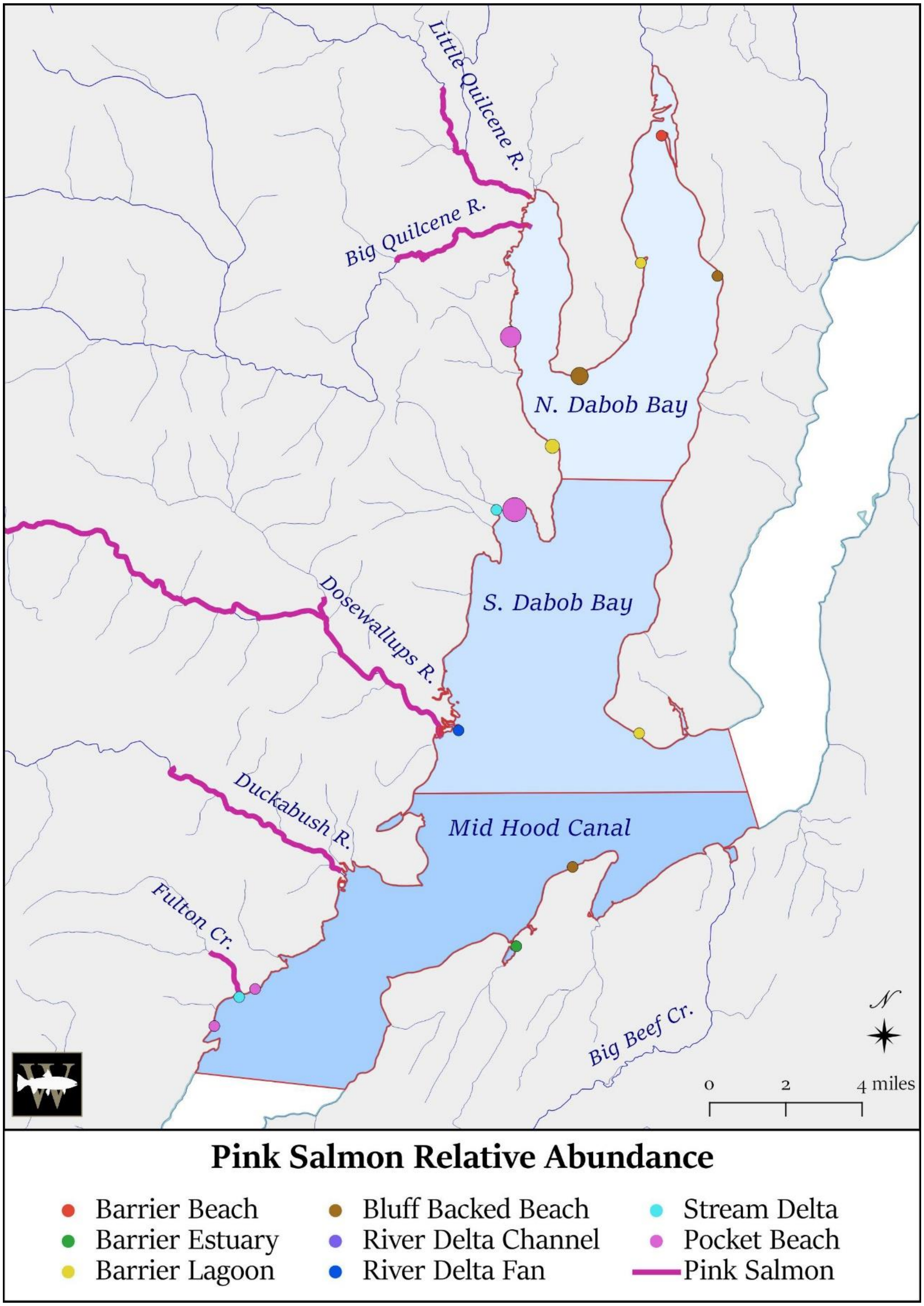

Figure 3-19. Mean log transformed pink salmon relative abundance is represented by plot size at each site sampled within the study region.

Single-Factor Habitat Use Analysis

Analyzed through one-way ANOVA, pink salmon exhibited statistically significant habitat preferences on a single factor basis ($P\ (|F_{7,2034}| \geq 8.392) < 0.001$). Pink salmon relative abundance (Figure 3-20) was greatest in pocket beach habitats ($P\ (|t| \geq 4.172) < 0.001$, Mean = 0.402, (CI ($0.326 \leq \widehat{Catch} \leq 0.479$) = 0.95)), followed by bluff backed beaches ($P\ (|t| \geq 1.912) = 0.056$, Mean = 0.277, (CI ($0.204 \leq \widehat{Catch} \leq 0.351$) = 0.95)) and barrier lagoons ($P\ (|t| \geq 1.681) = 0.093$, Mean = 0.266, (CI ($0.190 \leq \widehat{Catch} \leq 0.340$) = 0.95)). Relative abundance was lowest at delta channels ($P\ (|t| \geq -2.166) = 0.030$, Mean = 0.058, (CI ($0.000 \leq \widehat{Catch} \leq 0.133$) = 0.95)), barrier estuaries ($P\ (|t| \geq -1.342) = 0.180$, Mean = 0.103, (CI ($0.028 \leq \widehat{Catch} \leq 0.177$) = 0.95)), and delta fans ($P\ (|t| \geq -0.777) = 0.437$, Mean = 0.134, (CI ($0.060 \leq \widehat{Catch} \leq 0.207$) = 0.95)).

