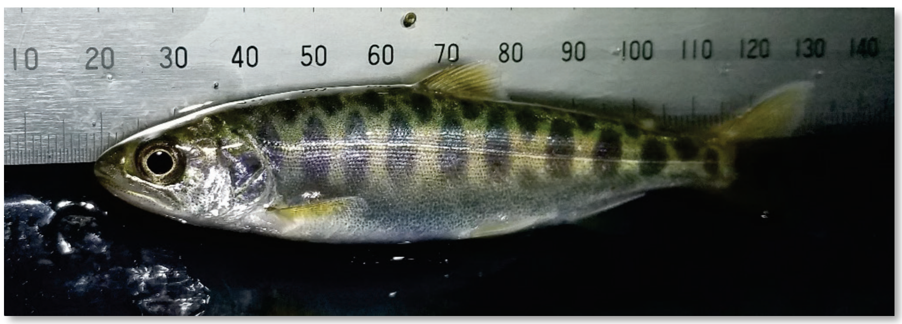
Snoqualmie River Juvenile Chinook with Extended Freshwater Rearing



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Snoqualmie River Juvenile Chinook with Extended Freshwater Rearing

Prepared for:

Snoqualmie Watershed Forum

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Citation

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EXECUTIVE SUMMARY

Snoqualmie River juvenile Chinook salmon (*Oncorhynchus tshawytscha*) display three distinct freshwater rearing and outmigration strategies: fry and parr, which spend days to months in freshwater habitats, and yearling, which spend up to a year in freshwater before outmigration. A portfolio of strategies helps to buffer inter-annual variability in environmental conditions and population dynamics, which spreads out demographic risks and decreases chances of encountering unsuitable environmental conditions. The importance of the yearling Chinook life history in the Snoqualmie River is apparent since they have greater marine survival compared to sub-yearling, contribute a considerable proportion of retuning adults, and return as older-larger adults. However, there is minimal information on juvenile yearling Chinook ecology and behavior in the Snoqualmie River. Thus, we conducted a study to better understand the yearling Chinook life history.

This report summarizes results of juvenile Chinook surveys conducted in the lower mainstem of the Snoqualmie River from October 2019 to February 2020. Further understanding juvenile yearling Chinook will be integral for salmon conservation, in particular, strategies aiming to support juvenile yearling Chinook and life-history diversity.

What was the distribution of juvenile yearling Chinook in fall and winter across the lower mainstem of the Snoqualmie River?

Juvenile yearling Chinook were consistently observed throughout the lower mainstem Snoqualmie River from October 2019 to February 2020. The number of sites where yearling Chinook were detected decreased from October to February. This may have been the result of volitional outmigration, displacement by floods, or mortality. During fall and winter, especially after floods, yearling Chinook may use floodplain channels and tributaries. However, there is little information on floodplain and tributary habitat use in the Snoqualmie River; thus, further research is needed.

Which mainstem edge habitats do juvenile yearling Chinook use during fall and winter?

Juvenile yearling Chinook use a variety of mainstem edge habitats during fall and winter. Yearling Chinook abundance in October was greater among unarmored banks, bars, and tributary confluences while abundance in December was greatest among bars and armored/unarmored banks. Yearling abundance was lowest in February and greater among armored banks and tributary confluences.

Yearling Chinook displayed minimal changes in size during fall and winter, suggesting minimal activity, feeding, and growth. During winter, yearling Chinook were frequently observed among both armored and unarmored banks. Bank habitats may provide shelter within coarse substrates, aquatic vegetation, roots, and large wood. Juvenile Chinook are known to prefer unarmored banks, compared to armored banks; however, over 47% of the lower Snoqualmie River is armored with bank armoring concentrated across reaches

where spawning and early rearing occurs. The prevalence and extent of bank armoring likely influences the availability and proximity of preferred unarmored banks.

Observation of juvenile yearling Chinook among tributary confluences, particularly in February, points to the importance of tributary connectivity and confluence areas for feeding, foraging, and refuge. Tributary confluences could also be where juveniles end up back in the mainstem Snoqualmie River after flood events.

Do juvenile Chinook, including all life histories, display size-specific habitat use and shifts in habitat use across seasonal periods?

Juvenile Chinook display distinct size-specific habitat use, which shifts as they grow and transition through early life stages. Smaller-younger juvenile Chinook were most frequent among bars and backwaters, which generally have greater low-velocity areas compared to other edge habitats; low-velocity areas are important for early life stages. Juvenile Chinook primarily used backwaters during late winter and early spring where they then shifted to using bars and unarmored banks from summer throughout fall and winter. Larger-older juvenile Chinook were most frequent among bars and banks, both unarmored and armored, throughout fall and winter. Larger juveniles have greater swimming abilities which may allow them to select higher-velocity bank habitats. Across seasons, juvenile Chinook were generally infrequent among armored banks with relatively greater abundance observed in winter. Shifts in habitat use highlight the benefits of habitat diversity and suggest that a mosaic of habitats across seasons is likely critical for juvenile Chinook.

Multiple juvenile Chinook size classes and life histories use the mainstem Snoqualmie River. Specifically, there are distinct seasonal modes in size-class frequencies indicating fry, parr, and yearling. In the Snoqualmie River, smaller juvenile fry and parr Chinook are present all the way into June and July. We speculate that these late-emerging juveniles may be the cohort that overwinters as yearling; however, further research in needed. The late emergence may result in the need for extended freshwater rearing to attain the size and condition needed for smoltification.

Which habitat attributes are associated with juvenile yearling Chinook presence and abundance?

Month, edge habitat type, and edge habitat width were the primary explanatory variables influencing juvenile yearling Chinook abundance. Abundance decreased from fall to winter with bars, unarmored banks, and tributary confluences having greater yearling Chinook abundance, compared to armored banks and backwaters. Wider edge habitats provide more space for rearing, refuge, and foraging areas, compared to narrower edge habitats. Additional factors, not measured in this study, likely influence the distribution, abundance, and habitat-specific use of juvenile yearling Chinook. These factors include resource availability, competitive interactions, large wood and vegetation cover, channel type and characteristics, season, and others.

What are the implications of this information for salmon conservation strategies and restoration projects?

It is essential for salmon conservation strategies in the Snoqualmie River to support juvenile yearling Chinook as well as life-history diversity and abundance. Focused efforts specific to yearling Chinook is ever important since there is a declining trend in the proportion of adults which displayed a juvenile yearling life history and a broader decline in the size of returning adults among Pacific Chinook populations. Since yearling Chinook spend an extended period among freshwater habitats, targeted conservation strategies focused on freshwater habitat conditions, particularly from summer throughout winter, may be integral in supporting yearling Chinook and life-history diversity. Integrating juvenile yearling Chinook into salmon conservation strategies and restoration projects may include:

- Designing mainstem Snoqualmie River projects with consideration of yearling Chinook habitat use and requirements from summer throughout winter, rather than focusing solely on sub-yearling juvenile Chinook in late winter and spring.
- Ensuring that improved and restored habitat areas are connected and engaged across a range of flows, specifically during summer and winter low flow periods.
- A greater emphasis on mainstem large wood to provide areas for overwintering and to improve edge habitat complexity throughout the year.
- Focused restoration of tributaries and confluence areas through improved connectivity, in-channel habitat diversity, water quality, and riparian buffers.
- Restoring temperature conditions in spring and summer as well as preserving thermal diversity in fall and winter, through widespread riparian restoration, increased channel and floodplain complexity, as well as increased channel, floodplain, and tributary connectivity.
- Adopting a multi-season approach to monitoring habitat conditions, juvenile salmon habitat use, and related juvenile salmon habitat needs.

An integrated salmon conservation approach which considers all juvenile Chinook life histories as well as habitat conditions across seasons may prove most effective. Supporting life-history diversity will help Chinook populations withstand environmental-population variability and will ensure that restoration and conservation efforts are strategic and comprehensive.

1.0 INTRODUCTION

Across the Puget Sound, Chinook salmon (*Oncorhynchus tshawytscha*) display a diversity of rearing and migration strategies throughout juvenile life stages. A portfolio of strategies helps to buffer inter-annual variability in environmental conditions and population dynamics, which spreads out demographic risks and decreases chances of encountering unsuitable environmental conditions (Hilborn et al. 2003, Kerr et al. 2010, Schindler et al. 2010). The Snoqualmie River supports a population of wild Chinook salmon, which is one of two Chinook populations in the greater Snohomish River Basin. Both Chinook populations are listed as threatened under the Endangered Species Act (SBSRF 2005).

Snoqualmie River juvenile Chinook display three life-history strategies: fry, parr, and yearling. Juvenile fry and parr are collectively known as sub-yearling Chinook, with fry generally spending days to 3 months in freshwater habitats and parr spending 3–6 months prior to migrating downstream. Juvenile yearling Chinook remain in freshwater habitats for an entire year prior to outmigration. Riverine outmigration of sub-yearling Chinook display two separate modes, with fry out-migrating in March and parr out-migrating in May and June (Kubo et al. 2013). Following Snoqualmie River outmigration, sub-yearling Chinook rear for extended periods in the Snohomish Estuary (Rice et al. 2013), adjacent nearshore habitats (Rice et al. 2013), and non-natal coastal streams (Beamer et al. 2013). After extended freshwater rearing, juvenile yearling Chinook out-migrate in late winter and early spring of the following year (Kubo et al. 2013). Juvenile yearling Chinook migrate through estuarine habitats quickly, rather than rearing for an extended period of time like sub-yearling Chinook (Beamer et al. 2005). In general, the larger and older juvenile Chinook are at the time of out-migration, the shorter their residence period in estuarine habitats (Kjelson et al. 1982, Levy and Northcote 1982, Healey 1991).

Life-history diversity, including extended freshwater rearing, may be a result of both genetic variation and phenotypic plasticity to environmental conditions (Ricker 1972, Healy, 1991, Taylor 1990a, 1990b). Differences in gene expression can translate to differential growth rates between sub-yearling and yearling Chinook (Carl and Healy 1984, Taylor 1990b), which can influence the timing of volitional out-migration, condition at out-migration, and subsequent smoltification. These genetic differences can also influence oceanic residence and distribution as well as adult migration and spawn timing (Healy 1991). Differences in environmental conditions can also influence Chinook life-history expression and the tendency of juveniles to display extended freshwater rearing. Environmental conditions that influence rearing strategies include the distance to marine environments, stream stability, stream flow, stream and air temperature regime, stream and estuary productivity, and general weather regimes (Taylor 1990a, Myers et al. 1998). Environmental conditions that decrease metabolic potential, limit growth, and limit feeding-foraging opportunities may result in juveniles needing extended freshwater residence to attain the size and condition required for smoltification. However, the tradeoff between extended freshwater rearing versus winter mortality encourages diversity in juvenile life history strategies (Dodson et al. 2013).

Juvenile salmon outmigration monitoring, conducted by the Tulalip Tribes, has provided estimates of Snoqualmie River juvenile salmon abundance since the early 2000s. There are limitations in estimating the abundance of the yearling life-history, since the rotary screw trap is less efficient at capturing yearling size classes; however, these monitoring observations are the best yearling abundance estimates available at this time. Juvenile salmon outmigration monitoring indicates that the majority of juvenile Chinook in the Snoqualmie River display the sub-yearling life histories and out-migrate within their first year; averaging 88% of overall catch from 2001 to 2019 (Kubo et al. 2013; Matt Pouley, Tulalip Tribes pers. comm.). However, a small proportion of yearling Chinook are consistently observed; averaging 12% of overall catch from 2001 to 2019. While the proportion of juveniles displaying the yearling life history is generally small, scale analyses conducted on spawning adults indicates that up to 35% of returning adults had a juvenile yearling life history (Diego Holmgren and Mike Crewson, Tulalip Tribes pers. comm.). Furthermore, Snoqualmie yearling Chinook tend to return as older-larger adults, typically 5–6 years old, compared to sub-yearling Chinook, which generally return at 3–4 years old.

