Snoqualmie River Project Effectiveness Evaluation – Aquatic Habitat and Juvenile Salmonid Observations





March 2021

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science and Technical Support Section
King Street Center, KSC-NR-5600
201 South Jackson Street, Suite 5600
Seattle, WA 98104
206-477-4800 TTY Relay: 711
www.kingcounty.gov/EnvironmentalScience

Alternate Formats Available
206-477-4800   TTY Relay: 711

Snoqualmie River Project Effectiveness Evaluation – Aquatic Habitat and Juvenile Salmonid Observations

Prepared for:

Snoqualmie Watershed Forum

Submitted by:

Josh Kubo
Water and Land Resources Division
King County Department of Natural Resources and Parks

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

This page intentionally left blank.

Acknowledgements

The author would like to thank the Snoqualmie Watershed Forum and the Snohomish Basin Salmon Recovery Technical Committee for supporting this effort. Special thanks go out to Elissa Ostergaard and Emily Davis for providing thorough input and guidance throughout the process. The author would like to thank Emily Davis, Alex Lincoln, Josh Latterell, Kollin Higgins, Jo Wilhelm, Aaron David, Dan Eastman, Elissa Ostergaard, Mike Thai, Micah Wait, Dave White, Saffa Bardaro, Kate O'Laughlin, and Josh Baldi for thorough comments and review.

Citation

King County. 2021. Snoqualmie River Project Effectiveness Evaluation – Aquatic Habitat and Juvenile Salmonid Observations. Prepared by Josh Kubo, Water and Land Resources Division. Seattle, Washington.

Table of Contents

Figures

Tables

Appendices

EXECUTIVE SUMMARY

Aquatic habitats throughout the Snoqualmie River watershed support the freshwater life stages of various salmonids, including Chinook salmon, bull trout, and steelhead trout, which are listed as threatened under the Endangered Species Act. Declining and depressed salmonid populations have been attributed to several factors including the wide-spread degradation of freshwater habitats. Mainstem edge habitats (i.e., low-velocity channel margins for rearing and refuge) are critical for juvenile salmonids throughout early life stages. Improving mainstem edge habitats has been the focus of several large river projects across the lower Snoqualmie River. With the large investments in these projects, it is imperative to know if and how projects improve habitat conditions and if juvenile salmonids have responded.

This report summarizes project effectiveness monitoring information from three restoration projects (Chinook Bend/Stillwater, Lower Tolt, and Upper Carlson) and two enhanced bank stabilization projects (Sinnema Quaale and Tolt Pipeline). Improvements to mainstem edge habitats are summarized across projects and juvenile salmonid responses are evaluated through a quantitative, comparative data synthesis (i.e., meta-analysis). Insight gained will help inform: (1) if projects actions are improving aquatic habitats, (2) if juvenile salmonids have responded to project actions, and (3) if there are distinct juvenile salmonid ecological and behavioral patterns, which projects and salmon conservation strategies should include.

Large river projects implemented across the lower Snoqualmie River are broadly grouped into two categories including restoration and bank stabilization.

Restoration projects aim to improve habitat quantity, quality, and connectivity by focusing on strategies that promote riverine and floodplain processes. Select strategies include the removal of bank armoring (i.e., riprap levees and revetments), increasing edge habitat area and complexity, and restoring natural processes that support dynamic and functioning habitats. Restoration projects may include full restoration, partial restoration, or habitat creation. Habitat creation can have an immediate habitat benefit but is limited in improving ecosystem processes. On the other hand, partial to full restoration can have both immediate and long-term benefits, and results in greater overall improvement to ecosystem processes. Restoration practitioners infer that the degree to which restoration projects are able to restore processes is contingent on the level of restoration, remaining reach- and watershed-scale constraints, and the need to integrate bank stabilization.

Bank stabilization projects focus on strategies that reduce risks to people, infrastructure, and property from channel migration and flood-related hazards. These projects seek to minimize detrimental impacts of bank hardening while also aiming to improve habitat conditions through bioengineering techniques, such as incorporation of vegetation and large wood. Project which incorporate bioengineering techniques are considered to be enhanced bank stabilization. Bioengineering techniques can have an immediate habitat benefit; however, benefits are limited in improving ecosystem processes and are typically not self-sustaining. Project implementers infer that mitigation of bank stabilization impacts and improvements to habitat conditions are contingent on the degree to which enhanced bank stabilization projects integrate bioengineering techniques as well as improve adjacent habitat areas.

Restoration projects and enhanced bank stabilization projects have improved mainstem edge habitats.

Evidence suggests that restoration projects (Chinook Bend/Stillwater, Lower Tolt, and Upper Carlson) have improved and increased aquatic habitats by removing bank armoring and restoring riverine processes. These restoration projects have increased mainstem low-velocity edge habitat area and extent, resulting in greater area for rearing and refuge. Increased edge-habitat area and channel complexity was largely driven by the formation of backwaters, bars, and unarmored banks. Restoration projects also improved edge habitat quality and complexity, by design, through increased large wood integration, engagement, and recruitment.

Enhanced bank stabilization projects (Sinnema Quaale and Tolt Pipeline) have improved edge habitat complexity, by design, through the integration of large wood and vegetation into bank stabilization features (bioengineered revetment banks). Additionally, the reconnection and restoration of the Deer Creek confluence, as part of the Tolt Pipeline project, increased tributary accessibility for juvenile salmonids and improved confluence habitat quality.

Juvenile Chinook and coho have positively responded to improved mainstem edge habitats.

The meta-analysis was focused on comparing improved edge habitats, including backwaters, bars, unarmored banks, and bioengineered banks, to degraded riprap armored banks. The meta-analysis indicated that across restoration and enhanced bank stabilization projects, juvenile Chinook and coho abundance was consistently greater among improved edge habitats, compared to degraded riprap armored banks (i.e., positive response to project actions).

Specifically, juvenile Chinook had a positive response, relative to riprap banks, across all improved edge habitat types with the greatest response observed among backwaters, bars, and unarmored banks. Juvenile coho also had a positive response across all improved edge habitat types with the greatest response observed among backwaters, bioengineered banks, and unarmored banks. Juvenile trout showed a mixed response across improved edge habitats with some habitats showing positive responses and other showing negative responses.

Process-based restoration is likely the best approach to maximize habitat improvements for juvenile Chinook.

While not directly tested in this report, meta-analysis results suggest that habitat benefits for juvenile Chinook are likely greater among restoration projects, compared to enhanced bank stabilization projects. Juvenile Chinook displayed the greatest response across backwaters, bars, and unarmored banks, which are frequently created and improved by restoration projects. On the other hand, juvenile Chinook had less of a response to bioengineered banks, which is the primary edge habitat type created by enhanced bank stabilization projects. While all improved edge habitat types can benefit juvenile Chinook, if projects aim to maximize habitat improvements, then process-based restoration is likely the best approach. If bank stabilization is necessary, then bioengineered approaches are better than traditional riprap armored designs.

Juvenile salmonids display size-specific habitat use as well as seasonal shifts in habitat use.

Distinct size classes and related life histories used specific edge habitat types. Smaller juvenile Chinook and coho were most frequent among bars and backwaters, which generally have greater low-velocity areas and may be critical when juveniles are smaller. Larger juvenile Chinook and coho were most frequent among unarmored banks and riprap armored banks, suggesting that as juveniles grow and reach larger sizes, they may be more likely to use bank habitats. Smaller trout appeared to be most frequent among bars and unarmored banks while larger trout were frequent among riprap armored banks. Relatively larger juvenile salmonids may use unarmored and armored bank habitats since they are able to withstand a greater range of flow velocities. Additionally, banks habitats may provide suitable holding areas for ambush predation opportunities, cover from avian predators, and areas for overwintering.