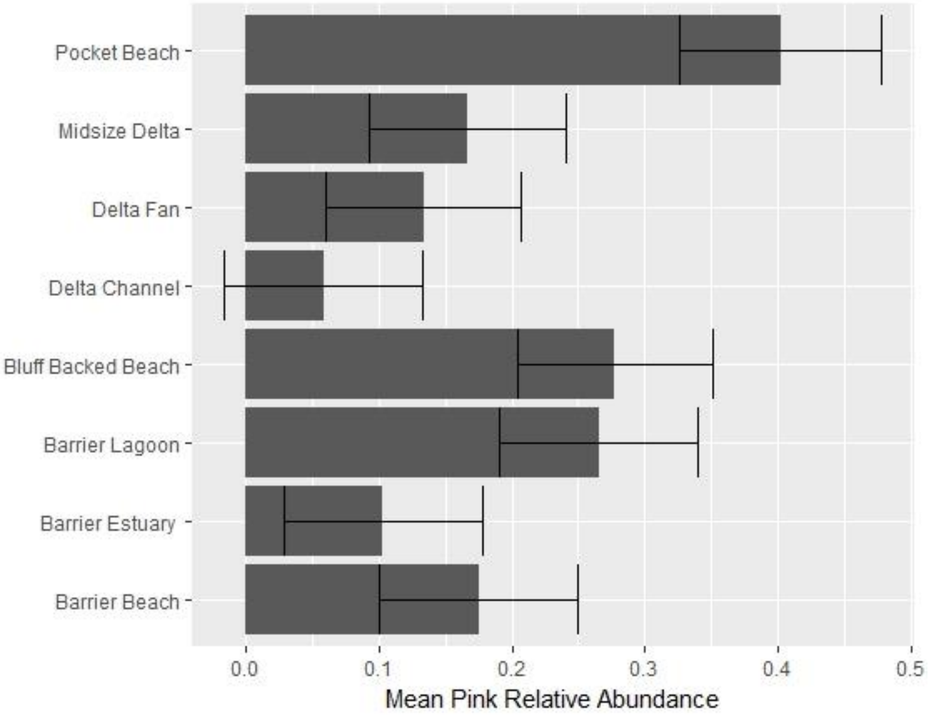

Figure 3-20. Mean log transformed pink salmon relative abundance at each shoreline type and the 95% confidence interval.

Occurrence Modeling

To explain occurrence of pink salmon fry in the Hood Canal nearshore environment, multiple GLM regression (Binomial, logit-link) was used for the sites visited (n = 514) throughout the 2018 study period. Considering the covariates listed in table 2-3, the following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Occurrence} = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{Temperature}) + \beta_3\,(\text{factor(Shoreline Type)}) + \beta_4\,(\text{Population Weighted Distance}) + \varepsilon$$

Week was the greatest predictor of pink salmon occurrence ($P\ (|F_{1,505}| \geq 53.767) < 0.001$), followed by shoreline type ($P\ (|F_{7,505}| \geq 4.183) < 0.000$), population weighted distance ($P\ (|F_{1,505}| \geq 10.935) = 0.001$), and temperature ($P\ (|F_{1,505}| \geq 4.586) = 0.033$). Each factor is described in order of statistical significance in Table 3-10. Of the assessed shoreline types, delta channel ($P\ (|t| \geq -3.187) = 0.001$) and delta fan habitats ($P\ (|t| \geq -2.974) = 0.003$) demonstrated a significant impact on pink salmon occurrence at the $P \leq 0.05$ level. These results lend further evidence of the pink salmon habitat preferences identified from single factor ANOVA analysis and the relative abundance results presented in Figure 3-20.

Table 3-10. Summary of factors from the multiple regression model used to explain occurrence of juvenile pink salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Factor	*P*-value	*F*-value
Week	0.000	53.767
Shoreline Type	0.000	4.183
Population Weighted Distance	0.001	10.395
Temperature	0.033	4.586

Temporal Habitat Use Modeling

To model the probability of detecting pink salmon fry in the Hood Canal nearshore environment based upon habitat and time, multiple GLM regression (Binomial, logit-link) was used for the sites visited (n = 514). Week, shoreline type, subregion, and all interaction terms were considered in the analysis. The following model was selected through the backwards-elimination/deletion approach:

$$\widehat{Probability\ of}\ Detection = \beta_0 + \beta_1\,(\text{Week}) + \beta_2\,(\text{factor(Shoreline Type)}) + \varepsilon$$

Modeling through the R-platform, week ($P\ (|F_{1,513}| \geq 116.415) < 0.001$) and shoreline type ($P\ (|F_{7,513}| \geq 3.068) = 0.004$) explained the probability of detecting juvenile pink fry catch in the nearshore environment; no interaction terms proved significant. Each partial regression coefficient is described in order of statistical significance in Table 3-11. Figures 3-21 through 3-22 show the probability of detecting juvenile pink fry in each of the studied habitat types relative to the barrier beach control on a site-by-site basis; intercept effects are shown at the $P \leq 0.10$ significance level. Note that only delta fan and delta channel habitats demonstrated significant treatment effects on intercept relative to the barrier beach control. As a result, only figures for these habitat types are provided.