Yearling Chinook can have greater marine survival compared to sub-yearling Chinook (Beamer et al. 2005) and the consistent contribution of yearling juveniles to returning adult cohorts highlights their importance in supporting population abundance and life-history diversity. However, there's a declining trend in the proportion of returning Snoqualmie River adult Chinook which had a juvenile yearling life history (Mike Crewson, Tulalip Tribes pers. comm.), and a broader decline in the size of returning adults among Pacific Chinook populations (Oke et al. 2020)(discussed in Section 4.0). These declining trends as well as the importance of yearling Chinook in maintaining life-history diversity emphasize the need to better understand how conservation and restoration efforts can bolster this life-history strategy.

Yearling Chinook have been opportunistically observed among mainstem, tributary, and floodplain areas across the lower Snoqualmie River watershed (King County 2017a); however, observations have been relatively infrequent and there hasn't been a concerted effort to monitor this specific life history. The majority of juvenile Chinook observations among mainstem areas has occurred during the sub-yearling rearing period (late winter to early summer). In an effort to understand the ecological and behavioral patterns specific to the yearling life-history, this study aimed to assess juvenile yearling Chinook patterns in fall and winter across the mainstem Snoqualmie River. The primary questions of this study included:

- What is the distribution of juvenile yearling Chinook during fall and winter across the lower mainstem of the Snoqualmie River?
- Which mainstem edge habitats do juvenile yearling Chinook use during fall and winter?
- Do juvenile Chinook, including all life histories, display size-specific habitat use and shifts in habitat use across seasonal periods?
- Which habitat attributes are associated with juvenile yearling Chinook presence and abundance?

2.0 METHODS

2.1 Survey Extent, Reaches, and Periods

The presence, distribution, and abundance of juvenile yearling Chinook was surveyed across the lower mainstem of the Snoqualmie River from river mile (RM) 34.3, near the Raging River confluence, downstream to RM 14.2, just upstream of the NE 124th Street bridge (Figure 1). Surveys were conducted among three separate reaches: Raging River confluence downstream to the Neal Road boat launch (reach 1; RM 31 to RM 34.3), Neal Road boat launch downstream to the Tolt River boat launch (reach 2; RM 23.8 to RM 31), and Tolt River boat launch to just upstream of the NE 124th Street bridge (reach 3; RM 14.2 to 23.8).

Each reach was surveyed for juvenile Chinook in October and December 2019 and February 2020. Fall and winter months were selected to target juvenile yearling Chinook since sub-yearling Chinook generally out-migrate from the system by summer (Kubo et al. 2013, Matt Pouley, Tulalip Tribes pers. comm.). While juvenile Chinook observed in October and December have not yet reached a year of age, for this study we categorized all juveniles displaying extended freshwater rearing as yearling Chinook.

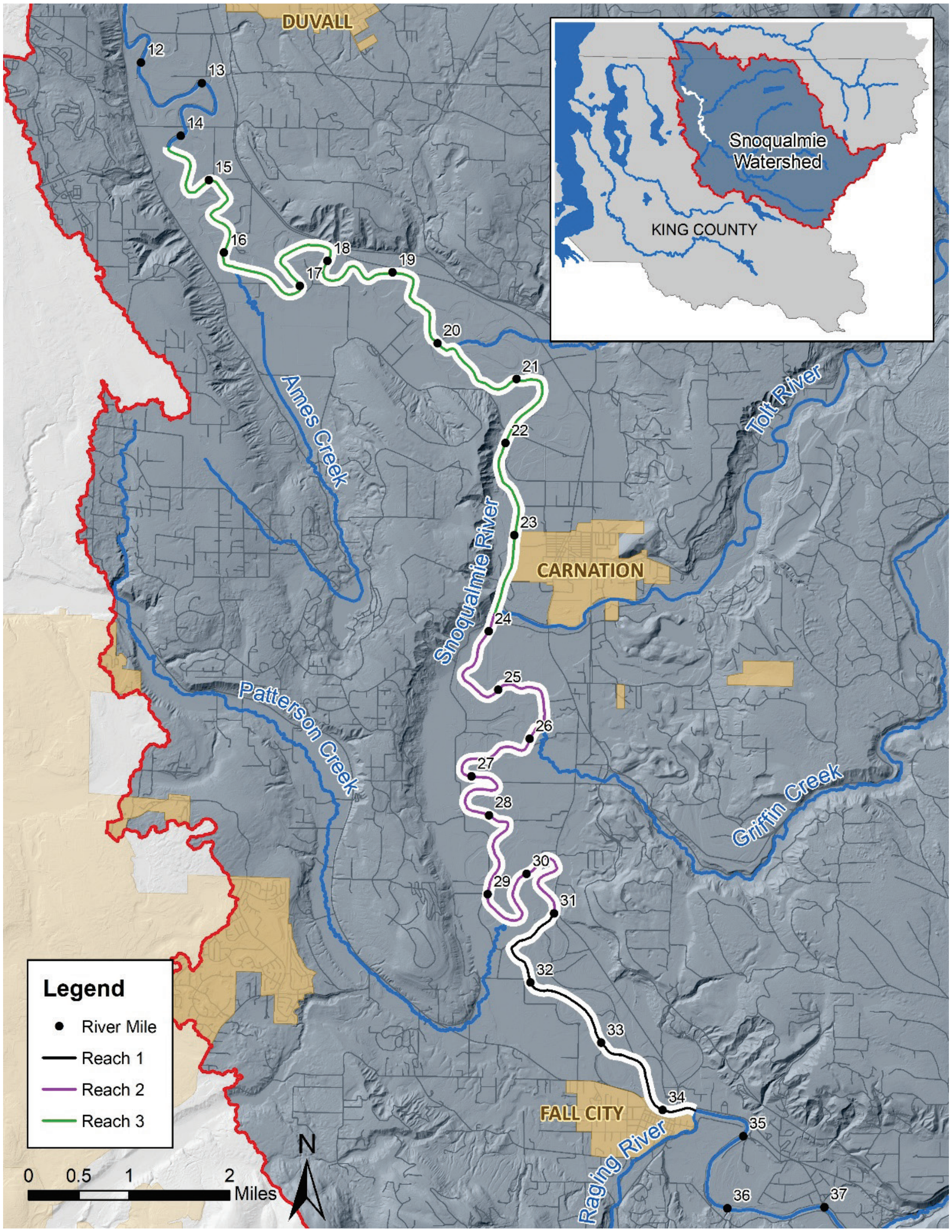

Figure 1. Juvenile yearling Chinook survey extent across the lower mainstem Snoqualmie River.

2.2 Edge Habitat Characterization and Transect Survey Locations

This study focused on evaluating juvenile Chinook presence, distribution, and abundance among mainstem edge habitats. Surveys focused on edge habitats since channel margins are often used by juvenile salmon for rearing during early life stages (Hillman et al. 1987, Bjornn and Reiser 1991, Beechie et al. 2005). Mainstem edge habitats are critical as rearing habitats for juvenile Chinook because they typically have lower water velocities, shallower depths, and greater cover than mid-channel areas (Hayman et al. 1996, Beechie et al. 2005).

Juvenile Chinook survey locations were determined by characterizing edge habitats across the entire mainstem Snoqualmie River survey extent. Edge habitats were characterized as either backwaters, edge-of-channel bars, mid-channel bars, unarmored banks, riprap armored banks, bioengineered armored banks, or tributary confluences (Table 1; see Appendix A for photos). From the combined pool of all edge habitat locations, a subset of specific survey transects were randomly selected for each edge habitat type. Multiple replicate locations for each edge habitat type were selected for transect surveys. In select reaches, a small number of potential survey transects were available for a given edge habitat type (e.g., bioengineered revetment banks and tributary confluences), so all representative transects were sampled. A new set of survey transect replicates were randomly selected for each monthly survey period.

Table 1. Mainstem edge habitat types and descriptions. Photos included in Appendix A.

Edge Habitat Type	Description
Armored Bank (riprap armored bank & bioengineered armored bank)	Riprap armored: Steep-gradient bank armored with placed riprap or large angular rock, designed to limit lateral channel migration. Bioengineered armored: Engineered bank feature designed to limit lateral channel migration, generally steep in gradient with placed riprap rock and/or large wood (e.g., engineered log structures, log jacks, and wood revetments). Designed to be resistant to erosion and increase channel roughness or redirect flow. Bioengineering features can improve edge habitat conditions compared to solely riprap rock.
Backwater	Partially enclosed slack-water area separated from the main river channel and often at the downstream/upstream end of a disconnected side-channel or behind a flow blocking feature (such as a gravel bar or wood jam). During most flows, backwater features are deposition zones for fine substrate, suspended sediments, and organic debris.
Bar (edge-of-channel bars & mid-channel bars)	Low-gradient depositional areas generally consisting of sand and gravel.
Unarmored Bank	Steep-gradient bank where erosional lateral channel migration is occurring with no artificial hardening.
Tributary Confluence	Transition area between a defined tributary stream/creek channel and the main river channel. Generally containing eddies or a strong current shear line (velocity line between high and low velocity flows).

2.3 Juvenile Chinook Surveys

Within each selected mainstem edge habitat type and replicate, a 25-m long transect was surveyed for juvenile Chinook presence and abundance using a cataraft-based electrofishing approach. The electrofishing cataraft was built by King County staff to specifically monitor juvenile salmonids in large rivers. The cataraft set-up consists of an aluminum rowing frame, 14' inflatable PVC tubes, flood lights, anode and cathode arrays, as well as Smith-Root 2.5 GPP electrofishing components. A cataraft approach was selected over snorkeling because turbidity in the Snoqualmie River can make it difficult to identify juvenile salmonids to species level during snorkel surveys (Martin Environmental and Shreffler Environmental 2002, Washington Trout 2003). Additionally, a cataraft approach was selected over net seining because a majority of the lower Snoqualmie has steep banks, making bank-based net seining difficult.

Electrofishing began about 30 to 60 minutes after sunset. Fish sampling occurred during hours of darkness, rather than daylight, because juvenile salmonids are mainly crepuscular/nocturnal during winter and early spring (Rosberg and Associates 1987, Emmett and Convey 1990, Bradford and Higgins 2001). Juveniles tend to hide during the day to avoid visual-based predators and come out under the cover of darkness to forage/feed (Metcalfe et al. 1999, Bradford and Higgins 2001). Additionally, previous observations among King County large river project monitoring efforts indicated that cataraft-based electrofishing had greater capture rates during darkness.

Along each 25-meter transect, fish were sampled by orienting the electrofishing cataraft towards the water's edge with the anode arrays placed within the edge habitat (~1.5 m away from channel's edge). Once at the start of the transect (upstream extent), two netters on the front of the boat began electrofishing, netting any stunned fish and placing them in a holding bucket, as the pilot maneuvered the cataraft along the shore to the end of the transect (downstream extent). The pilot of the cataraft rowed along each transect and controlled the generator and electrofishing settings. After each transect, the pilot recorded the effort (seconds of electrofishing) and fish data. Captured fish were anesthetized using MS-222, identified to species or genus, measured for fork length (tip of the head to the fork in the caudal fin), and then placed in a bucket of fresh water until they were fully recovered and could be released safely.