Juvenile salmonids display seasonal shifts in habitat use, suggesting that a diversity of edge habitats is needed to support juveniles as they grow and transition through early life stages. Juvenile Chinook and coho primarily used backwaters during spring where they then shifted to using bars and unarmored banks during late spring and early summer. Trout used backwaters, bars, and unarmored banks somewhat consistently across spring, with the exception of bars, which were primarily used around late spring and summer. Juvenile Chinook and trout used riprap armored banks and bioengineered banks primarily during fall and winter.

Addressing remaining constraints and integrating adaptive management will help projects maximize habitat improvements.

Remaining constraints, including existing shoreline armoring and altered hydraulic, sediment, and wood recruitment regimes, can limit the potential of restoration projects to restore riverine processes. Restoration projects need to take broader reach-scale approaches to ensure that the scale and degree of restorative actions align with the extent of constraints and degradation. Larger restoration projects, which address a suite of constraints and incorporate broader reach-scale restoration will be most effective in improving mainstem habitats.

Prioritizing near-term adaptive management will help address remaining constraints as well as project elements that fall short of expectations. Near-term adaptive management can provide a direct feedback loop to address factors that limit habitat improvements, helping projects reach full restoration potential.

Restoration projects need to take aggressive approaches to ensure riverine and floodplain processes are restored. This is especially apparent where constraints upstream, downstream, and across the river remain or are unlikely to be addressed in the near-term. Aggressive actions include mainstem large wood jams to route flow into created channels, deeper-wider pilot side channel excavation to ensure engagement across a range of flows, and prioritization of remaining reach-scale constraints such as existing and remaining bank armoring.

Monitoring at appropriate spatial and temporal scales will provide greater estimates of habitat improvements and salmonid responses.

Project interactions and cumulative benefits across projects should be considered when evaluating and monitoring habitat improvement projects. Monitoring efforts should align with a scale and extent that is inclusive of all projects in a given reach. Using methods that efficiently and effectively capture mainstem edge habitat characteristics will bolster the ability of monitoring efforts to describe project-related habitat improvements for juvenile salmonids.

Monitoring effort should adopt or continue inter-annual evaluations to capture variability in channel movement, habitat formation, and salmonid populations. Monitoring that captures inter-annual information on habitat and salmonids is likely to provide greater estimates of habitat improvements and salmonid responses. Monitoring efforts should also include multi-season sampling to capture year-round habitat conditions and juvenile salmonid habitat use. Multi-season sampling will help to better understand habitat conditions throughout juvenile salmonid freshwater residence and will ensure that projects support all life-histories.

Supporting habitat and life-history diversity will bolster salmon conservation efforts.

A diversity of mainstem edge habitats is needed to support juvenile salmonids. Juvenile salmonids use a variety of edge habitats, display clear shifts in habitat use across seasons, and use specific habitats among each life stage. Projects and strategies that provide a diversity of improved edge habitats and increase edge habitat area will provide the greatest benefits for juvenile salmonids, by improving productivity and increasing overall habitat capacity.

Habitat improvement projects will need to consider habitat conditions across seasons to ensure that projects address all relevant impairments and constraints. Accounting for habitat conditions across under-represented seasons, including summer and winter, will help projects provide optimal improvements throughout juvenile salmonid freshwater residence. Additionally, projects which integrate multi-season habitat conditions and support juveniles across life stages will help to maintain life-history diversity. Supporting life-history diversity will help salmonid populations withstand environmental-population variability and will ensure that restoration and conservation efforts are strategic and comprehensive.

1.0 INTRODUCTION

The Snoqualmie River watershed supports several salmonid populations, including Chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*), which were listed as threatened under the Endangered Species Act (ESA) in 1999. Additionally, Puget Sound steelhead trout (*Oncorhynchus mykiss*) were listed as threatened in 2007. Puget Sound salmonid populations are considered threatened due to several factors including wide-spread habitat degradation (Federal Register 1999, McElhany et al. 2000, SBSRF 2005). Across the Snohomish River basin, including the Skykomish River and Snoqualmie River sub-basins, salmonid habitat degradation has primarily occurred due to the construction of fish passage barriers, bank and floodplain modifications, loss of wetlands, altered channel conditions including large wood removal, and altered riparian functions and conditions (Haring 2002, SBSRTC 2004, SBSRF 2005).

In response to the federal ESA listings, a recovery planning effort was started in 1999 and resulted in the creation of the Snohomish River Basin Salmon Conservation Plan (hereafter referred to as the 2005 Salmon Plan). The 2005 Salmon Plan guides the recovery and conservation of salmonids through various strategies and actions focus on improving habitat conditions that support viable salmonid populations (SBSRF 2005). Efforts focused on restoring and preserving functioning riverine, floodplain, and riparian processes are believed to provide the greatest habitat benefits for salmonids. Additionally, restoring and protecting watershed-wide conditions and processes are likely critical to create and maintain quality habitat into the future.

Across the Snohomish River Basin, the loss and degradation of rearing habitat is thought to be a primary factor affecting Chinook salmon population performance (SBSRTC 2004, SBSRF 2005). Specifically, greatly diminished and degraded rearing habitat along mainstem channel margins is thought to be a key limiting factor for Chinook in the Snoqualmie River watershed (Haring 2002, SBSRF 2005). Mainstem channel margins are critical for juvenile Chinook, as they primarily rear among these areas (Hayman et al. 1996, Beechie et al. 2005). The impairment of channel margin edge habitats, including shoreline armoring, removal of large wood, and degraded riparian corridors, can result in reduced rearing habitat capacity and productivity (Beamer and Henderson 1998, Spence et al. 1996, Ward and Wiens 2001). Conservation actions that focus on improving rearing habitat complexity, availability, and connectivity are predicted to be most effective in improving Chinook populations.

Since the adoption of the 2005 Salmon Plan, several large river projects have been implemented across the lower Snoqualmie River watershed. It is imperative to understand how these projects have impacted and potentially improved habitat conditions as well as if and how salmonids respond to project-related actions. Evaluating the effectiveness of projects helps to understand if projects achieved their goals, how projects could be improved in the future, and if salmon conservation strategies are resulting in improved habitat conditions. Project-specific monitoring and analyses can provide useful information; however, there’s an ongoing need for a collective evaluation of monitoring

observations across projects. Thus, this report summarizes effectiveness monitoring information from several large river projects across the lower Snoqualmie River. The primary goals and implications of this project effectiveness evaluation are:

1) Summarize project-related improvements to aquatic habitat areas, specifically, whether the quantity and quality of mainstem edge habitats has improved across projects. This will help inform if project actions and habitat improvement strategies are resulting in improved habitat conditions.
2) Evaluate if and how juvenile salmonids have responded to project-related actions, through changes in relative abundance from degraded edge habitat conditions to improved edge habitat conditions. This will help to understand if juvenile salmonids presence and abundance has improved due to project actions and if juvenile salmonids are responding to habitat improvement strategies.
3) Summarize observations of salmonid size classes and life-history patterns, size-specific habitat use, and seasonal shifts in habitat use. This will provide critical juvenile salmonid ecological and behavioral information, helping to better align projects and salmon conservation strategies with Snoqualmie River salmonid populations.

2.0 MAINSTEM LARGE RIVER PROJECTS ACROSS THE LOWER SNOQUALMIE RIVER WATERSHED

Large river projects implemented across the lower Snoqualmie River are broadly grouped into two categories including process-based restoration and bank stabilization. Project are grouped based on differences in project goals, project-related elements, and the degree to which projects are able to restore habitat processes, enhance habitat conditions, and/or mitigate impacts.