Table 3-11. Summary of covariates from the multiple regression model used to explain presence and absence of juvenile pink salmon fry in the nearshore, ranked by *P*-value for last entry into the model.

Independent Variable	***P*-value**	***t*-value**	**Coefficient**	$\widehat{SE}$
Week	0.000	9.390	1.368	0.046
Intercept Term	0.000	-7.530	0.045	0.019
Shoreline Type (Delta Channel)	0.030	-2.174	0.373	0.169
Shoreline Type (Delta Fan)	0.064	-1.853	0.443	0.195
Shoreline Type (Barrier Estuary)	0.165	-1.390	0.547	0.237
Shoreline Type (Pocket Beach)	0.282	1.076	1.573	0.662
Shoreline Type (Midsize Delta)	0.326	-0.982	0.655	0.282
Shoreline Type (Bluff Backed Beach)	0.461	0.736	1.357	0.562
Shoreline Type (Barrier Lagoon)	0.610	0.511	1.237	0.516

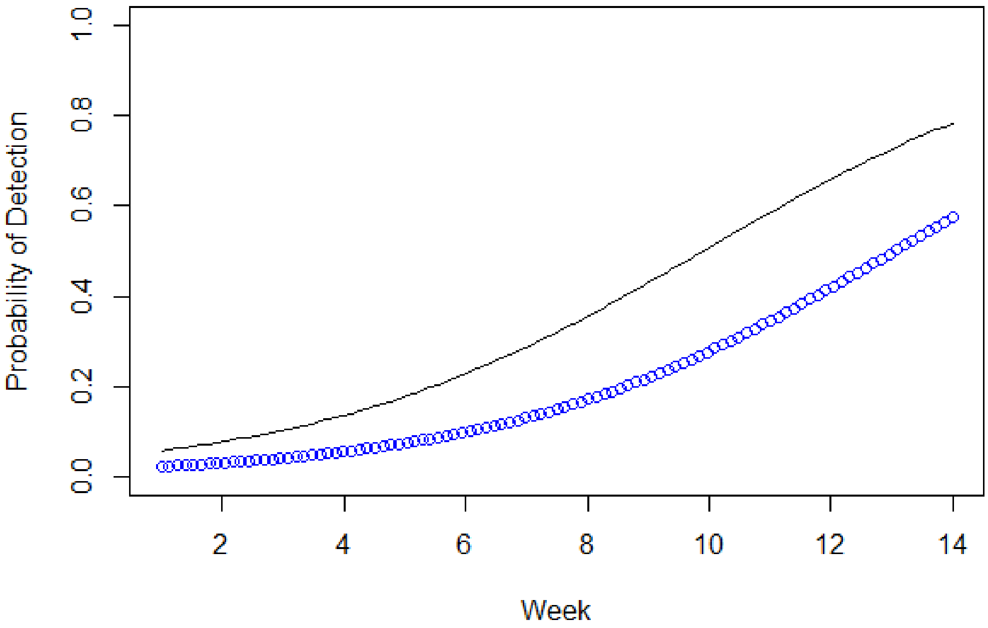

Figure 3-21. Probability of detecting juvenile pink fry at barrier beaches (control, black line) vs. delta channels (treatment, blue points).