2.4 Aquatic Habitat Surveys

Edge habitat characteristics among surveyed transects were measured during the week of each juvenile Chinook survey. Characteristics included edge habitat width and depth, large wood presence and dimensions (length and diameter classes), substrate composition, and temperature. Width and depth were measured every 5 meters, for a total of five measurements per transect. Depth measurements were taken at 1.5 meters from the water's edge, since this was the area where electrofishing would occur. Width measurements were taken from the channel wetted edge to the extent of the edge habitat area, where flows change from lower-velocity edge habitats to higher-velocity mid-channel

areas. Depth and width measurements were collected from a cataraft using a stadia rod and laser rangefinder during a cataraft float survey.

2.5 Analyses

The relative abundance of juvenile Chinook across edge habitat types was evaluated through catch-per-unit-effort (CPUE), which was determined by dividing the number of Chinook captured at each transect by the amount of time in seconds spent actively electrofishing (Crozier & Kennedy 1994). Relative abundance represented by CPUE as compared to a density or overall abundance estimate can be beneficial for two reasons. First, CPUE is a semi-quantitative method that requires less time and fewer personnel to complete than methods used to estimate absolute abundance such as complete census observations, mark/recapture, and removal methods (Crozier and Kennedy 1994, Guy and Brown 2007, Van Den Avyle and Hayward 1999). Second, large river environments are inherently difficult to sample, which makes estimating absolute abundance and density difficult.

To understand size-specific habitat use and shifts in habitat use across seasons, observations from this study were combined with project effectiveness monitoring data from Snoqualmie-specific large river projects. Past project monitoring efforts primarily focused on juvenile salmonid presence and abundance between late winter and early summer, targeting the spring rearing and outmigration period for sub-yearling Chinook. Combining project monitoring data sets with observations from this study, which targeted yearling Chinook during fall and winter, help to provide insight into potential seasonal shifts in habitat use and abundance. The projects included in this combined evaluation were: (1) located on the mainstem Snoqualmie River within the study survey extent, (2) had comparable juvenile salmonid data collection methodologies, and (3) had similar edge habitat types (i.e., backwaters, bars, unarmored banks, armored banks). The selected projects included two restoration projects (Upper Carlson Restoration and Floodplain Connection; Chinook Bend and Stillwater Restoration and Floodplain Connection) and two bank stabilization projects (SE 19th Protection; Sinnema Quaale SR-203 and Snoqualmie Trail Protection). Project monitoring data sets had few tributary confluence observations; thus, tributary confluences were not included as an edge habitat type in the combined analysis. Similar to the evaluation of juvenile Chinook abundance across edge habitat types, the seasonal evaluation used relative abundance (CPUE).

To evaluate explanatory variables potentially associated with observed juvenile Chinook distribution and abundance, we used classification and regression tree analyses (Breiman et al. 1984). Classification and regression trees (CART) are statistical methods which use recursive partitioning to separate a response variable into groups based on the values of explanatory variables. Response variables can be categorical (classification trees) or numeric (regression trees) and the explanatory variables can be categorical and/or numeric. The explanatory variables analyzed in this study include month, reach, edge habitat type, temperature (°C), flow (USGS 12149000 near Carnation, WA), edge habitat average width (m), edge habitat average depth (m), and total large wood count. CART methods represent the structure of the data in a simple and interpretable way and can

handle non-parametric data and high-level interactions between variables (De'ath and Fabricius 2000, Strobl et al. 2009). Trees are built by first splitting the data based on the predictor variable with the strongest association with the response variable, after testing associations with every predictor variable within the dataset. The process is then applied separately to each partitioned subgroup recursively aiming to differentiate mutually exclusive groups, each of which are as homogeneous as possible. Finally, the tree can be pruned back to the partition level that best fits the data by finding the level where additional splitting does not improve the model fit. This is done by comparing complexity parameter values at each partition and selecting the complexity that has the least cross-validation error. The complexity parameter is similar to a cost statistic which adds a penalty for increasing tree complexity. The final pruned tree represents the model that has the least cross-validation error and best fits the response variable.

There are several limitations across juvenile Chinook abundance observations due to the methods used, salmonid behavioral-ecological patterns, as well as habitat access and availability. The electrofishing capture probability across each edge habitat type is likely different and could influence respective abundance estimates. For example, it is likely that cataraft-based electrofishing has greater sampling efficiency among shallower edge habitats like bars and some backwaters since the electrical field as well as fleeing fish are constrained by habitat boundaries, compared to steep/deep bank habitats. Capture efficiency declines with depth (Zale et al. 2012), thus CPUE values for deeper edge habitats are likely biased low. Future analysis and comparison across sample methodologies may be needed to develop appropriate correction factors.

Observations may also be influenced by habitat availability and proximity. If certain preferred edge habitat types are absent from reaches or mainstem areas, habitat-use patterns may be skewed to different edge habitat types. For example, the literature suggests that juvenile Chinook prefer unarmored banks, compared to riprap armored banks (Knudsen and Dilley 1987, Beamer and Henderson 1998, Quigley and Harper 2004). Unarmored banks may be the preferred bank habitat; however, a significant portion of the lower Snoqualmie River has bank armoring (King County 2018). Widespread bank armoring likely limits the availability and spatial proximity of suitable unarmored bank habitats, which may result in juveniles using armored banks or other edge habitat types.

3.0 RESULTS AND DISCUSSION

3.1 What was the distribution of juvenile Chinook in fall and winter across the lower mainstem of the Snoqualmie River?

A total of 179 juvenile yearling Chinook were observed across the entire survey season, including 105 in October, 45 in December, and 26 in February. Juvenile yearling Chinook were consistently observed across all three survey reaches (Table 2). Across months, yearling Chinook were distributed throughout the survey extent, from the Raging River downstream to the NE 124th St Bridge (Figure 2–Figure 4). Yearling Chinook were found at fewer locations in December compared to October, and at even fewer locations in February, compared to the previous two survey periods.

Decreases in juvenile yearling Chinook presence as the survey season progressed may be the result of volitional outmigration, displacement by floods, or mortality. Specific to flooding, after the October survey event the Snoqualmie River had a large flood (Figure 5), which may have displaced juveniles downstream or onto floodplain and tributary areas. Several large floods between the December and February survey events (Figure 6) might have resulted in similar juvenile Chinook displacement and/or redistribution. Despite the floods, juvenile yearling Chinook were still consistently observed across the mainstem Snoqualmie River. These observations highlight the benefits of floodplain, tributaries, and off-channel areas for flood refuge. While observations decreased among mainstem areas, yearling Chinook were likely concurrently using floodplain channels and tributaries. Juvenile yearling Chinook are known to use floodplain channels during winter periods (Lowery et al. 2013); however, floodplain use in the Snoqualmie River is a data gap and requires further research.

Table 2. Juvenile Chinook observations across edge habitats and survey reaches in the lower mainstem Snoqualmie River (October and December 1999, February 2020). Note: due to flooding in February and logistical challenges, reaches 1 and 2 were surveyed during a single event resulting in less replicates for each edge habitat type among a given reach.

		Overall Juvenile Chinook Catch (transect replicates)		
Reach	**Edge Habitat Type**	**October**	**December**	**February**
Reach 1 (RM 31 to RM 34.3)	Armored Bank	2 (4)	1 (3)	2 (2)
	Backwater	0 (2)	0 (2)	0 (3)
	Bar (edge-of-channel)	14 (4)	9 (5)	3 (3)
	Bar (mid-channel)	0 (1)	0 (2)	0 (1)
	Unarmored Bank	9 (3)	4 (3)	2 (2)
	Tributary Confluence	-	-	-
Reach 2 (RM 23.8 to RM 31)	Armored Bank	4 (3)	4 (3)	1 (2)
	Backwater	0 (1)	0 (1)	0 (1)
	Bar (edge-of-channel)	8 (3)	3 (3)	0 (1)
	Bar (mid-channel)	21 (3)	1 (3)	0 (2)
	Unarmored Bank	5 (3)	3 (4)	1 (2)
	Tributary Confluence	6 (4)	1 (3)	0 (3)
Reach 3 (RM 14.2 to 23.8)	Armored Bank	1 (4)	12 (3)	0 (2)
	Backwater	3 (2)	0 (2)	2 (3)
	Bar (edge-of-channel)	7 (4)	3 (4)	1 (4)
	Bar (mid-channel)	11 (2)	2 (4)	0 (3)
	Unarmored Bank	17 (3)	1 (3)	1 (4)
	Tributary Confluence	-	1 (2)	13 (3)

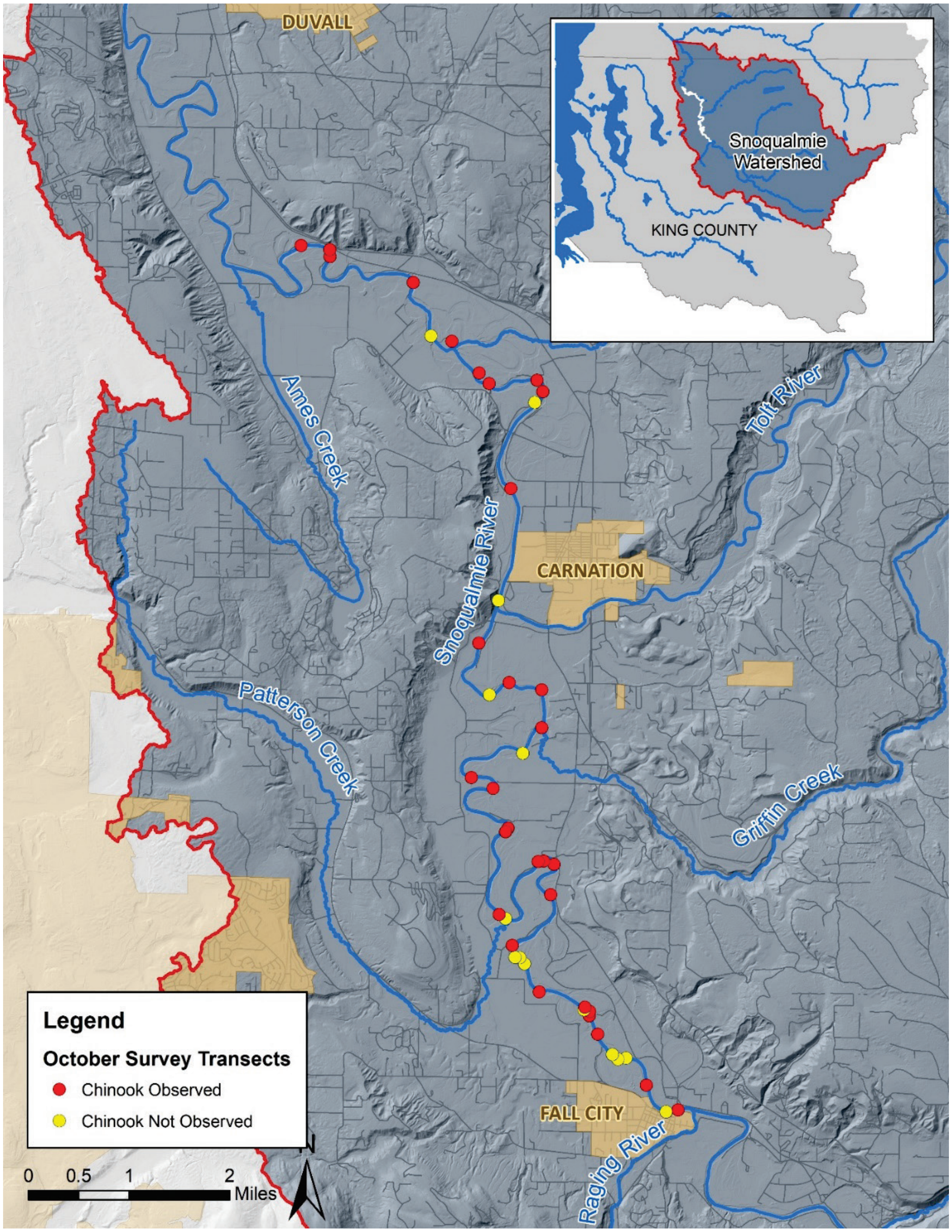

Figure 2. Juvenile Chinook obervations in October 2019 across randomly selected survey transects in the lower mainstem Snoqualmie River.