2.1 Process-Based Restoration Projects

Restoration projects focus on strategies that promote riverine and floodplain processes, which support dynamic and functioning habitats. These projects aim to improve habitat quantity, quality, and connectivity to support juvenile salmonids across early life stages. Large river restoration projects have been designed to address high priority ecological actions outlined in the 2005 Salmon Plan, including:

- Removal of human-made instream barriers along or adjacent to priority watercourses.
- Reconnection and restoration of off-channel habitats (e.g., side-channels, sloughs, dead-end channels, wetlands, etc).
- Restoration of edge habitat (slow water margin along mainstem rivers) and shoreline condition.
- Restoration of instream habitat complexity and structure (e.g., large wood and related complex channel characteristics).
- Restoration of hydrologic and sediment processes.
- Enhancement and protection of riparian and forest cover.
- Restoration of channel migration.
- Reconnection of floodplains.

All of these actions are essential for mainstem river restoration as they improve habitat capacity and availability, which benefit salmonid growth and survival. Shoreline armoring and channel simplification have considerable impacts on mainstem rivers. Shoreline armoring limits the availability and accessibility of off-channel habitats, floodplain areas, and reduces edge habitat complexity and cover (Spence et al. 1996, Beamer and Henderson 1998, Ward and Wiens 2001). Additionally, juvenile salmonids tend to prefer natural unarmored banks compared to armored banks (Knudsen and Dilley 1987, Beamer and Henderson 1998, Quigley and Harper 2004). With over 40% of the lower Snoqualmie, Tolt, and Raging rivers being armored (King County 2002 & 2018a), the removal of armoring

has been a primary focus of restoration projects. Restoration projects also aim to improve edge habitat complexity and conditions, largely because edge habitats are critical for juvenile salmonids (Hayman et al. 1996, Beechie et al. 2005).

The degree that restoration projects are able to restore processes and maintain functioning habitats is contingent on the level of restoration, remaining reach- and watershed-scale constraints, and the need to integrate bank stabilization. Restoration projects may include full restoration (restoring processes that create and maintain habitats and biota), partial restoration (restoring or improving selected ecosystem processes), and/or habitat creation (creation of locally appropriate habitat types) (Beechie et al. 2010). Each restoration approach results in different levels of ecosystem response as well as different time horizons for achieving ecological benefits. For example, habitat creation, such as the excavation of a side channel, can have an immediate habitat benefit but is limited in restoring ecosystem processes. On the other hand, partial to full restoration, such as the removal of riprap bank armoring, can have both immediate and long-term benefits, and results in greater overall improvement to ecosystem processes. Restoration benefits achieved over longer time horizons may include channel migration, large wood recruitment, and changes in hydrologic and sediment regimes.

Riverine and floodplain conditions from a reach- to watershed-scale can have a significant influence on the ability of projects to restore processes and ecological functions. For example, armored shorelines along adjacent and/or opposite banks can limit the potential for channel migration, channel splits, erosion and accretion processes, and habitat formation. These remaining reach-scale constraints can have a significant impact on project performance by limiting riverine and floodplain processes. Additionally, altered sediment and hydrologic regimes as well as limited large wood recruitment at a watershed-scale can limit the potential for habitat creation and sustainment. Similar to reach-scale constraints, limitations in watershed-scale processes can influence the ability of projects to restore processes and ecological functions.

Restoration projects are frequently required to concurrently protect critical infrastructure and property from potential channel migration and flood-related hazards. This results in restoration projects needing to incorporate some degree of bank stabilization (generally occurring at set-back locations behind the project area). When bank stabilization is required, restoration projects aim to use bioengineered techniques, which include the incorporation of vegetation and large wood into bank stabilization features. Bioengineered techniques are hypothesized to be less impactful to aquatic habitats, compared to hard armoring like large angular rock (i.e., riprap). However, any kind of bank stabilization likely limits riverine and floodplain processes. The degree to which projects are required to integrate these bank stabilization features will subsequently limit the potential of projects to fully restore habitat forming processes.

2.2 Bank Stabilization Projects

Bank stabilization projects focus on strategies that reduce risks to people, infrastructure, and property from channel migration and flood-related hazards. The 2005 Salmon Plan

acknowledges that "in certain circumstances, bank stabilization and/or repair is necessary for the protection of critical infrastructure and property, especially when these protections have the potential to reduce risks from channel migration and flooding". Historically, bank stabilization was done using large riprap rock to armor banks. As previously highlighted, armored banks have several negative impacts on aquatic habitats and salmonids. Subsequently, in areas with no feasible alternative to bank stabilization or repair, bioengineering techniques are recommended.

Bank stabilization projects which integrate bioengineering techniques (aka enhanced bank stabilization) seek to reduce detrimental impacts of bank hardening while also aiming to improve edge habitat conditions (compared to solely riprap rock). These bioengineering techniques result in constructed and static habitat features. Similar to a habitat creation restoration approach, bioengineering techniques can have an immediate response; however, benefits are limited in improving ecosystem processes and are typically not self-sustaining. Bank stabilization projects can also include additional strategies to reduce impacts and improve conditions such as the re-vegetation of riparian, floodplain, and upland areas. Since any kind of structural bank armoring impacts aquatic habitats, project implementers infer that the more bank stabilization projects are able to integrate bioengineering techniques, especially when replacing older bank structures, the more projects are able to reduce impacts.

Enhanced bank stabilization projects that include restoration actions are likely to provide relatively greater benefits to aquatic habitats and salmonids. Restoration elements that improve adjacent and reach-scale habitat areas may include the creation of vegetated channels and floodplain benches/alcoves, reconnection and restoration of tributary confluence areas, correcting fish passage barriers, and maintaining reach-scale erosion and accretion processes. These improvements provide benefits by supporting riverine and floodplain processes adjacent and around bank stabilization areas.

2.3 Select Restoration and Bank Stabilization Projects Across the Lower Snoqualmie River Watershed

Several large river projects have been implemented across the lower Snoqualmie River watershed (Table 1 and Figure 1). While this list is not comprehensive, the included projects have: 1) goals and objectives that represent restoration and enhanced bank stabilization projects, 2) project monitoring specific to aquatic habitats and juvenile salmonids, and 3) comparable habitat and salmonid data collection methodologies (discussed in detail in section 3.0*: Monitoring Mainstem Aquatic Habitats and Salmonids Across Large River Projects).* The project-specific goals and objectives detail how individual projects aim to provide restoration and/or bank stabilization benefits as well as how projects specifically improve habitat conditions.

Table 1. Select large river projects across the lower Snoqualmie River watershed, including project-specific goals and objectives. Goals and objectives discussed further in Appendix B–F.

Project Type	Project	Goal Category	Goals and Objectives
Process-Based Restoration	Chinook Bend/Stillwater Restoration and Floodplain Connection	Habitat Complexity and Connectivity	Promote the formation of complex riverine and floodplain habitat for rearing and spawning salmonids.
			Increase channel edge habitat complexity.
			Restore channel and floodplain hydraulics and connectivity.
		Riverine and Floodplain Forming Processes	Restore the natural sediment transport regime.
			Restore lateral channel migration.
			Increase channel splitting and avulsion potential.
			Increase wood recruitment and accumulation.
		Re-Vegetation	Restore diverse riparian corridor of native plants.
		Mitigate and Reduce Risks	Moderate future migration by encouraging the formation of natural logjams along the mainstem channel margin.
			Do not increase the risk to public infrastructure or private property from flooding or bank erosion.
	Lower Tolt Restoration and Floodplain Connection	Habitat Complexity and Connectivity	Restore salmonid spawning and rearing habitat in the lower Tolt River by returning the complexity, diversity, and morphology of habitats characteristic of an unconstrained channel.
			Promote formation of pools and channel complexity through natural production of large wood and increased channel sinuosity.
		Riverine and Floodplain Forming Processes	Emphasize natural channel migration and development of side channels by removing or setting back constraining levees.
			Allow more natural frequency of inundation of the floodplain.
		Re-Vegetation	Restore a mature riparian vegetation corridor providing shoreline shading, habitat for insect prey and terrestrial species, and large wood.
	Upper Carlson Restoration and Floodplain Connection	Habitat Complexity and Connectivity	Reconnect right bank floodplain with river at lower flows.
			Promote formation of complex, woody right bank edge habitat.
		Riverine and Floodplain Forming Processes	Allow the river to expand and migrate toward the right bank at natural rates.
			Promote channel aggradation and form bar habitat along the left bank.
		Re-Vegetation	Re-establish riparian forests.