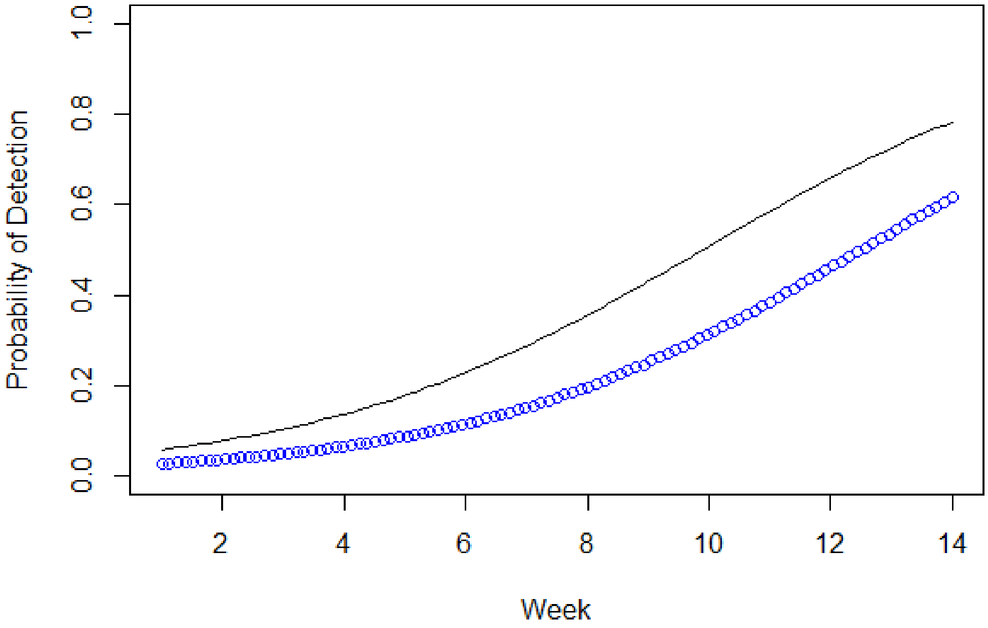

Figure 3-22. Probability of detecting juvenile pink fry at barrier beaches (control, black line) vs. delta fans (treatment, blue points).

3.5 Chinook Salmon

Over the course of the 2018 study, only 54 juvenile Chinook salmon fry (all < 50 mm) and one smolt (81 mm) were encountered. Chinook salmon were documented in the estuary for the first time on January 22, 2018. Over 78% of Chinook salmon juveniles handled were captured between the last week of January and the end of February. Chinook salmon were most abundant in delta channels (n = 15), followed by mid-size deltas (n = 12), pocket beaches (n = 9), delta fans (n = 6), barrier estuaries (n = 5), barrier lagoons (n = 4), and bluff backed beaches (n = 4). No Chinook salmon were found at barrier beach habitats (Figure 3-23). Most Chinook salmon captured were in the mid Hood Canal subregion (n = 30) (Figure 3-24). Due to the low numbers of Chinook salmon captured, GLM abundance and occurrence modeling was not conducted.

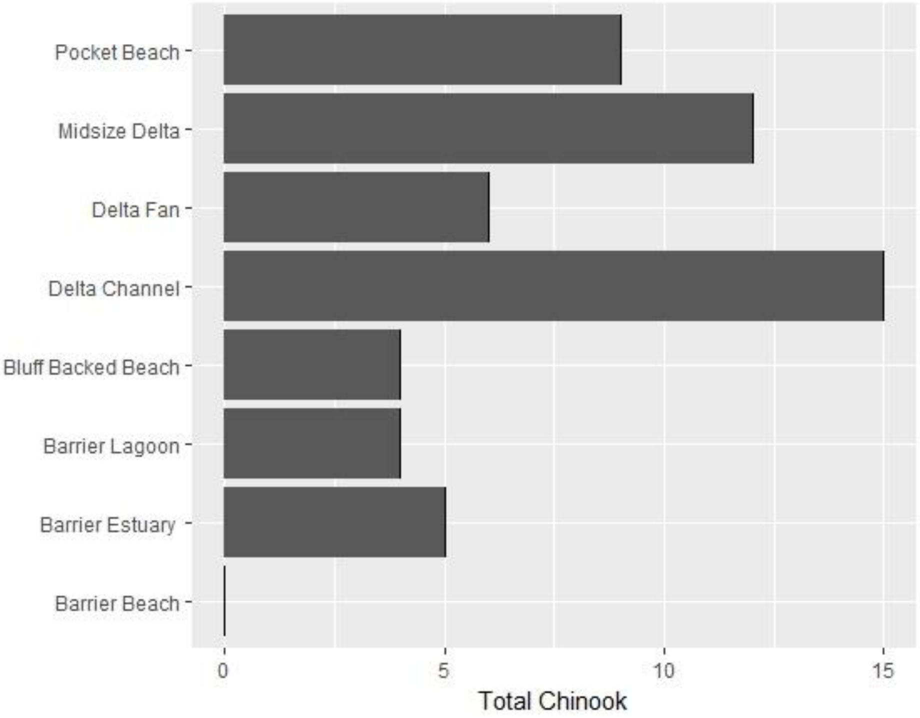

Figure 3-23. Total Chinook salmon juveniles encountered at each shoreline type.