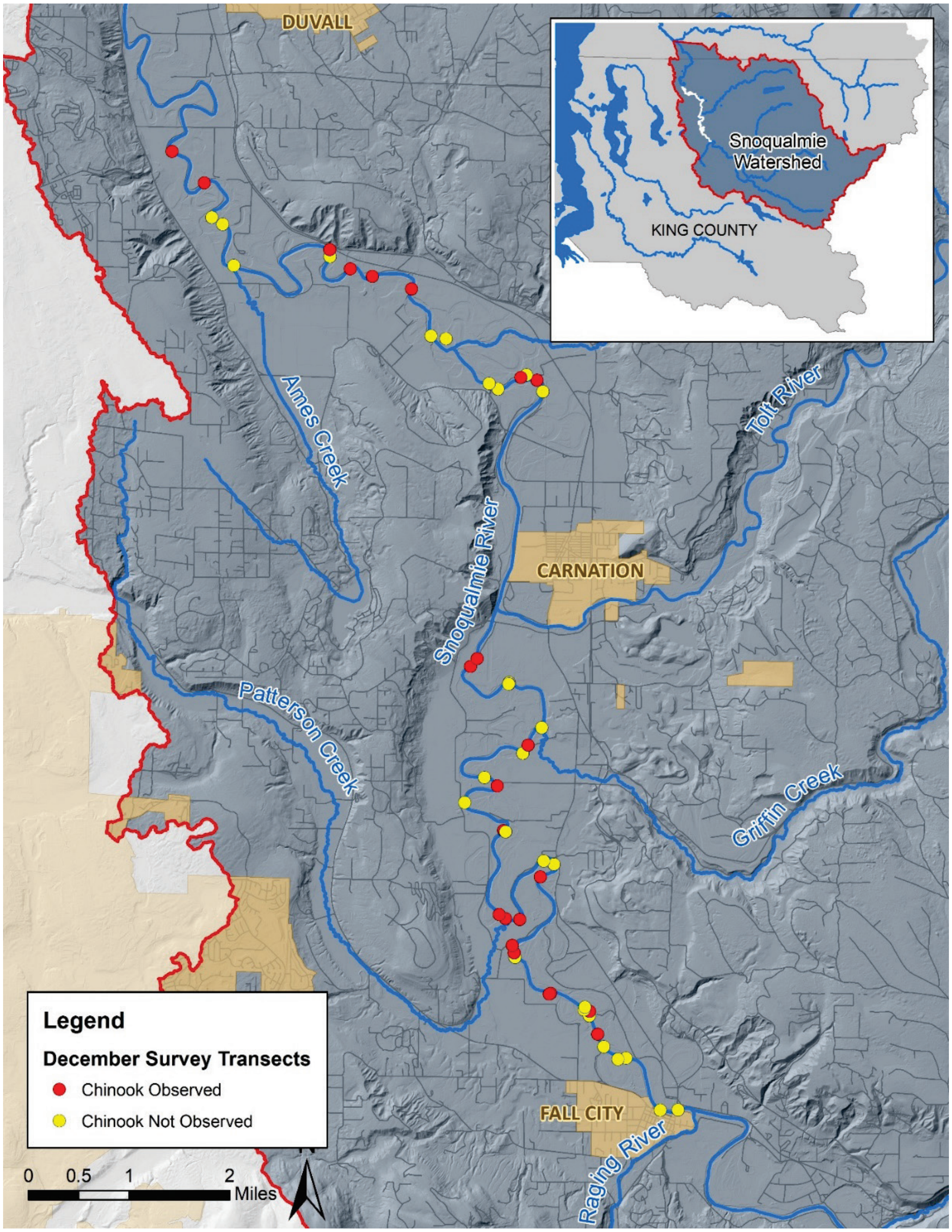

Figure 3. Juvenile Chinook obervations in December 2019 across randomly selected survey transects in the lower mainstem Snoqualmie River.

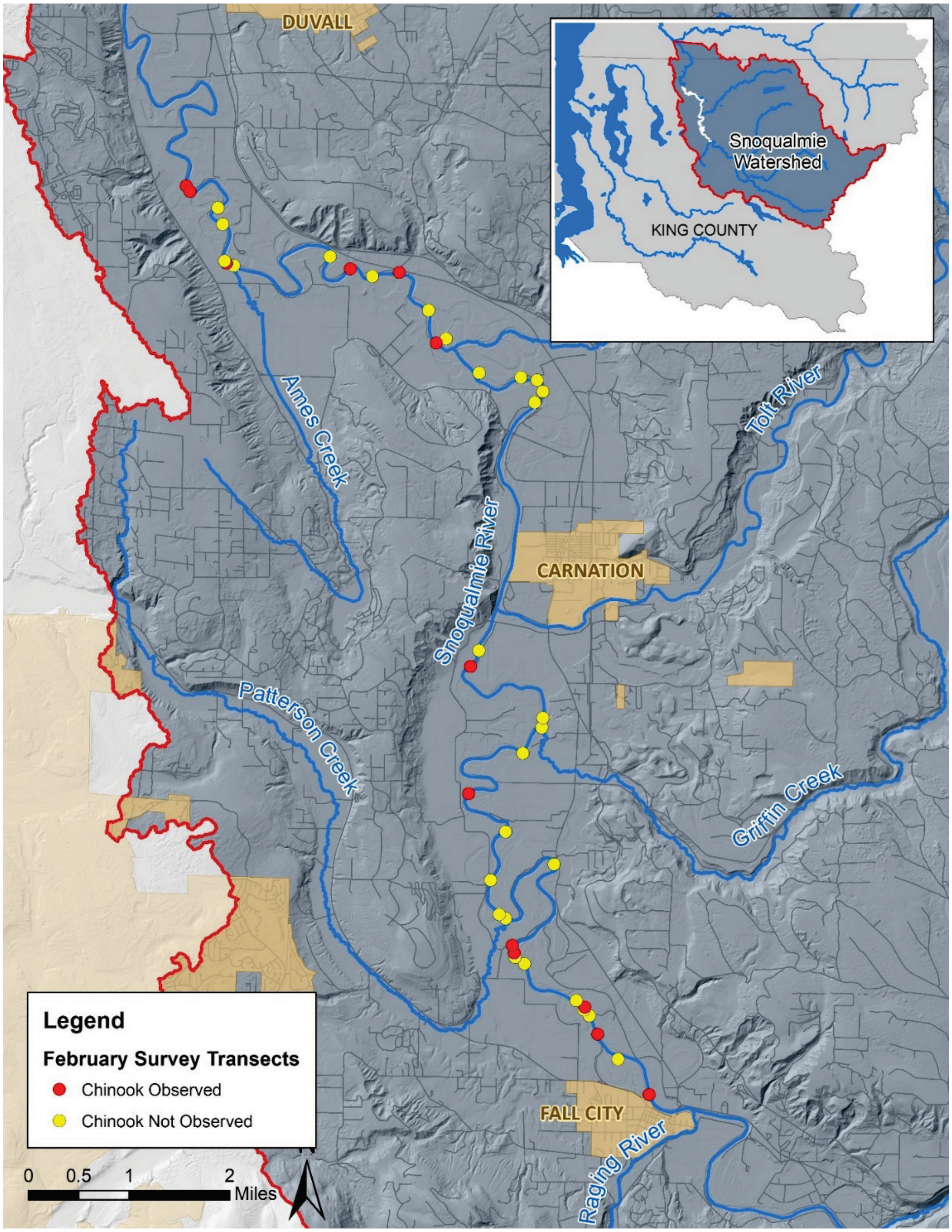

Figure 4. Juvenile Chinook observations in February 2020 across randomly selected survey transects in the lower mainstem Snoqualmie River.

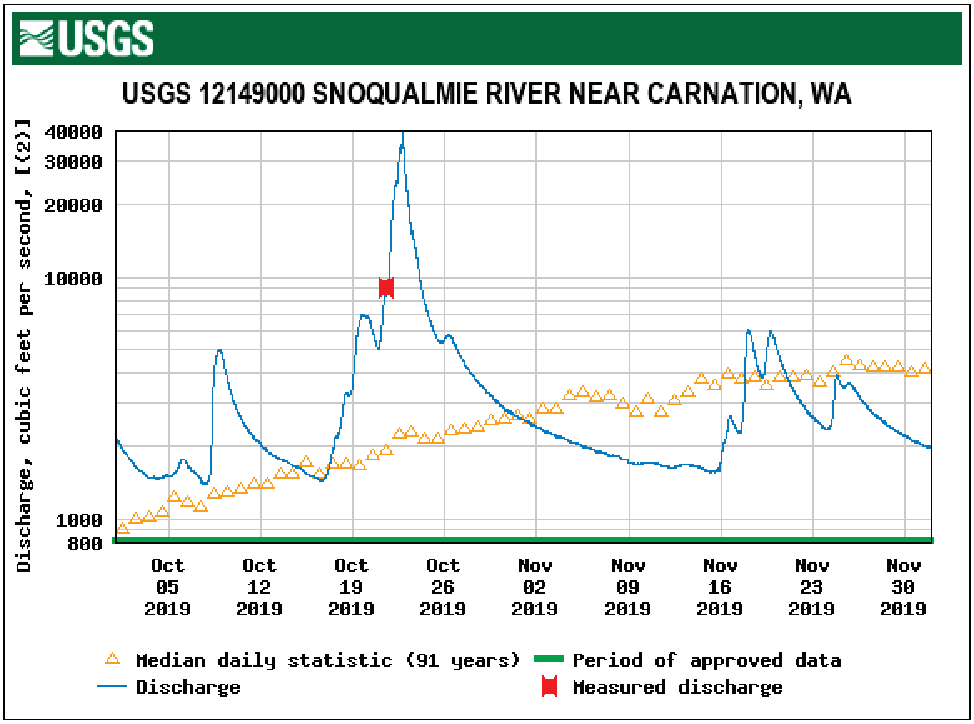

Figure 5. **Snoqualmie River discharge (cubic feet per second) near Carnation, WA (USGS 12149000) from October through November 2019.**

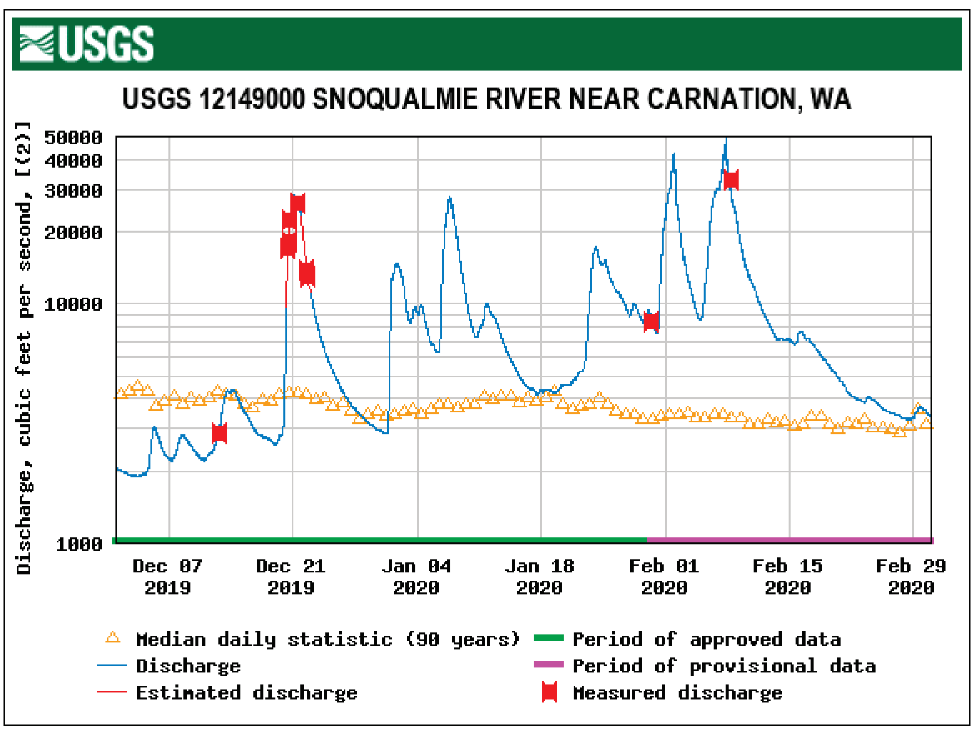

Figure 6. **Snoqualmie River discharge (cubic feet per second) near Carnation, WA (USGS 12149000) from December 2019 through February 2020.**

3.2 Which mainstem edge habitats do juvenile Chinook use during fall and winter?

Juvenile yearling Chinook were consistently observed across the entire suite of surveyed edge habitat types, with the exception of backwaters (Figure 7 and Table 2). During the October surveys, Chinook were more abundant among unarmored banks, bars, and tributary confluences, compared to armored banks and backwaters. In December, abundance was greater among armored banks, unarmored banks, and bars. In February, abundance was greater among armored banks and tributary confluences.