Project Type	Project	Goal Category	Goals and Objectives
Enhanced Bank Stabilization	Tolt Pipeline Protection and Deer Creek Restoration	Habitat Complexity and Connectivity	Provide improved aquatic edge habitat complexity and areas of slow water refuge through integration of large wood jacks and jams into the bioengineered revetment.
			Reconnect Deer Creek through removal of a crushed culvert and replacement with a set-backed boxed culvert and regulated flapgate.
			Restore lower Deer Creek through creation of a floodplain alcove, channel meandering, and large wood arrays.
		Re-Vegetation	Re-vegetation of banks and upland areas.
		Habitat Complexity and Connectivity	Reconnect Deer Creek through removal of a crushed culvert and replacement with a set-backed boxed culvert and regulated flapgate.
			Restore lower Deer Creek through creation of a floodplain alcove, channel meandering, and large wood arrays.
		Mitigate and Reduce Risks	Reduce risks to Tolt River water supply line from channel migration hazards.
			Reduce the long-term maintenance needs and costs of flood hazard management.
	Sinnema Quaale SR-203 and Snoqualmie Trail Protection	Habitat Complexity and Connectivity	Reduce risks to Snoqualmie Valley Trail, State Highway 203, and fiberoptic lines from channel migration hazards.
			Provide improved aquatic edge habitat complexity through integration of large wood structures into the bioengineered revetment.
		Re-Vegetation	Re-vegetation of banks and upland areas.
		Mitigate and Reduce Risks	Reduce risks to Snoqualmie Valley Trail, State Highway 203, and fiberoptic lines from channel migration hazards.
			Reduce the long-term maintenance needs and costs of flood hazard management.

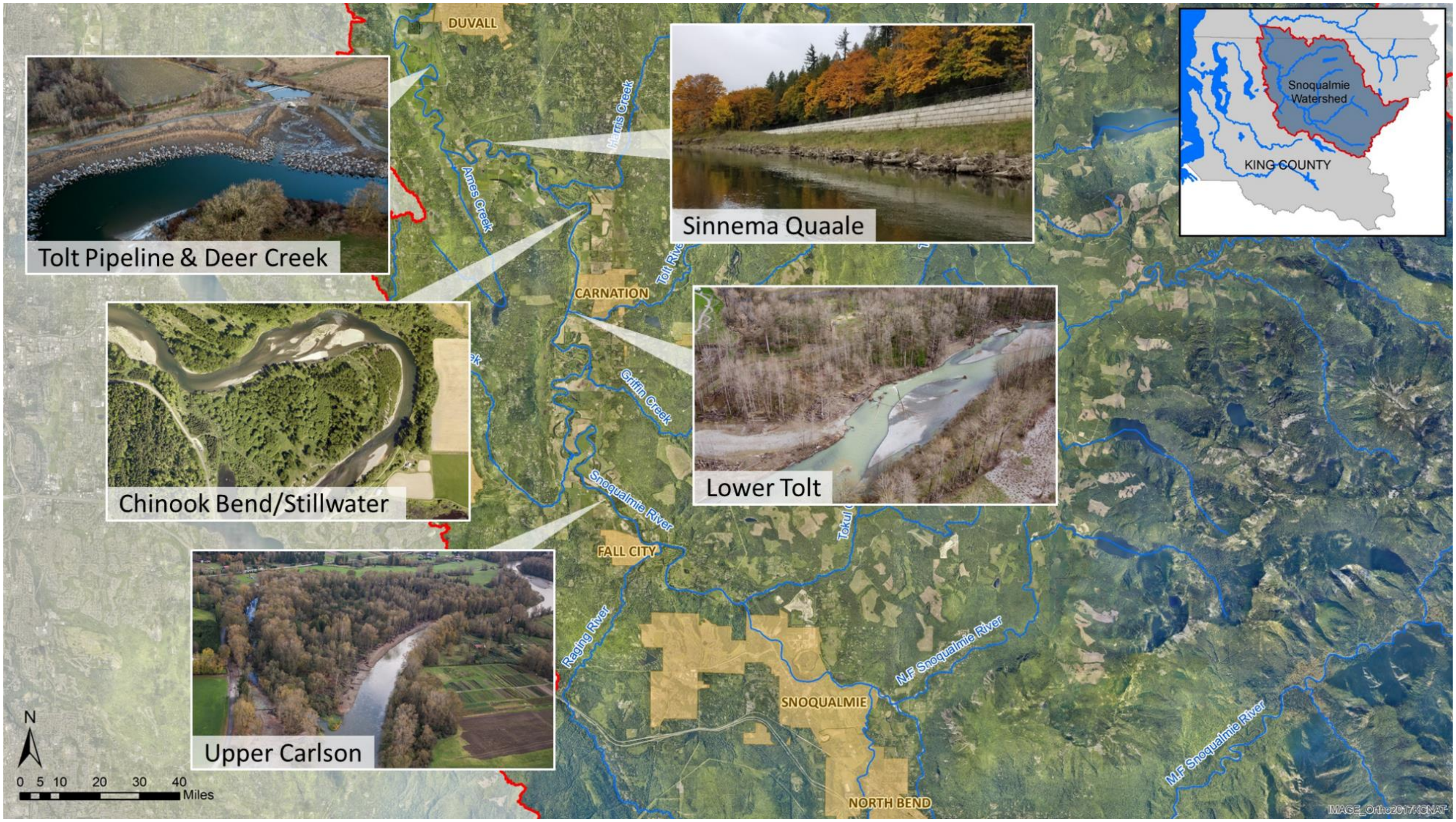

Figure 1. Select large river projects across the lower Snoqualmie River watershed. Restoration projects include Chinook Bend/Stillwater, Upper Carlson, and Lower Tolt. Enhanced bank stabilization projects include Tolt Pipeline and Sinnema Quaale.

3.0 MONITORING MAINSTEM AQUATIC HABITATS AND SALMONIDS ACROSS LARGE RIVER PROJECTS

Extensive monitoring has been conducted by King County across large river projects to help evaluate implementation, performance, and effectiveness. Monitoring efforts generally include multiple indicators and metrics aimed at evaluating project-related changes to in-channel, bank, riparian, and floodplain areas. Monitoring efforts are focused on various elements including, but not limited to:

- Aquatic habitat conditions (e.g., edge habitat condition, in-channel habitat complexity, low-velocity habitat areas, and spawning habitat extent).
- Salmonid responses (e.g., salmonid habitat use, distribution, relative abundance, species-specific patterns, growth, survival, and productivity).
- Channel characteristics and processes (e.g., channel movement/migration, cross-sectional form, planform, and sediment aggradation).
- Riparian and floodplain vegetation conditions (e.g., vegetation survival, vegetation coverage, and stem densities).
- Large wood presence and condition (e.g. log jam frequency, large wood volume, abundance, and retention).
- Riverine and floodplain connectivity (e.g., frequency of inundation and flows supporting channel engagement).
- Flood risk reduction (e.g., flood surface elevation, frequency of inundation, and flood frequency interval).
- Channel migration hazards (e.g., migration rates and flow velocities).
- Public safety management (e.g., large wood safety and facility condition).