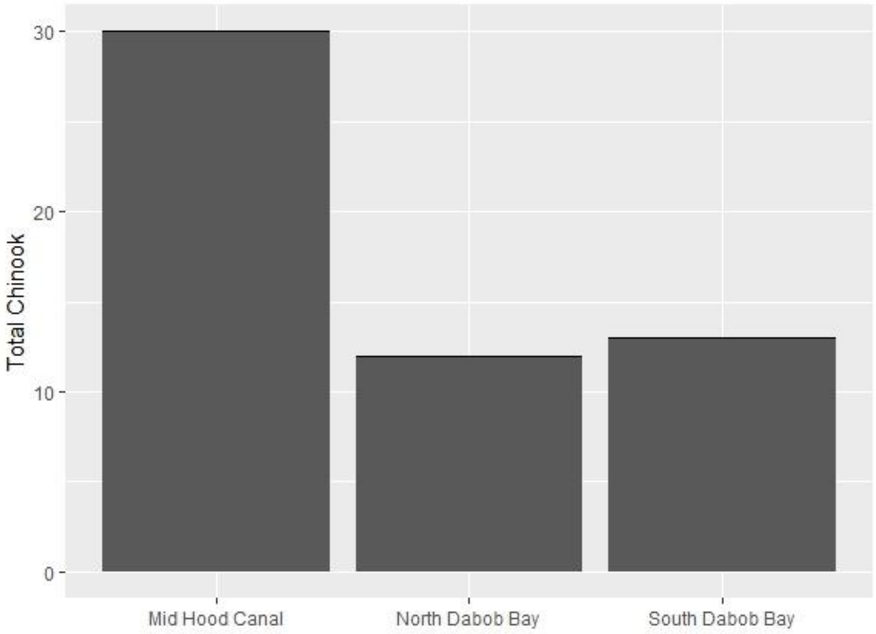

Figure 3-24. Total Chinook salmon juveniles encountered in each subregion.

3.6 Coho Salmon

Only 191 juvenile coho salmon were captured and released during the 2018 study. Of the coho salmon captured, 127 were fry (< 70 mm) and 64 were smolts (> 70 mm). Coho salmon were documented in the estuary for the first time on January 16 and peaked in abundance during the month of March in which 79 coho salmon were captured. Coho salmon smolts were found primarily in barrier lagoons (n = 59). Coho salmon fry were most abundant in barrier estuaries (n = 46), delta channels (n = 43), and midsize deltas (n = 19). Coho salmon fry were least abundant at barrier beaches (n = 0), bluff backed beaches (n = 2), barrier lagoons (n = 4), delta fans (n = 5), and pocket beaches (n = 9) (Figure 3-25). Most coho salmon captured were in the south Dabob Bay subregion (n = 75), followed by north Dabob Bay (n = 65) and mid Hood Canal (n = 50) (Figure 3-26). Due to the low numbers of coho salmon captured, GLM abundance and occurrence modeling was not conducted.

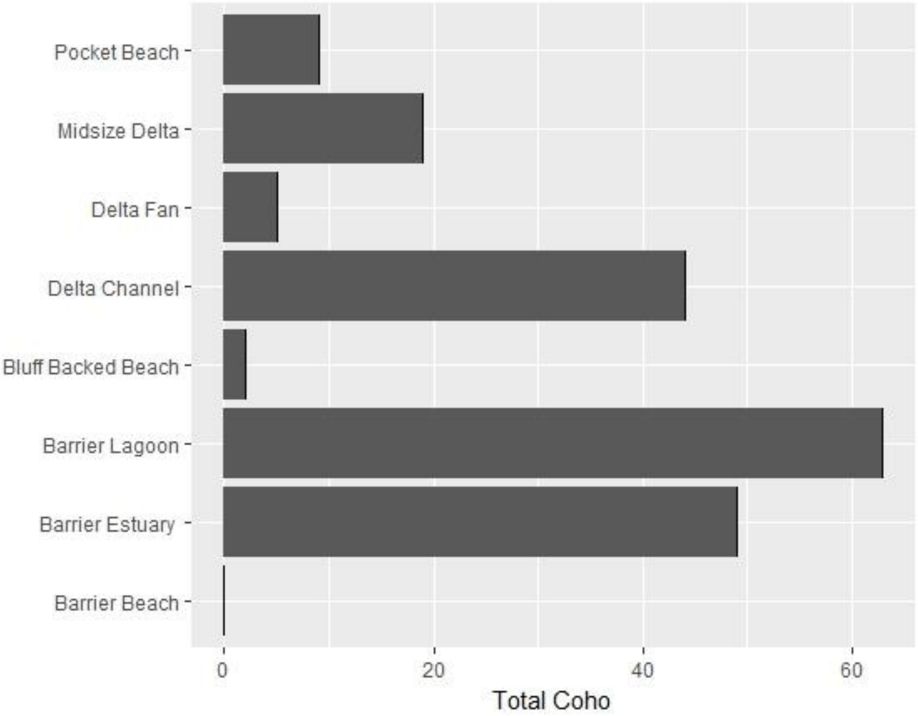

Figure 3-25. Total coho salmon juveniles encountered at each shoreline type. Note that almost all coho found at barrier lagoons were smolts, while the remaining coho found at all other shoreline types were primarily fry.