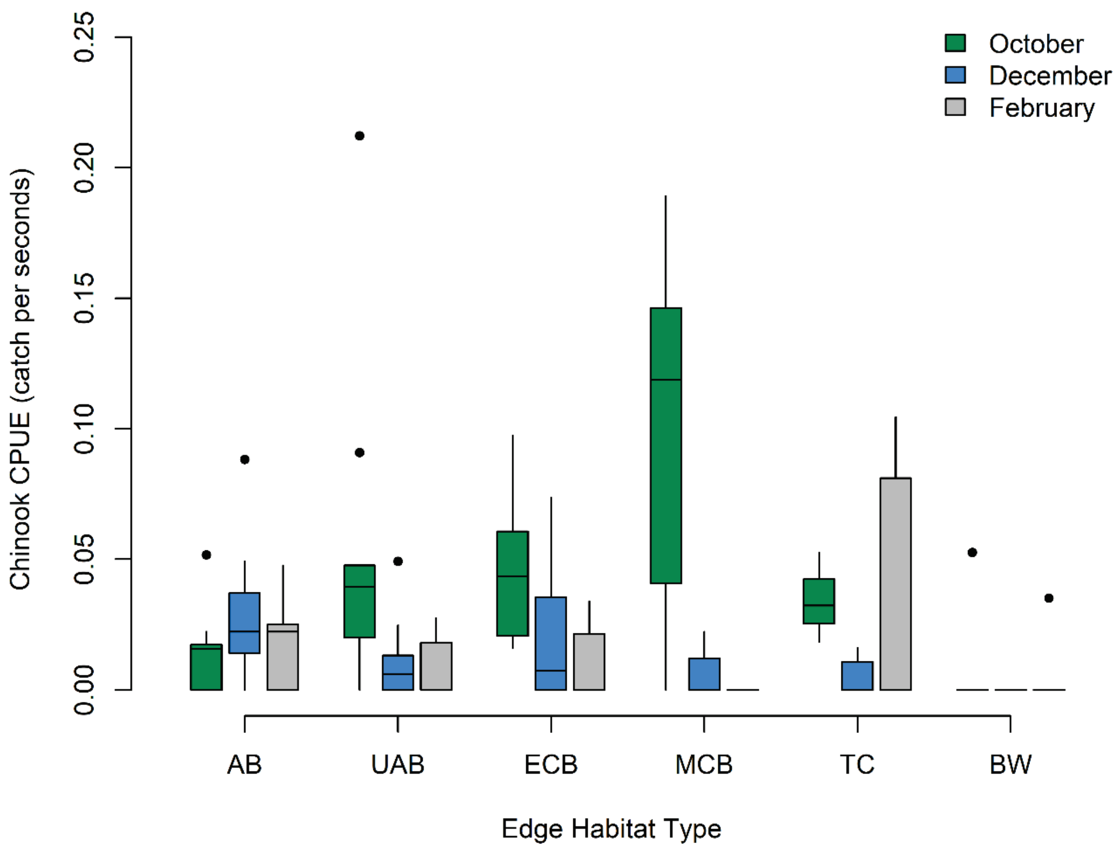

Figure 7. The relative abundance (CPUE; catch-per-seconds of electrofishing) of juvenile Chinook across edge habitat types and monthly periods. Edge habitat codes: AB (armored banks), UAB (unarmored banks), ECB (edge-of-channel bars), MCB (mid-channel bars), TC (tributary confluences), BW (backwaters). Boxes indicate the first quartile, median, and third quartile. The whiskers indicate maximum and minimum values up to 1.5x the inter-quartile range and the points are observations beyond 1.5x the inter-quartile range.

During overwintering periods, juvenile salmonids are less active and feed relatively little (Huusko et al. 2007). Our study supports these observations, showing that juvenile yearling Chinook displayed minimal changes in size during fall and winter. For example, the median juvenile yearling Chinook size was relatively similar from October to February (Figure 8), suggesting that feeding and foraging was merely maintaining metabolic needs rather than promoting additional growth. Minimal activity, feeding, and growth was likely due to lower winter water temperatures and lower seasonal food availability.

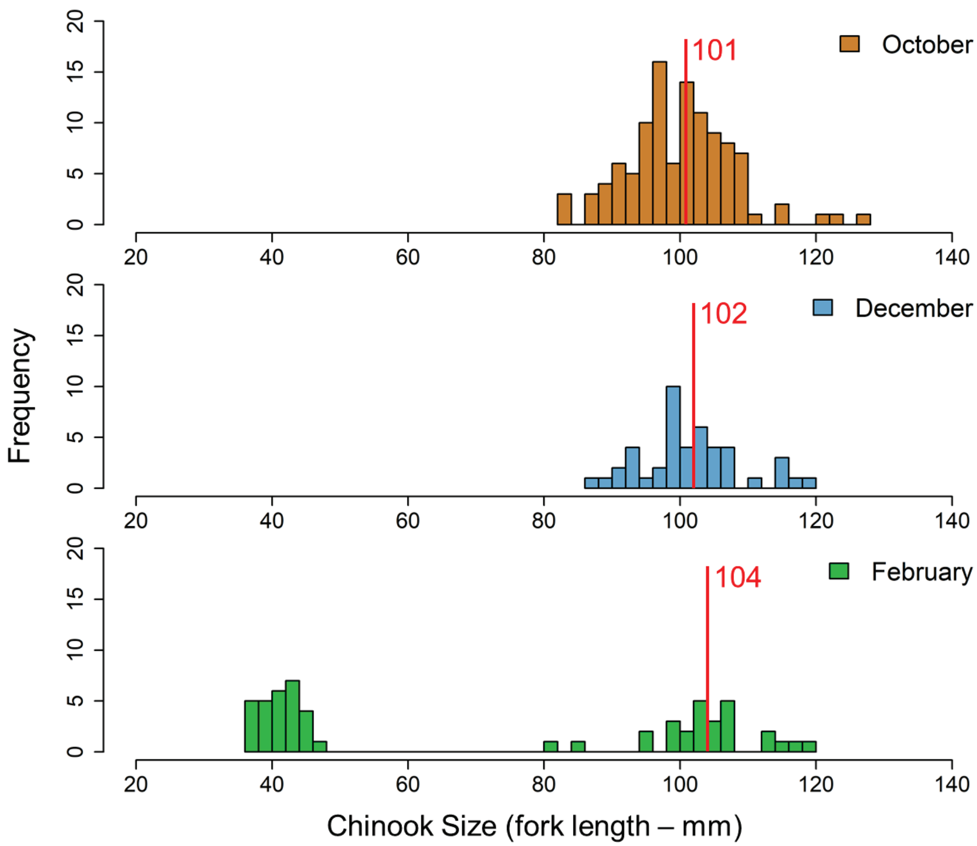

Figure 8. Frequencies of juvenile Chinook sizes (fork length – mm) among surveyed monthly periods. Median size among the larger juveniles (>80 mm) is indicated by the red line with the value noted. The mode of smaller juvenile sizes in February (<50 mm) display sub-yearling Chinook, which were not included in the median calculation.

Observations during winter periods suggest that bank habitats (unarmored and armored) as well as bars may provide potential overwintering areas. Mainstem shoreline edges, particularly bank habitats, are known to support overwintering for juvenile yearling Chinook (Emmett and Convey 1990, Levings and Lauzier 1990, Beamer et al. 2010, Lowery et al. 2013). Among bank habitats, overwintering juvenile salmonids typically use the low-velocity microhabitats among coarse substrates, aquatic vegetation, roots, and large wood, as shelter to minimize swimming energy expenditures, reduce predation risks, and maintain limited foraging (Rosberg and Associates 1987, Muhlfeld et al. 2001, Muhlfeld et al. 2003).

Relatively greater abundance among armored banks, compared to unarmored banks, may indicate that habitat availability rather than solely habitat preference could be driving habitat use. For example, Chinook are known to prefer unarmored banks compared to riprap armored banks (Knudsen and Dilley 1987, Beamer and Henderson 1998, Quigley and Harper 2004). Unarmored banks may be the preferred bank habitat; however, the lower mainstem Snoqualmie River has greater than 47% of its banks armored (King County 2018). Furthermore, bank armoring is concentrated in the mainstem Snoqualmie River within 3 miles below the Raging River (59% armored) and 4 miles below the Tolt River (52% armored); both where spawning and early rearing occurs. This widespread bank armoring likely limits the availability and spatial proximity of suitable unarmored bank habitats, which may result in juveniles using armored banks or other edge habitat types.

Across fall-winter survey periods, few juvenile yearling Chinook were observed among backwaters. These observations were similar to those in the Skagit River where backwaters were infrequently used by juvenile yearling Chinook (Beamer et al. 2010). Backwaters are known to support early Chinook life stages when juveniles are smaller in size and thus more likely to require low-velocity and off-channel areas (discussed further in Section 3.3). Juvenile Chinook tend to shift from using backwaters during early life stages to other edge habitats throughout the year.

During surveys in February, juvenile yearling Chinook were frequently observed among tributary confluences (Figure 7). The benefits of floodplain and tributary habitats for salmonid growth and survival have been well documented (Sommer et al 2001, Jeffres 2008, Rice et al. 2008). Juvenile yearling Chinook in the Snoqualmie River may be using confluence areas for feeding, foraging, and refuge prior to outmigration. Juveniles may have also been found near tributary confluences in February due to the recent flooding. Flood waters may have displaced and re-distributed juvenile Chinook from the mainstem to the surrounding floodplain. The mainstem Snoqualmie River has natural and constructed levees throughout its extent. Thus, as flood waters recede, the floodplain tends to drain through tributaries outlets and low-lying areas, rather than through over-bank flows. This drainage pattern may result in juveniles ending up back in the mainstem after flooding events through tributary confluences.

3.3 Do juvenile Chinook, including all life histories, display size-specific habitat use and shifts in habitat use across seasonal periods?