All of these elements not only inform project effectiveness but help to characterize projects and convey information important for project teams, resource managers, salmon recovery basin partners, landowners, local jurisdiction, and other groups. While all of these elements are important for individual project evaluation and characterization, this report will largely focus on project monitoring specific to mainstem aquatic habitat conditions and juvenile salmonid responses.

3.1 Aquatic Habitat Monitoring

3.1.1 Mainstem Low-Velocity Edge Habitats

Aquatic habitat monitoring across mainstem Snoqualmie River projects is largely focused on characterizing and mapping low-velocity edge habitat areas (further detail included in

Appendix B–F). Low-velocity edge habitats are mainstem channel margins defined as having velocities that are less than approximately 1.5 feet per second (0.46 meters per second) (Beechie et al. 2005). Monitoring efforts focus on mainstem low-velocity edge habitats because juvenile salmonids often use these areas for rearing during early life stages (Hillman et al. 1987, Bjornn and Reiser 1991, Beechie et al. 2005). Off channel habitats such as side-channels, beaver ponds, oxbows, and tributaries are also important for juvenile salmonids (Cederholm and Scarlett 1981, Swales and Levings 1989); however, they areas are not represented through mainstem monitoring efforts.

Mainstem edge habitats are critical for juvenile salmonids because they typically have lower water velocities, shallower depths, and greater cover than mid-channel areas (Levings and Lauzier 1991, Hayman et al. 1996, Beechie et al. 2005). Low-velocity edge habitats are important for juvenile salmonid foraging-feeding as well as for velocity and predator refuge. With the widespread loss of mainstem rearing habitat, particularly along channel margins (SBSRF 2005), understanding how large river projects influence edge habitats is critical for evaluating project benefits and effectiveness.

3.1.2 Low-velocity Edge Habitat Mapping and Estimation

Across mainstem Snoqualmie River projects, low-velocity edge habitats were evaluated based on two primary approaches: edge habitat mapping and edge habitat estimation. Edge habitat mapping included the mapping of low-velocity habitat areas with hand-held GPS units where wadeable surveys were feasible. Edge habitat estimation was specific to areas where wadeable mapping was not feasible including deeper channel areas and focused on estimating edge habitats (e.g., edge type, widths, depths) where juvenile salmonids were monitored (further discussed in section 3.2: *Juvenile Salmonid Monitoring*). The former approach provides an inventory of low-velocity habitat areas throughout a project reach and is most suitable for areas where deposition and channel splitting provide depths suitable for wading. The latter approach does not provide an inventory of low-velocity areas but rather provides an estimation of edge habitat conditions across salmonid-surveyed transects. This approach is suitable across project reaches of the lower Snoqualmie River where wide-deep channel areas are predominant.

The boundary between edge habitats and mid-channel areas is based on a visible current shear line, with edge units having lower velocity and mid-channel areas having higher velocity (Beechie et al. 2005). Each edge habitat area was mapped from the edge of water to the visible current shear line, where velocities exceed approximately 1.5 feet per second (shear lines were determined based on visual interpretation). Edge habitat types were mapped, delineated, and characterized based on descriptions in Table 2.

Table 2. Mainstem edge habitat types, description, and low-velocity habitat characteristics.

Edge Habitat Type	Description	Low-Velocity Habitat Characteristics
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.	Majority of area characteristic of zero to very low-velocity flows.
Bar	Low-gradient depositional areas generally consisting of sand and gravel. Bars are typically formed during channel forming flows and when rivers recede from flood or seasonal high flow events.	During most flows, the margins of bars have low slope with shallow low velocity zones. Low-velocity areas generally increases with lower flows until the base of the bar is reached. Generally, have wider low-velocity areas than bank habitats.
Bioengineered Bank	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.	A narrow seam of low-velocity flow generally occurs between wood features and along the bioengineered bank. Low-velocity areas caused by small eddies and disrupted flows from wood and bank armoring features.
Unarmored Bank	Steep-gradient bank where erosional lateral channel migration is occurring with no artificial hardening.	A narrow seam of low velocity flow caused by erosion debris and large wood. Low-velocity areas caused by small eddies and disrupted flows from wood and debris.
Riprap Armored Bank	Steep-gradient bank armored with placed riprap or large angular rock. Designed to limit lateral channel migration.	A narrow seam of low velocity flow at the edge of riprap features normally caused by small eddies and disrupted flows from angular rock.

For projects using the edge habitat mapping approach (Chinook Bend/Stillwater and Lower Tolt), all low-velocity edge habitat areas within the project reach were mapped via foot and cataraft using a Trimble GPS unit. The mapped extents of each low-velocity edge habitat area were processed using ArcMap to create polygons for each low-velocity edge habitat type. These polygons were used to represent the area extents of each low-velocity edge habitat.

For projects using the edge habitat estimation approach (Upper Carlson, Tolt Pipeline, Sinnema Quaale), representative transects along each edge habitat type in the project reach were characterized (based on Table 2) and measured for width and depth. Specifically, for

each edge habitat type, typically two to three 25-meter-long transects were characterized and surveyed. Along each transect, 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 (area where juvenile salmonid electrofishing would occur) and width measurements were taken from the channel wetted edge to the extent of the low-velocity area. Depth and width measurements were collected from a cataraft using a stadia rod and laser range finder during a cataraft float survey.

In addition to edge-habitat characterization and delineation, selected edge habitat transects were chosen to represent control or treatment areas. Control edge habitat transects were chosen to represent areas that were likely not impacted by project actions (e.g., existing riprap armored banks, backwaters, bars, and unarmored banks). Treatment transects were chosen to represent areas within a restoration or enhanced bank stabilization project reach that were either directly or indirectly impacted by the project actions (e.g., newly formed unarmored banks, backwaters, and bars, as well as constructed bioengineered banks). Direct impacts include changes in bank conditions, such as the removal of revetment or installation of bioengineered bank, and indirect impacts include changes in adjacent bar and backwater formation, resulting from project-related changes to hydraulic and sediment dynamics.

3.2 Juvenile Salmonid Monitoring

Juvenile salmonids as well as other fish species were monitored within edge habitats across all projects listed in Table 1. Monitoring efforts have primarily focused on juvenile salmonid presence and abundance between late winter and early summer, to target the spring rearing and outmigration period for juvenile Chinook salmon. Project monitoring generally included 25-m long transects across each edge habitat with at least 2-3 transect replicates surveyed among each edge habitat type. Additionally, monitoring included transects specific to treatment and control edge habitats, with monitoring occurring during pre- and post-project periods.

Projects aim to monitor salmonids before and after project completion; however, there has been variation in survey methodology and approaches. In an effort to standardize and align monitoring methodologies, current strategies focus on two primary approaches including cataraft-based electrofishing and wadeable net-seining. Cataraft-based electrofishing has been used primarily across project reaches where net-seining was ineffective or difficult to deploy, including deep channels, steep banks, and deep-wide areas. Net-seining was used for the Lower Tolt project and for one year of post-project monitoring at the Chinook Bend/Stillwater project reach; otherwise, cataraft-based electrofishing was used for all other projects listed in Table 1.

3.2.1 Cataraft-Based Electrofishing

Projects that used the cataraft-based electrofishing approach were conducted using a modified cataraft built by King County staff to monitor juvenile salmonids in large rivers. The cataraft setup 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.

Electrofishing began about 30 to 60 minutes after sunset, following daytime edge habitat mapping and characterization. Fish sampling occurred during hours of darkness, rather than daylight, because juvenile salmonids are mainly crepuscular/nocturnal during 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 and feed (Metcalfe et al. 1999, Bradford and Higgins 2001). Additionally, previous observations among King County large river monitoring efforts indicated that cataraft-based electrofishing had greater capture rates during darkness.