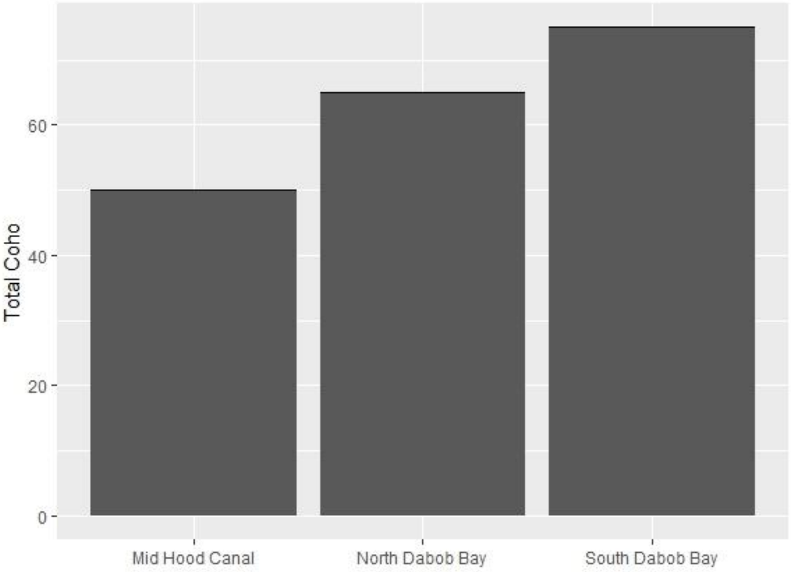

Figure 3-26. Total coho salmon juveniles encountered in each subregion.

Discussion

4.1 Chum Salmon

The main objective of this study was to determine potential nearshore habitat preferences by juvenile summer and fall chum salmon and identify environmental and temporal covariates explaining abundance and occurrence for habitat restoration and protection purposes. The study was designed to focus on the most productive subregion of Hood Canal for summer chum salmon to better discern habitat use preferences. One standardized beach seining methodology was employed to help eliminate potential calibration errors and to control for the effects of fish size on habitat use (Healey 1982; Quinn 2005). Results of the 2018 study suggest that summer and fall chum salmon fry exhibit differential use of nearshore estuarine habitats within the Hood Canal (H_{a1}). Furthermore, occurrence and relative abundance can be explained by a suite of habitat, environmental, and temporal variables, including temperature, salinity, depth, substrate, tide stage, and tide height (H_{a2}). Ultimately, this information can be utilized to inform the recovery strategy for ESA-listed Hood Canal summer chum.

Considering differences in evolutionary history, juvenile emergence timing, and nearshore ecosystem conditions, habitat use patterns by seasonal chum salmon runs should vary within Hood Canal throughout the juvenile outmigration (Simenstad et al. 1980; Fresh 2006). As a species, chum salmon fry occurrence and relative abundance in the Hood Canal nearshore environment were driven primarily by time of year and shoreline type (Table 3-1 and Table 3-2). The probability of chum salmon detection at each shoreline type increased during the January through April study period, but relationships varied significantly in terms of slope and intercept (Figures 3-6 through 3-11). Most importantly, significant week and shoreline type interaction (slope) effects were detected for delta habitats and bluff backed beaches. This change in the rate of chum salmon occurrence in space and time relative to the base condition indicates seasonality in habitat use patterns, and therefore life-history specific habitat preferences in Hood Canal. GLM evaluation of interaction effects between shoreline type and seasonal classification lends further evidence of habitat preference by ESU.

Analyzing occurrence and relative abundance for each individual chum salmon life-history type through ANOVA and GLM, there are notable differences in habitat use. Although both life-histories of chum salmon demonstrated a strong affinity for pocket beach habitats (Figure 3-5)—a conclusion previously drawn for the chum salmon species in other regions of Puget Sound (Beamer et al. 2012)—summer chum salmon exhibited significant preference for barrier lagoons and barrier estuaries relative to the fall run. Furthermore, summer chum showed a lesser tendency to rear within delta habitats. These results are clearly visible through graphical evidence provided in Figures 3-12 and 3-14 and are confirmed through single factor ANOVA and both GLM occurrence and relative abundance modeling. Disregarding pocket beaches—which may be preferred as a result of low current velocities relative to adjacent rocky shorelines (Balchen 1976)—summer chum occurrence was most strongly impacted by the presence of barrier lagoons and barrier estuaries, with occurrence declining significantly in delta fan habitats. Relative abundance also appeared driven by shoreline type, with catch of summer chum greatest at pocket beaches, barrier lagoons, and barrier estuaries. Surprisingly, distance from the source of spawning populations did not explain summer chum relative abundance or occurrence. This result could be due to the reduced size of the study region. Essentially anywhere sampling occurred in 2018, large chum producing systems were in close proximity and migration throughout the region may not have been challenging for the species.