Combining the observation from this study with mainstem Snoqualmie River project effectiveness monitoring provides useful insight into size-specific habitat use and seasonal shifts in habitat use. When juvenile Chinook are smaller in size and younger, they are most frequently observed among bars and backwaters (Figure 9). Bars and backwaters generally have greater low-velocity areas compared to other edge habitat types (King County 2017b, 2020, in prep.). Shallow slow-water habitats are critical for early juvenile salmonid life stages by proving opportunities for rearing and flow refuge (Beechie et al. 2005). Smaller

size classes of juvenile Chinook also used unarmored and armored banks, but at considerably lower frequencies compared to other edge habitat types. This may be due to smaller juveniles having limited swimming abilities among higher velocity banks habitats (discussed below). These collective observations highlight the importance of bars and backwaters for smaller juvenile Chinook during the earliest life stages.

Larger-older juvenile Chinook were most frequently observed among bars, unarmored banks, and armored banks. These observations suggest that as juvenile Chinook grow and reach larger sizes, they continue to use bars and additionally use bank habitats. Observations of juvenile yearling Chinook, specifically among bank habitats, is likely under-represented since the majority of project monitoring observations do not target the yearling life history and seasons when they use bank habitats. Larger juvenile Chinook may be able to use bank habitats as larger-sized fish have greater swimming abilities among higher-velocity flows. Additionally, bank habitats can have high frequencies of large trout (King County 2020, in prep.), which larger juvenile Chinook may be less vulnerable to, compared to smaller juvenile Chinook, due to greater evading abilities and predator gape limitations.

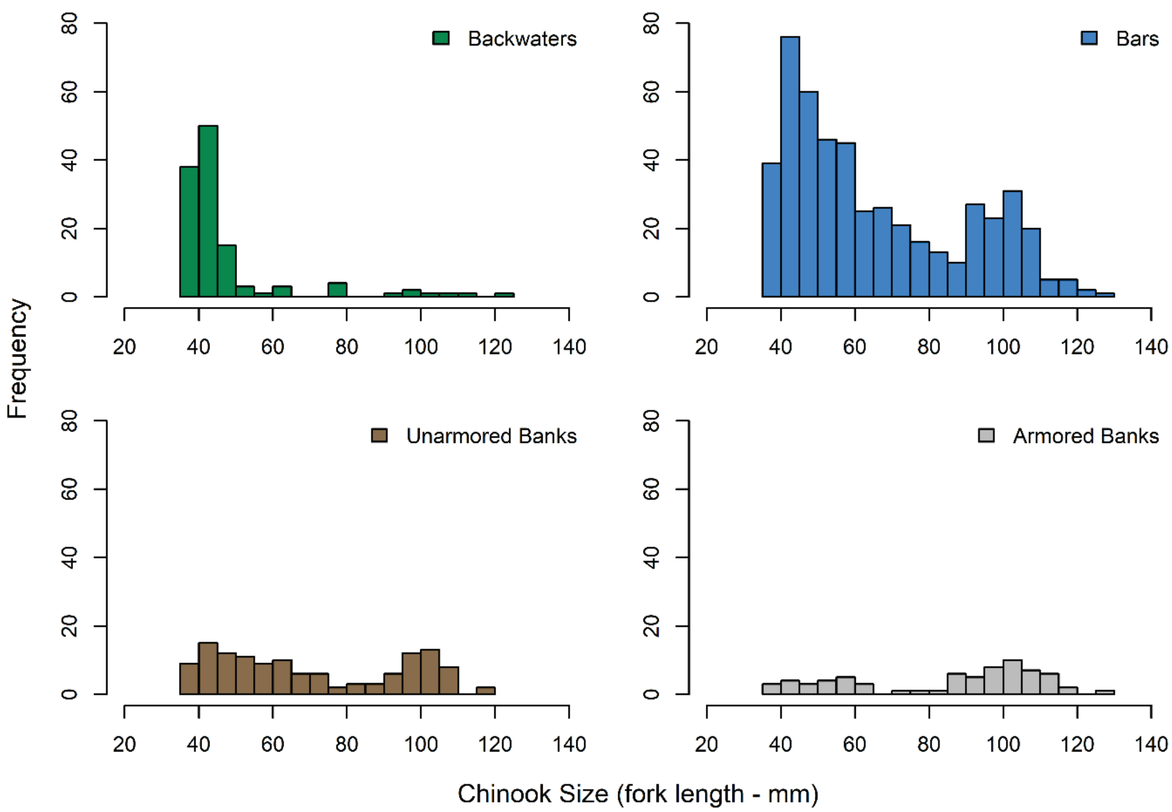

Figure 9. Juvenile Chinook size (fork length – mm) frequency plot across edge habitat types. Plots include observation from this study as well as project monitoring observations from select mainstem Snoqualmie River projects (discussed in Section 2.5). Larger size clases are likely under-represented since the majority of monitoring observations do not target the yearling life history.

Juvenile Chinook display a shift in habitat use as they grow and transition through early life stages. Juvenile Chinook primarily use backwaters during late winter and early spring, with peak abundance occurring from March through May (Figure 10). As juvenile Chinook grow during spring and early summer, they shift from using backwaters to using bars and unarmored banks, with peak abundance in these two habitats occurring around May through July. Juvenile Chinook may use mainstem edge habitats throughout summer, as noted by Lowery et al. (2013); however, there is limited data during these periods in the Snoqualmie River and thus only speculation. Juvenile Chinook continue to use bars and unarmored banks during fall and winter periods. Observations of juvenile Chinook among armored banks are low, compared to other edge habitat types, with relatively greater abundance observed during winter (Dec–Feb). The late-winter period is when juvenile Chinook are largest in size. Similar to size-specific observations, seasonal habitat use from summer throughout winter are likely under-represented since the majority of monitoring observations do not target the yearling life history. Collectively, seasonal shifts in habitat use highlight the benefits of habitat diversity and suggest that a mosaic of habitats across seasons is likely critical for juvenile salmon as they grow and transition through early life stages.

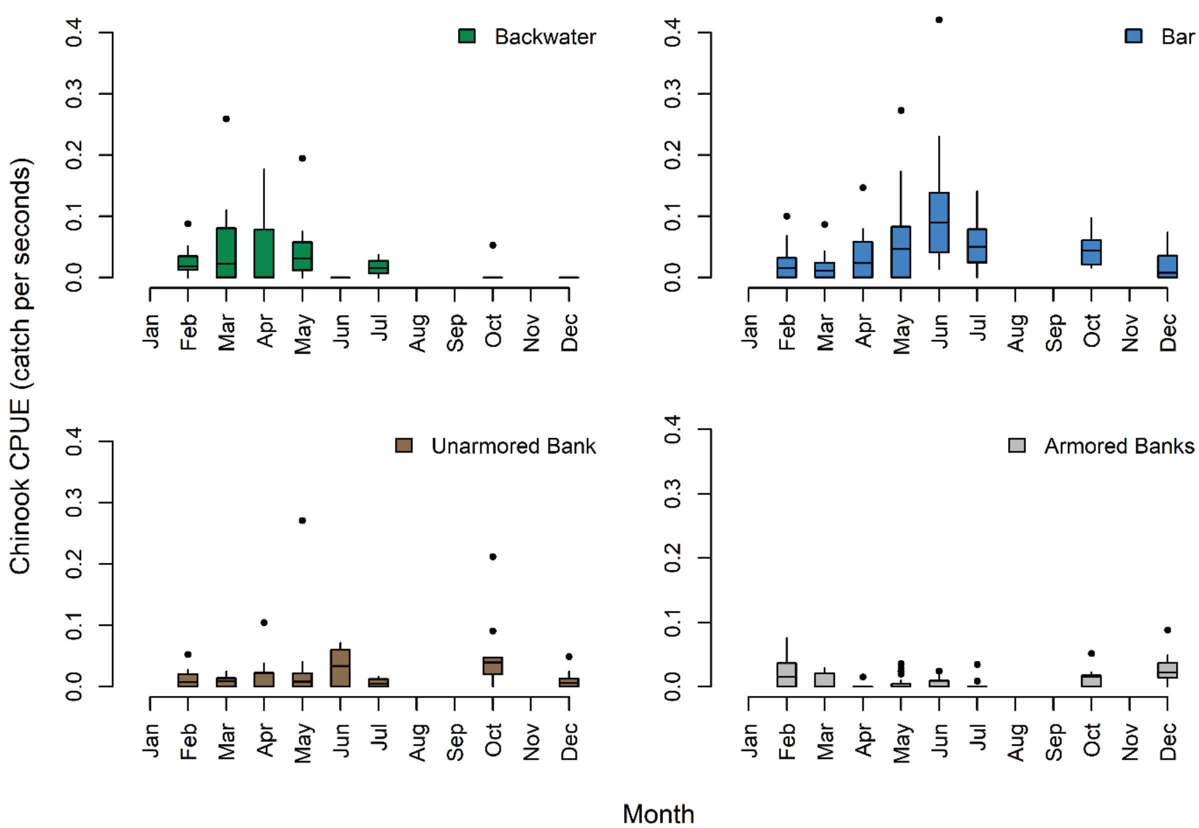

Figure 10. Juvenile Chinook catch across months and edge habitat types. Plots include observation from this study as well as project monitoring observations from select mainstem Snoqualmie River projects (discussed in Section 2.5). Boxes indicate the first quartile, median, and third quartile. The whiskers indicate maximum and minimum values up to 1.5x the inter-quartile range and the points are observations beyond 1.5x the inter-quartile range.

Evaluation of size frequencies reveal the multiple juvenile Chinook size classes and life histories using the mainstem Snoqualmie River. Earlier in the year (Feb–Mar), there are two modes in juvenile Chinook size classes: smaller sizes are juveniles that recently emerged from redds (fry) and larger sizes are yearlings that overwintered in the system (Figure 11). As the spring progresses (Apr–May), there is continued emergence of smaller fry Chinook, a greater frequency of grown medium-sized Chinook (parr), as well as a low frequency of larger yearling Chinook. By late spring and early summer (Jun–Jul), parr are the most frequently observed size class. During late fall and winter (Oct–Dec), a cohort of larger juvenile Chinook remain among freshwater habitats, which likely contribute to the yearling life-history.

In the Snoqualmie River watershed, smaller juvenile Chinook (fry and parr) are present all the way into June and July (Figure 11). Monitoring from other large river systems in King County indicate that Chinook emergence and freshwater residence tends to decrease throughout spring with few observations of smaller fry size classes occurring in late spring and early summer (King County unpub. data). We speculate that the late-emerging fry in the Snoqualmie River may be the juveniles that overwinter as yearlings. This is an important research gap that deserves additional attention.

Extended freshwater residence has generally been associated with rivers or reaches with lower growth potential including latitudes north of the 55th parallel and in headwaters (Taylor 1991, Healey 1991). Lower growth potential for juvenile salmonids is associated with lower water temperatures, shorter photoperiods, and longer distances from marine areas. Cooler water temperatures and shorter growing seasons may decrease metabolic potential and subsequent growth, resulting in juveniles needing extended freshwater residence to attain the sizes and condition required for smoltification. The Snoqualmie River may provide conditions more conducive for sub-yearling Chinook, such as warmer spring-summer temperatures and longer photoperiods (compared to northern latitudes); however, the yearling life history is still consistently expressed. The late emergence of juvenile Chinook in spring and early summer may result in the need for extended freshwater rearing and thus the yearling life-history. Late emergence could be a result of late-spawning adult Chinook as well as spawning occurring in colder tributaries or reaches.

The persistence of the yearling life-history may also be a result of both genetic variation and phenotypic plasticity to environmental conditions (Ricker 1972, Healy, 1991, Taylor 1990a, 1990). Differences in gene expression and environmental conditions can affect growth rates, which influence the timing of volitional out-migration, condition at out-migration, and subsequent smoltification. Lower growth rates and nonoptimal conditions likely influence the need for extended freshwater rearing. The fry, parr, and yearling life-histories provide a portfolio of strategies, which help to spreads out demographic risks and decrease chances of encountering unsuitable environmental conditions (Hilborn et al. 2003, Kerr et al. 2010, Schindler et al. 2010).