Along each 25-meter-long transect, fish were sampled by orienting the electrofishing cataraft towards the water's edge with the anode arrays placed within the low-velocity edge habitat. Once at the start (upstream extent) of the transect, two netters on the front of the boat began electrofishing, netting (net mesh was 3/16-in) 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). A third person piloted 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.

3.2.2 Net-Seining

Projects that used the net-seining approach were conducted using one of two net-seine configurations. One net was 4-feet deep and 30-feet long with a capture bag measuring 4-feet by 6-feet (mesh size was 3/16-inch for the net wings and 1/8-inch for the capture bag). The other net was 4-feet deep and 25-feet long with a capture bag measuring 4-feet by 6-feet (mesh size was 3/16-inch for the net wings and 1/8-inch for the capture bag).

Net-seining was conducted beginning about an hour after sunset following daytime edge habitat mapping and characterization. Similar to cataraft-based electrofishing, fish sampling occurred at night rather than day due to a higher likelihood of juvenile salmonid presence and capture rate. The net-seine was deployed by two or three biologists from upstream to downstream within each edge habitat type. One biologist walked down the water's edge while another biologist walked parallel at the low-velocity edge shear line. At the end of the set, the biologist walking the low-velocity shear line would swing over to the water's edge to meet the other biologist(s) and they would then quickly retrieve the net by pulling in the bottom lead line and the top cork line at an even pace (creating a "pursing" effect). Any fish caught in the seine would be entrained into the bag where samplers would then remove them and place them into buckets. To seine backwater habitats, the same technique was used except that seining was done in an upstream direction. In some circumstances it was possible to seine the entire wetted width of a backwater habitat. After

each net-seine, the effort (seconds of netting) as well as fish species and length information were recorded. Captured fish were anesthetized using MS-222, identified to species or genus, measured for fork length, and then placed in a bucket of fresh water until they were fully recovered and could be released safely.

3.3 Project-Specific Analyses and Methodological Caveats/Limitations

Across projects, analysis of juvenile salmonid presence and abundance among edge habitats focused on juvenile Chinook, coho, and trout (rainbow, steelhead, and cutthroat). Analyses focused on evaluating the relative abundance of juvenile salmonids across each edge habitat type, including comparison of treatment and control transects, as well as comparison across pre- and post-project periods (project-specific details included in Appendix B–F: *Snoqualmie River Project-Specific Observations: Mainstem Aquatic Habitats and Juvenile Salmonids*).

Projects using the cataraft-based electrofishing approach evaluated relative fish abundance either through catch-per-unit-effort (CPUE) or by catch-per-transect-length (Catch/25-m). 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. However, while CPUE can be a useful metric, this metric operates under the assumption that there is a positive relationship between catch and effort (i.e., more effort may equate to greater catch). Relationships between salmonid catch and electrofishing effort vary within sampled transects and across projects. Thus, some projects focused on representing relative fish abundance through catch-per-transect-length and other projects focused on catch-per-unit-effort.

Projects using the net-seining approach evaluated relative fish abundance among each edge habitat type by dividing the number of each fish species captured within a net-seine set by the number of seconds spent actively netting (seconds representing effort). This provided a CPUE estimation, which would represent relative abundance across edge habitats.

There may be several limitations across project-specific fish abundance observations due to the methods used, salmonid behavioral-ecological patterns, as well as habitat access and availability. For a given project, the same sampling method was used across edge habitats; however, the capture probability across each edge habitat type may be different and could influence respective abundance estimates. For example, it may be possible 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. Deeper channel areas may have relatively lower electrofishing efficiency and capture probability since only a fraction of the water column is sampled.

Since capture efficiency declines with depth (Zale et al. 2012), CPUE values for deeper edge habitats may be biased low. This highlights the importance of understanding sampling efficiency across methodologies and edge habitats (e.g., paired sample events and the use of multiple paired methodologies). This information could be incorporated into efficiency estimates and related correction factors that may help in adjusting observational information. Due to limited information on efficiency estimates, the analyses included in this report does not include correction factors. 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, juvenile Chinook are known to prefer unarmored banks compared to riprap armored banks (Knudsen and Dilley 1987, Beamer and Henderson 1998, Quigley and Harper 2004). However, the lower Snoqualmie River has a significant amount of bank armoring, specifically concentrated among spawning and rearing reaches (King County 2002 and 2018a). Widespread bank armoring likely limits the availability and proximity of preferred unarmored bank habitat, resulting in juveniles using armored banks or other edge habitats.

4.0 PROJECT EFFECTS ON AQUATIC HABITAT CONDITIONS

Restoration projects and enhanced bank stabilization projects have improved mainstem edge habitats.

- Restoration projects (Chinook Bend/Stillwater, Lower Tolt, and Upper Carlson) have increased low-velocity edge habitat area and extent.
- Improved edge habitats (e.g., restored unarmored banks, bars, backwaters) were wider and shallower, compared to riprap armored banks, resulting in greater low-velocity areas.
- Restoration projects improved edge habitat quality and complexity, by design, through increased large wood integration, engagement, and recruitment.
- The integration of large wood and vegetation into enhanced bank stabilization projects (Sinnema Quaale and Tolt Pipeline) had, by design, increased edge habitat quality and complexity.
- Reconnecting and restoring the Deer Creek confluence, as part of the Tolt Pipeline protection project, increased accessibility for juvenile salmonids and improved confluence habitat quality.

Maximizing habitat improvements requires aggressive actions and prioritization of remaining constraints.

- Restoration projects need to take aggressive approaches, especially where constraints upstream, downstream, and across the river remain or are unlikely to be addressed in the near-term.
- Aggressive actions include mainstem large wood jams, deeper-wider side channel excavation, and consideration of remaining reach-scale constraints.
- Near-term adaptive management should be prioritized to address constrained reaches, re-visit remaining constraints, and address factors that limit habitat improvements.

Restoration projects and enhanced bank stabilization projects use a variety of strategies to improve habitat conditions and support juvenile salmonids. Understanding the effectiveness of projects in addressing habitat goals is the focus of various monitoring efforts. This section provides an overview of project effects on mainstem low-velocity edge habitats (project-specific information included in Appendix B–F: *Snoqualmie River Project-Specific Evaluations and Observations: Mainstem Aquatic Habitats and Juvenile Salmonids*).

4.1 Increased Low-Velocity Habitat Area

Low-velocity edge habitat area has increased across restoration projects (Chinook Bend/Stillwater, Lower Tolt, Upper Carlson) where large amounts of riprap armoring had been removed, helping to promote channel migration and habitat formation. This was especially apparent at the Chinook Bend/Stillwater project reach, where low-velocity habitat area, especially among lower to moderate spring flows, had increased from pre-project periods (2009) to post-project periods (2011 and 2019) (Figure 2 and 3) (King County 2017a and in prep.–a). Not only has low-velocity edge habitat area increased, but channel complexity at the Chinook Bend/Stillwater project reach has improved with increased channel splitting and the formation of bar, backwater, and bank habitats (King County 2017a and in prep.–a).

Habitat improvements across the Chinook Bend/Stillwater reach are likely due to the interaction between projects and the reach-scale restoration of riverine processes. The Chinook Bend project removed ~610 meters (2000 ft) of revetment on the left bank of the project reach from 2009 to 2011. The Stillwater project (implemented by Wild Fish Conservancy) removed ~640 meters (2100 ft) of revetment along the outside bend on the north side of the project reach in 2013, promoting channel migration into the adjacent floodplain. The restoration of channel migration supported reach-scale hydrologic and sediment processes across both projects. This resulted in sediment deposition and channel splitting, especially throughout the lower half of the Chinook Bend/Stillwater reach. The interaction between the projects and collective restoration of riverine processes has increased low-velocity habitat areas and improved edge habitat conditions.