In contrast, fall chum salmon demonstrated a strong preference for delta habitats (Figure 3-14). Figures 3-8 through 3-10 for all delta habitats exhibit significant interaction between week and shoreline type (treatment slope effects), suggesting that the rate of change in chum salmon occurrence increases relative to the base condition over the sampling period with the arrival of fall chum salmon fry (Table 3-3). Significant interaction effects detected between delta shoreline types and fall classification for both occurrence and abundance lend further evidence of differential habitat use preferences. On a single-factor basis, ANOVA relative abundance analyses demonstrate that use of delta habitats (including stream delta alluvial fans, river delta alluvial fans, and river delta channels) by fall chum salmon appears equivalent to that of frequented pocket beaches and bluff backed beaches. Barrier estuaries are utilized to a significantly lesser extent, with relative abundance statistically equivalent to that of the barrier beach base condition. Beyond demonstrating differential habitat use preferences by ESU and season, these analyses also draw attention to the importance of stream delta alluvial fans for chum salmon emerging during spring months. While large river delta systems have been the primary focus of regional habitat restoration plans due to their importance to rearing juvenile Chinook and chum salmon (Beamer et al. 2003), less attention has been drawn to the need for protecting and restoring small river and stream delta habitats. This study shows that these small river and stream delta alluvial fans provide preferred habitat for fall chum salmon. Although these sub-estuaries may be smaller than those associated with the sixteen major river systems that feed Puget Sound, they are uniquely complex nearshore environments (Collins & Sheik 2005; Cereghino et al. 2012) that may play a significant role in maintaining the portfolio effect which sustains life-history and genetic diversity of regional salmon stocks (WDFW 2002; Schindler et al. 2010).

Differential habitat-use patterns displayed by the two seasonal runs of chum salmon fry in the Hood Canal study region may be the product of nearshore ecosystem conditions during separate periods of emergence (Simenstad et al. 1980; Salo 1991; Fresh 2006). Common ecological theory for salmonid populations suggests that differences in embryonic development rates for seasonal salmon runs of a species will compensate for divergence in spawn timing to enable hatching of juveniles in a common period most optimal to the survival of a regional population group (Koski 1975; Beacham and Murray 1986; Tallman 1986; Salo 1991). In other words, fall chum salmon eggs should develop at a greater rate than summer chum salmon eggs, resulting in a common period of juvenile emergence from the gravel during optimal ecological spring conditions. Although embryonic development rates appear different between the two ESUs (Tynan 1997), estuarine emergence timing for the two seasonal chum salmon runs in Hood Canal differs significantly from separation in spawn timing (Small et al. 2016). This causes each genetically distinct run to encounter unique nearshore ecosystem conditions, which, in part, may drive variance in observed habitat use patterns.

River deltas are known for their importance to rearing juvenile Chinook salmon fry and small parr (Congleton et al., 1981; Beamer et al. 2003; Quinn 2005; Beamer et al. 2013). These habitats are shallow and highly productive as a result of high carbon input from freshwater sources and intertidal conversion of carbon to forms desirable to salmonids (Simenstad et al. 1982); therefore, deltas provide shelter from larger predators that prefer deeper waters and abundant food resources to juveniles during one of the most vulnerable life-history stages (Salo

1991; Beamer et al. 2003; Quinn 2005). Beamer et al. (2003) hypothesize that loss of functional delta habitat has resulted in increased Chinook salmon use of remaining embayment habitats, including barrier lagoons and barrier estuaries, throughout Puget Sound and elsewhere. In a sense, embayments may serve as a substitute for delta rearing habitat if habitat loss is significant or ecological conditions (e.g. low productivity, density dependence) discourage use.

In a similar fashion to Chinook salmon, chum salmon are highly dependent on the estuary for growth prior to outmigration to the Pacific Ocean (Salo 1991; Quinn 2005). Potentially, river delta habitats of Hood Canal could be less productive (e.g. lower densities of harpacticoid copepods) during the early summer chum salmon outmigration relative to the later emergence period for fall chum salmon due to environmental and/or ecological factors; this could result in a cost benefit trade-off promoting use of shallow embayment features for food and shelter from predators and /or current during cooler winter months. Alternatively, less productive conditions during the early summer chum emergence might encourage rapid emigration (Bax 1983). This would lead to a shorter rearing period within river delta systems and Hood Canal proper (Simenstad and Salo 1982; Bax 1983; Salo 1991). Migrating more swiftly from natal river systems to reach more productive ocean conditions, summer chum may temporarily seek shelter from larger predators and currents in shallow embayments during the brief estuarine rearing period and exit from Hood Canal, resulting in greater relative use of embayment features during a less productive season. This hypothesis is supported by the work of Bax (1983) and Simenstad and Salo (1982) who examined emigration rates and diet during both winter and spring seasons in Hood Canal. During years of study in the late 1970s and early 1980s, chum salmon migrated swiftly from the estuary during winter months (7-14 km/d) and slowed dramatically during the spring (3-5 km/d) (Bax 1983). This difference in emigration timing appeared to be positively correlated with the abundance of epibenthic and neritic zooplankton, which was lower during winter months and greater during warmer spring months (Simenstad and Salo 1982). Therefore, it seems probable that residence within and use of delta habitat by summer chum salmon for rearing purposes may be lower as a result of a general lack of food resources throughout the canal; this would amplify the relative preference for embayment habitat during a less productive season. Whether or not this ecological outcome is an adaptational reaction to present estuarine conditions or the result of historical conditions and evolution remains unknown.