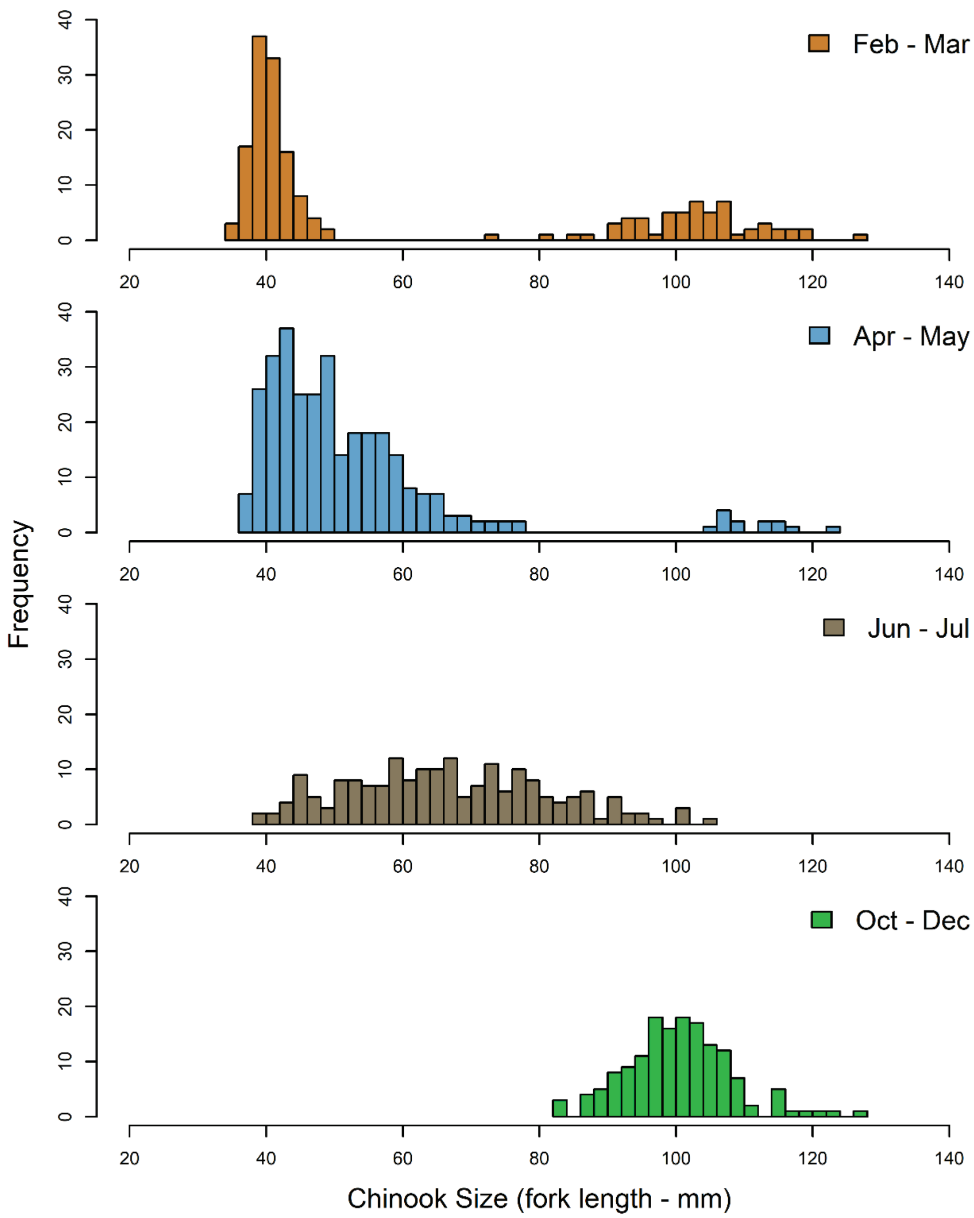

Figure 11. Size frequency plots of juvenile Chinook across seasonal periods. Plots include observation from this study as well as project monitoring observations from select mainstem Snoqualmie River projects (discussed in Section 2.5).

3.4 Which habitat attributes are associated with juvenile yearling Chinook presence and abundance?

Regression tree analysis indicated that month, edge habitat type, and edge habitat width were significant explanatory variables influencing the observed juvenile yearling Chinook abundance (CPUE) (Figure 12). The final regression tree for juvenile yearling Chinook abundance was pruned to the complexity parameter with the lowest cross-validation error (0.94), resulting in 4 splits and 5 final nodes. Month was the primary determinant of juvenile Chinook relative abundance. Observations across months were split with October having greater yearling Chinook CPUE than December and February. After month, edge habitat type was the secondary determinant, with greater juvenile yearling Chinook abundance in October observed in mid-channel bars, compared to armored banks, backwaters, edge-of-channel bars, tributary confluences, and unarmored banks. Among these latter edge habitat types, juvenile yearling Chinook were more abundant among edge-of-channel bars, tributary confluences, and unarmored banks, compared to armored banks and backwaters. Across edge-of-channel bars, tributary confluences, and unarmored banks in October, juvenile yearling Chinook abundance was greater when edge habitats were wider than 11 meters.

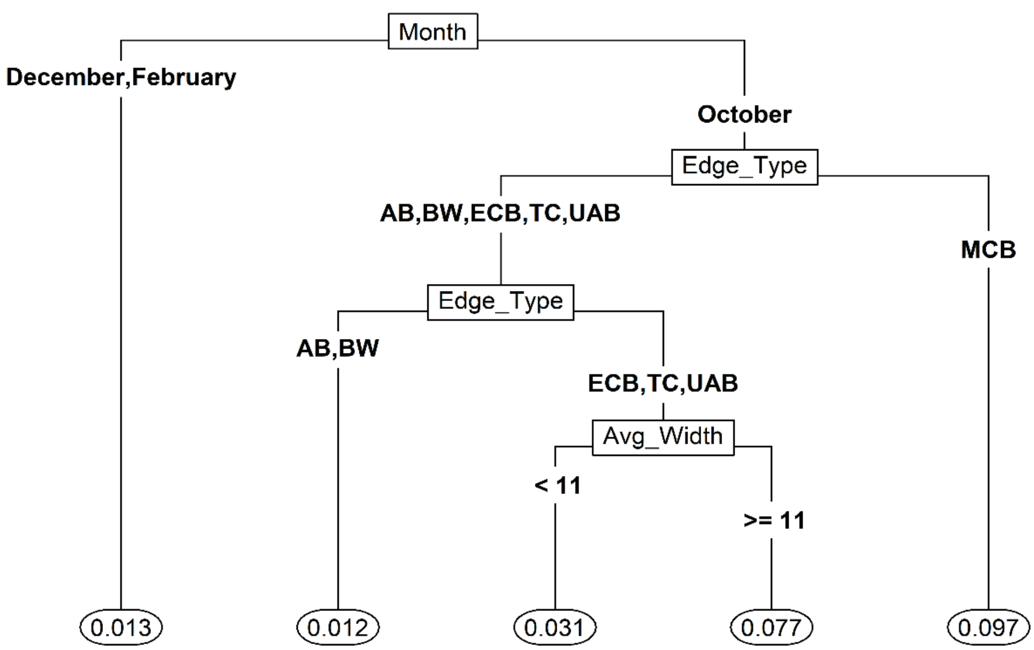

Figure 12. Regression tree plot of juvenile yearling Chinook relative abundance (CPUE; catch-per-seconds of electrofishing) based on primary driving factors. Tree was pruned to the lowest complexity parameter. Numbers at the final nodes indicate the relative CPUE for that respective group. Plot codes: AB (armored banks), BW (backwaters), ECB (edge-of-channel bars), MCB (mid-channel bars), UAB (unarmored banks), TC (tributary confluences), Edge_Type (mainstem edge habitat type), and Avg_Width (average width of edge habitat types).

Our regression tree results reinforce other lines of evidence showing a relative decrease in overall abundance from fall to winter. Additionally, the regression tree results further support other lines of evidence demonstrating that bars, unarmored bank, and tributary confluences had the greatest yearling Chinook abundance. Wider edge habitats may provide larger rearing, refuge, and foraging areas, compared to narrower edge habitats.

There are likely additional factors influencing distribution, abundance, and habitat-specific use, that were not measured as part of this study and may merit inclusion in future studies. At a finer spatial scale, variation in microhabitat resource availability, temperature conditions, competitive interaction, and predator pressures likely influence juvenile Chinook during overwintering periods. At a reach scale, factors including distance from major river confluences, channel wetted width, wood cover, and vegetation cover are associated with juvenile yearling Chinook presence/abundance (Beniston et al. 1986, Lowery et al. 2013). Additionally, at a riverscape scale, habitat use for yearling Chinook appeared to be related to hydro-region (i.e., areas with similar precipitation and hydrographs), channel type, and season (Lowery et al. 2013).

Our study focused on evaluating mainstem edge habitat use; however, yearling Chinook likely use a variety of other channel types during fall and winter. Juvenile yearling Chinook have been opportunistically observed among tributary and floodplain channels across the lower Snoqualmie River watershed (King County 2017a). Additionally, yearling Chinook are known to overwinter in floodplain channels (Lowery et al. 2013) as well as tributaries and tributary confluences (Rosberg and Associates 1987, Levings and Lauzier 1990). Among these areas, this study only investigated tributary confluences. Further investigation across floodplain channels, tributaries, and off-channel areas would be beneficial.

The regression tree analysis indicated that large wood was not a primary driving factor influencing observed Chinook abundance; however, this may be due to an overall lack of large wood across the survey extent. Juvenile yearling Chinook are known to overwinter near large wood (Swales et al. 1986, Rosberg and Associates 1987, Lowery et al. 2013) but the lower Snoqualmie River has a paucity of large wood due to a century of snagging, dredging, removal of wood jams, and degradation of riparian forests (King County 2018). The widespread lack of large wood likely influences opportunities for juvenile Chinook to overwinter near large wood and log jams.

4.0 CONCLUSIONS

What was the distribution of juvenile yearling Chinook in fall and winter across the lower mainstem of the Snoqualmie River?

Juvenile yearling Chinook were consistently observed throughout the lower mainstem Snoqualmie River during fall and winter. The number of sites where yearling Chinook were detected decreased from October 2019 to February 2020. This may have been the result of volitional outmigration, displacement by floods, or mortality. During fall and winter, especially after floods, yearling Chinook may use floodplain channels and tributaries. However, there is little information on floodplain and tributary habitat use in the Snoqualmie River; thus, further research is needed.

Which mainstem edge habitats do juvenile yearling Chinook use during fall and winter periods?

Juvenile yearling Chinook use a variety of mainstem edge habitats during fall and winter. Yearling Chinook abundance in October was greater among unarmored banks, bars, and tributary confluences while abundance in December was greatest among bars and armored/unarmored banks. Yearling abundance was lowest in February and greater among armored banks and tributary confluences.

Yearling Chinook displayed minimal changes in size during fall and winter, suggesting minimal activity, feeding, and growth. During winter, yearling Chinook were frequently observed among both armored and unarmored banks. Yearling Chinook likely used bank habitats for overwintering since they provide shelter within coarse substrates, aquatic vegetation, roots, and large wood. Juvenile Chinook are known to prefer unarmored banks, compared to armored banks. However, over 47% of the lower Snoqualmie River is armored with bank armoring concentrated across reaches where spawning and early rearing occurs (below the Raging and Tolt rivers). The prevalence and extent of bank armoring likely influences the availability and proximity of preferred unarmored banks.