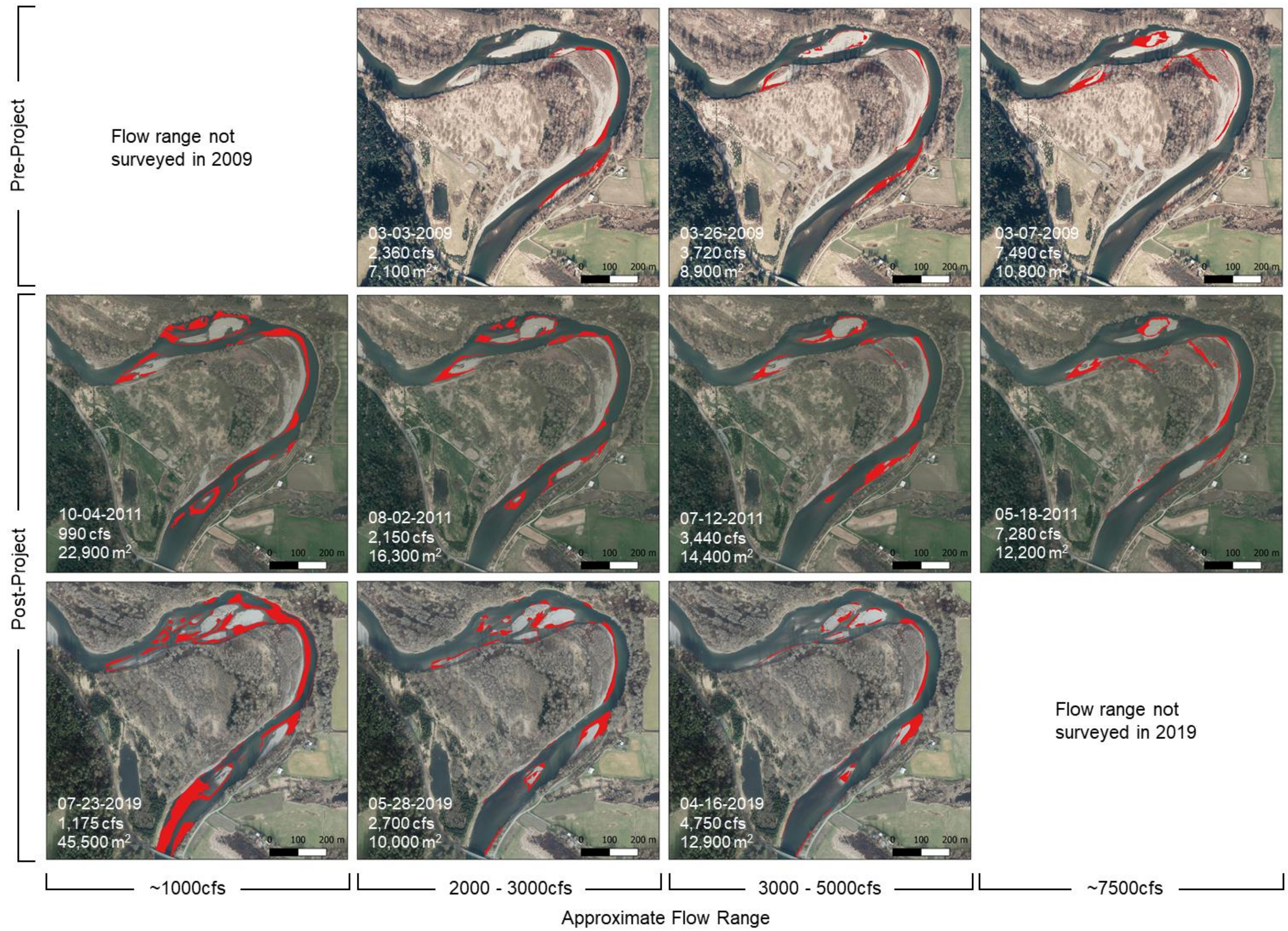

Figure 2. Low-velocity edge habitat areas (red shapes) before (2009) and after (2011 & 2019) Chinook Bend/Stillwater project completion. Chinook Bend on the left bank was completed by 2011 and Stillwater on the right bank was completed in 2013. Aerial imagery corresponds with survey years. Survey dates, river flow (cubic-feet-per-second at USGS 12149000), and total area (m^2) of low-velocity habitat are shown in the corner of each map. Note: the March 3, 2009 survey did not map downstream low-velocity habitat areas and July, 2019 was the only time the bridge area was mapped.

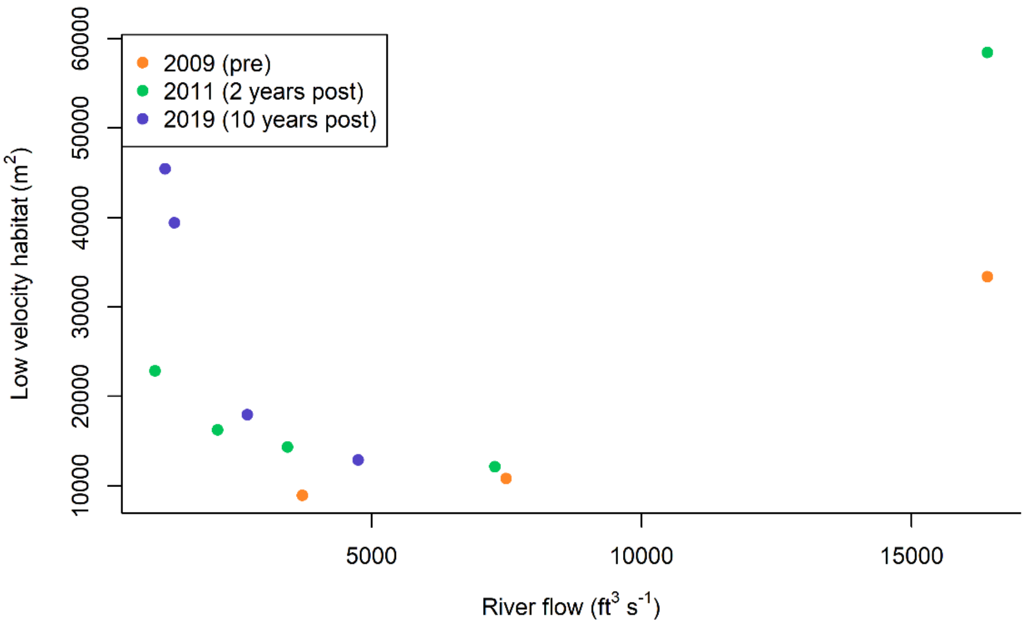

Figure 3. Total low-velocity edge habitat area (m^2) at Chinook Bend/Stillwater project reach as a function of discharge (cubic-feet-per-second at USGS 12149000) across pre-project (2009) and post-project (2011 & 2019) surveys. Chinook Bend was completed by 2011 and Stillwater was completed in 2013.

Increases in low-velocity habitat area were also seen at the Lower Tolt project. Low-velocity habitat area increased from pre-project periods (2009) to post-project periods (2011, 2014, 2019) across a range of flow levels (Figure 4 and 5) (King County in prep.–b). Overall increases in edge-habitat area across post-project periods were largely driven by increased bar, backwater, and side-channel habitats (King County in prep.–b). Across post-project periods, there was a decline in edge-habitat area from 2011 to 2014, possibly due to gravel bars aggraded and/or thalweg incision. However, overall edge-habitat area in 2014 was still greater than pre-project periods and areas continued to increase from 2014 to 2019. Fluctuations in edge-habitat areas across post-project periods highlight inter-annual changes in channel movement and habitat formation, which influence the overall area, extent, and location of low-velocity habitats.