4.2 Other Salmonids

The sampling methodology utilized in this study was selected specifically to discern nearshore habitat use preferences by seasonal runs of chum salmon fry. As a result, salmonids that commonly outmigrate as larger yearlings or subadults (specifically coho salmon, steelhead, and cutthroat trout) were not captured in great enough numbers to enable analyses of stock-specific data. In addition, Chinook salmon fry have become so rare in the Hood Canal nearshore that statistical conclusions could not be drawn from the 2018 sampling effort. Nevertheless, pink salmon escapement, despite being unusually low in 2017, was significant enough to enable statistical analyses to inform future management efforts within the Hood Canal region. Similar to chum salmon, pink salmon exhibited unique habitat use preferences. The species appeared to have an affinity for pocket beach, bluff backed beach, and barrier lagoon habitats within the canal. Occurrence of pink salmon was impacted significantly by shoreline type, with a reduced occurrence probability observed at delta fan and delta channel habitats. These findings generally confirm results of prior habitat studies conducted within Puget Sound, indicating preference for open beach habitats (Beamer et al. 2012). Although occurrence and abundance were driven primarily by time of year and habitat, this analysis also suggests that presence of the species is impacted by temperature and the size and distance to the source of spawning populations (population weighted distance).

Considering recent low returns of ESA-listed Puget Sound Chinook salmon, future investigation of juvenile Chinook salmon use of nearshore estuarine habitats will surely be of importance to regional fisheries managers. This 2018 investigation, among others by WFC in 2016 and 2017 which utilized a larger size of small mesh beach seine, suggest that the beach seining methodology is ineffective in capturing significant quantities of Chinook salmon juveniles in the nearshore environment of Hood Canal to enable effective statistical analyses. Going forward, researchers should consider use of environmental DNA (eDNA) to detect occurrence and relative abundance of rare nearshore species that may evade capture (such as Chinook salmon). Recent advancements in eDNA demonstrate that this sampling methodology is effective in the nearshore environment (Kelly et al. 2018; Tillotsen et al. 2018) and may dramatically increase effectiveness and reduce labor, costs, and handling/stress mortality associated with data collection in the nearshore environment.

4.3 Conclusions

This study represents the first effort to utilize genetic modeling data to retrospectively distinguish summer from fall chum salmon within the Hood Canal nearshore environment. It is the first informed attempt to determine habitat use preferences by chum salmon population group within the region. Results of the study suggest that summer and fall chum salmon fry exhibit differential use of nearshore estuarine habitats within the Hood Canal that may be dependent on seasonal nearshore ecosystem conditions. Given cooler and less productive estuarine emergence conditions, summer chum salmon juveniles emigrate at a faster rate from Hood Canal than later emerging fall chum salmon (Simenstad and Salo 1982; Bax 1983). Differences in nearshore ecosystem conditions and subsequent impacts on emigration likely result in reduced summer chum residence time within seasonally unproductive delta habitats; this may increase relative abundance of chum salmon in barrier lagoons and barrier estuaries within the Hood Canal outmigration corridor during cooler winter months. These findings demonstrate the importance of embayment habitat features (such as barrier lagoons and estuaries) to the recovery of ESA-listed Hood Canal summer chum salmon. Protection and restoration of embayment features (in addition to preferred pocket beach habitats) will help maintain or increase shelter and feeding opportunities for juvenile chum salmon that may seek substitute rearing habitats to seasonally unproductive or anthropogenically diminished river deltas prior to leaving Puget Sound.

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Appendices

A.1 Habitat Type Examples

Figure A-1. Bluff backed beach - these habitats are open shorelines where the upland rises directly landward of the beach forming both high, steep cliffs, as well as more gentle slopes. They are formed as eroding shoreline advances into upland areas developing an erosional platform that underlies the beach with a low-tide terrace.

Figure A-2. Barrier beach - these open beaches are formed by the transport and deposition of sand and gravel seaward of the original coastline. They consist of a relatively continuous ridge of sand and gravel rising a small distance above high tide. Barriers often form across embayments in the coastline, at distinct bends in the shoreline, or where sediment transported alongshore converges from two directions.

Figure A-3. Pocket beach - these open beaches are typically compartmentalized between rocky headlands and promontories. They are primarily comprised of coarse sediment. This shore form is generally oriented perpendicular to the major direction of wave approach (swash-aligned).

Figure A-4. Barrier lagoon – these habitats are tidal embayments that lack a significant freshwater source such as a perennial stream.

Figure A-5. Barrier estuary – these habitats are estuarine embayments with a significant freshwater source that are partially isolated from open marine water by a barrier beach and with tidal exchange occurring through a narrow entrance channel (Shipman 2008).

Figure A-6. River delta channel – these habitats are distributaries or blind channels through a delta’s alluvial fan.

Figure A-7. River delta alluvial fan – these habitats are the shallow fan of a delta formed by deposition of sediment carried by a large river system. They are often characterized by fine sediments.

Figure A-8. Stream delta alluvial fan – These habitats are the shallow fan of a delta formed by deposition of sediment carried by a small river or stream system.