Observation of juvenile yearling Chinook among tributary confluences, particularly in February, points to the importance of tributary connectivity and confluence areas for feeding, foraging, and refuge. Tributary confluences could also be where juveniles end up back in the mainstem Snoqualmie River after flood events.

Do juvenile Chinook, including all life histories, display size-specific habitat use and are there shifts in habitat use across seasonal periods?

Juvenile Chinook display distinct size-specific habitat use, which shifts as they grow and transition through early life stages. Smaller-younger juvenile Chinook were most frequent among bars and backwaters, which generally have greater low-velocity areas compared to other edge habitat types; low-velocity areas are important for early life stages. Juvenile Chinook primarily used backwaters during late winter and early spring where they then

shifted to using bars and unarmored banks from summer throughout fall and winter. Larger-older juvenile Chinook were most frequent among bars and banks, both unarmored and armored, throughout fall and winter. Larger juveniles have greater swimming abilities which may allow them to select higher-velocity bank habitats. Across seasons, juvenile Chinook were infrequent among armored banks with relatively greater abundance observed in winter. Shifts in habitat use highlight the benefits of habitat diversity and suggest that a mosaic of habitats across seasons is likely critical for juvenile Chinook.

Multiple juvenile Chinook size classes and life histories use the mainstem Snoqualmie River. Specifically, there are distinct seasonal modes in size-class frequencies indicating fry, parr, and yearling. In the Snoqualmie River, smaller juvenile Chinook (fry and parr) are present all the way into June and July. We speculate that these late-emerging juveniles may be the cohort that overwinters as yearling; however, further research in needed. The late emergence may result in the need for extended freshwater rearing to attain the size and condition needed for smoltification. Late emergence could be a result of late-spawning adults and spawning in colder tributaries or reaches. Additionally, the persistence of the yearling life history may be due to both genetic variation and environmental conditions, which influence the timing of volitional out-migration, condition at out-migration, and subsequent smoltification. The fry, parr, and yearling life histories provide a portfolio of strategies, which help to buffer variability among freshwater and marine environments.

Which habitat attributes are associated with juvenile yearling Chinook presence and abundance?

Month, edge habitat type, and edge habitat width were the primary explanatory variables influencing juvenile yearling Chinook presence and abundance. Abundance decreased from fall to winter with bars, unarmored banks, and tributary confluences having greater yearling Chinook abundance, compared to armored banks and backwaters. Wider edge habitats provide more space for rearing, refuge, and foraging areas, compared to narrower edge habitats.

Additional factors, not measured in this study, likely influence the distribution, abundance, and habitat-specific use of juvenile yearling Chinook. Driving factors may include those at a microhabitat scale such as variation in resource availability, temperature conditions, competitive interactions, and predator pressures. Factors at a reach scale may include distance upstream from major river confluences, channel wetted width, wood cover, and vegetation cover. At a riverscape scale, hydro-region (i.e., areas with similar precipitation and hydrographs), channel type, and season are potential driving factors. Large wood presence and abundance may be an additional factor influencing juvenile yearling Chinook distribution and abundance. However, a widespread lack of large wood across the lower Snoqualmie River watershed likely limits opportunities for juvenile Chinook to overwinter near large wood and log jams.

What are the implications of this information for salmon conservation strategies and restoration projects?

It is essential for salmon conservation strategies in the Snoqualmie River watershed to support Chinook life-history diversity and abundance. Life-history diversity helps to spread out demographic risks and decreases chances of encountering unsuitable environmental conditions (Hilborn et al. 2003, Kerr et al. 2010, Schindler et al. 2010). Diversity among juvenile life histories can also translate to variation in oceanic residence and distribution as well as adult migration and spawn timing (Healy 1991). The Snoqualmie River Chinook population is depressed, with declining abundance and productivity (SBSRF 2005, NMFS 2014); thus, it will be critical to maintain and support life-history diversity for population recovery and persistence.

The importance of the yearling Chinook life history is apparent since they have greater marine survival compared to sub-yearling Chinook (Beamer et al. 2005) and contribute a considerable proportion of retuning adults (Diego Holmgren and Mike Crewson, Tulalip Tribes pers. comm.). However, there has been a declining trend in the proportion of returning Snoqualmie River adult Chinook which displayed a juvenile yearling life history (Figure 13; Mike Crewson, Tulalip Tribes pers. comm.). Furthermore, there are broader declines in the size of returning adults among Pacific Chinook populations (Oke et al. 2020). Since yearling Chinook tend to return as older-larger adults, compared to sub-yearlings, the broader decline may in part reflect trends specific to the yearling life history. Declining trends at local and broader scales may be due to a combination of degraded freshwater rearing and refuge habitat (SBSRF 2005), as well as variability in oceanic productivity (Mantua et al. 1997, Wells et al. 2006, Sharma et al. 2013). Since yearling Chinook spend an extended period among freshwater habitats, targeted conservation strategies focused on freshwater habitat conditions, particularly from summer throughout winter, may be integral in supporting yearling Chinook and life-history diversity.

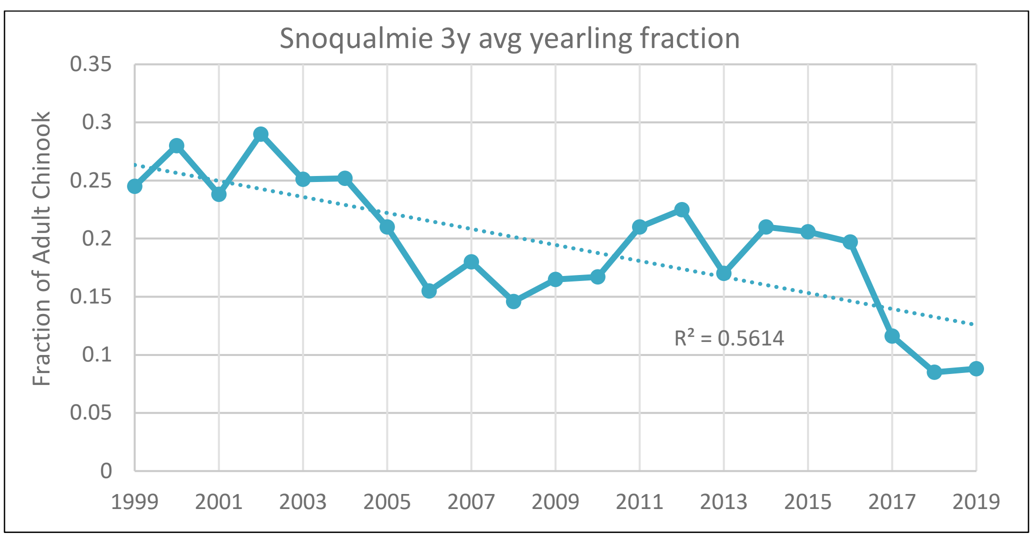

Figure 13. The fraction of returning adult Chinook (3-year average) which had a juvenile yearling life history. Figure provided by Mike Crewson, Tulalip Tribes Natural Resources Department.

Specific strategies should be structured around mainstem edge habitat conditions across seasons, floodplain and tributary areas, habitat availability and connectivity across seasons, and season-specific life-history needs. Observations from this study as well as future research that takes all life-history strategies into account will help refine salmon conservation strategies for the Snoqualmie River watershed.

Salmon conservation efforts are currently focused on mainstem rivers since the loss of rearing habitat quantity and quality along mainstem river reaches is thought to be a primary factor affecting Chinook salmon population performance in the Snohomish Basin (SBSRF 2005). Consideration of edge habitat conditions and juvenile salmonid habitat requirements has thus far largely been focused on the sub-yearling cohort. Project designs are primarily structured around sub-yearling juvenile salmon habitat requirements during late winter and spring, specifically aiming to support rearing and refuge among early life stages. Our study emphasizes the need to also consider habitat use from summer throughout winter when designing projects, since mainstem edge habitats are frequently used by juvenile yearling Chinook throughout these periods.

To support juvenile yearling Chinook, projects will need to ensure that improved and restored habitat areas are connected and engaged across a range of flows, specifically during summer and winter low flows. Improving habitat availability and connectivity during summer and winter periods will help yearling Chinook access preferred habitats. Additionally, since juvenile yearling Chinook overwinter near large wood (Swales et al. 1986, Rosberg and Associates 1987, Lowery et al. 2013), a greater emphasis on mainstem large wood addition is likely needed. Mainstem large wood will provide areas for winter refuge and increase edge habitat complexity throughout the year.

Floodplain and tributary habitats are not only important for salmonid growth and survival (Sommer et al 2001, Jeffres 2008, Rice et al. 2008) but are known to specifically support juvenile yearling Chinook during overwintering periods (Rosberg and Associates 1987, Levings and Lauzier 1990, Lowery et al. 2013). While the need for floodplain and tributary habitat restoration is detailed in the Snohomish River Basin Salmon Conservation Plan (SBSRF 2005), it tends to be of lower priority than mainstem restoration. Further consideration of floodplain and tributary habitat use by yearling Chinook may be needed to capture year-round habitat conditions and improvement needs. Stream channels throughout the Snoqualmie River floodplain have largely been modified (e.g., dredged, straightened, widened, armored, etc.). Focused restoration of tributaries and confluence areas may include improved connectivity, in-channel habitat diversity, water quality, and riparian buffers. The restoration of smaller tributaries within the floodplain has largely been focused on water quality benefits; however, further emphasis on habitat complexity and connectivity will be necessary to support yearling Chinook.

Supporting yearling Chinook may also require further consideration of water quality conditions across life stages and seasons. For example, summer temperature conditions are largely considered in respect to adult salmon tolerances; however, it may be necessary to also consider temperature impacts to juvenile Chinook. Altered growth rates and life-stage transitioning during warmer springs and summers may result in earlier juvenile Chinook

outmigration and/or displacement into less desirable areas, which can result in potential asynchronies with food resources and truncated growth seasons (Fullerton et al. 2017, Munsch et al. 2019, Hawkins et al. 2020). Additionally, altered growth and life-stage transitioning may result in emergence and outmigration during unsuitable flow conditions which can lead to increased competitive or predator interactions as well as spatio-temporal overlap with native and non-native fish species (Steel et al. 2019). Restoring temperature conditions in spring and summer as well as preserving thermal diversity in fall and winter will be important to support yearling Chinook. Especially since salmon that rely on extended freshwater rearing are likely more vulnerable to shifts in freshwater thermal regimes (Lowery et al 2013). Strategies to improve temperature conditions may include widespread riparian restoration, increased channel and floodplain complexity, increased channel, floodplain, and tributary connectivity, and others.

Since restoration projects in the Snoqualmie River are primarily structured around sub-yearling juvenile salmon habitat requirements, project monitoring is largely focused on habitat conditions and habitat use during the spring rearing and outmigration period. In order to understand year-round habitat conditions, juvenile salmon habitat use, and related juvenile salmon habitat needs, monitoring efforts will need to take a multi-season approach. Not only would this help to detail year-round project benefits but would provide further information on the behavior and ecology of all life histories, helping to better inform project effectiveness and salmon conservation strategies.

An integrated salmon conservation approach which considers all juvenile Chinook life-histories as well as habitat conditions across seasons may prove most effective. Supporting life-history diversity will help Chinook populations withstand environmental-population variability and will ensure that restoration and conservation efforts are strategic and comprehensive.

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Appendix A: Mainstem Snoqualmie River Edge Habitat Types

Figure A-1: Riprap Armored Bank.

Figure A-2: Bioengineered Armored Bank.

Figure A-3: Backwater.

Figure A-4: Edge-of-Channel Bar.

Figure A-5: Mid-Channel Bar.

Figure A-6: Unarmored Bank.

Figure A-7: Tributary Confluence.