While there were considerable increases in mainstem edge-habitat area across the Lower Tolt project, overall project improvements fell short of expectations. Specifically, the overall project reach included pilot side-channels, floodplain channels, and floodplain large wood complexes, which were expected to be engaged across a range of flows. However, pilot-floodplain channel engagement and mainstem avulsion was largely limited with created channels only inundating at the highest flood flows. The limitations of these project elements suggest that more aggressive actions were likely needed, including mainstem large wood jams to route flow into created channels, deeper-wider pilot side channel excavation to ensure engagement across a range of flows, and further consideration of remaining reach-scale constraints, such as existing armoring throughout the lower Tolt River.

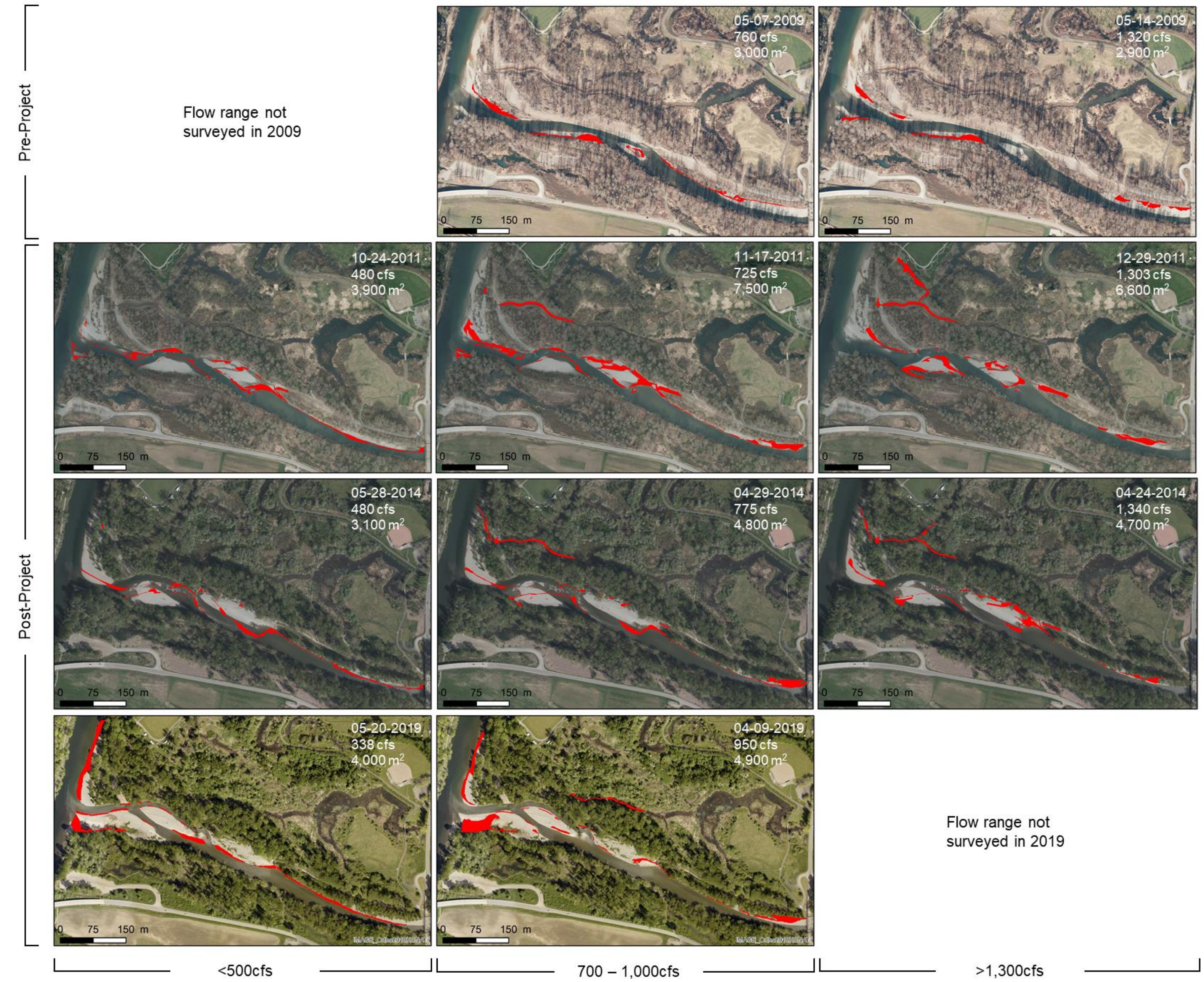

Figure 4. Low-velocity edge habitat areas (red shapes) before (2009) and after (2011, 2014, 2019) Lower Tolt project completion. Aerial imagery corresponds with survey years. Survey dates, river flow (cubic-feet-per-second at USGS gage 12148500), and total area (m^2) of low-velocity habitat are shown in the corner of each map. Note: total area calculations for April and May, 2019 do not include areas on the mainstem Snoqualmie River downstream of confluence.

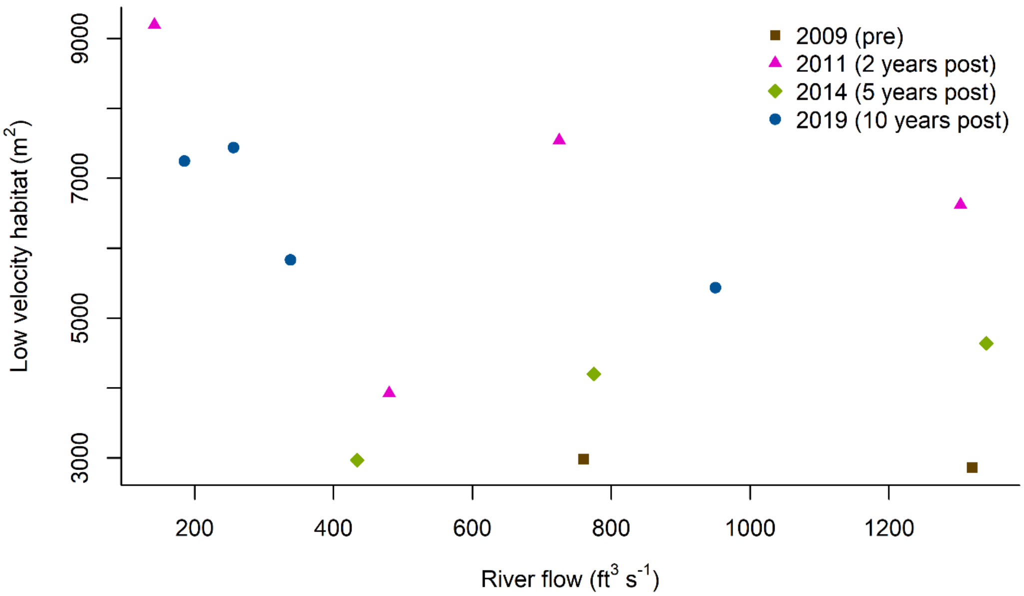

Figure 5. **Total low-velocity edge habitat area (m²) at the Lower Tolt project as a function of discharge (cubic-feet-per-second at USGS 12148500) across pre-project (2009) and post-project (2011, 2014, 2019) surveys.**

In addition to Chinook Bend/Stillwater and Lower Tolt, the restoration of hydrologic and sediment processes along the Upper Carlson project reach resulted in the formation of new edge-habitat areas. The Upper Carlson restoration project included the removal of ~488 meters (1600 ft) of revetment/levee along the right bank, which promoted channel migration and widening, resulted in the formation of a one-acre gravel bar, at low and moderate flows, and a related backwater along the left bank (Figure 6) (King County 2018b, 2020, & in prep.–c). This is especially important since bar and backwater habitats were relatively limited across the project reach prior to project completion.

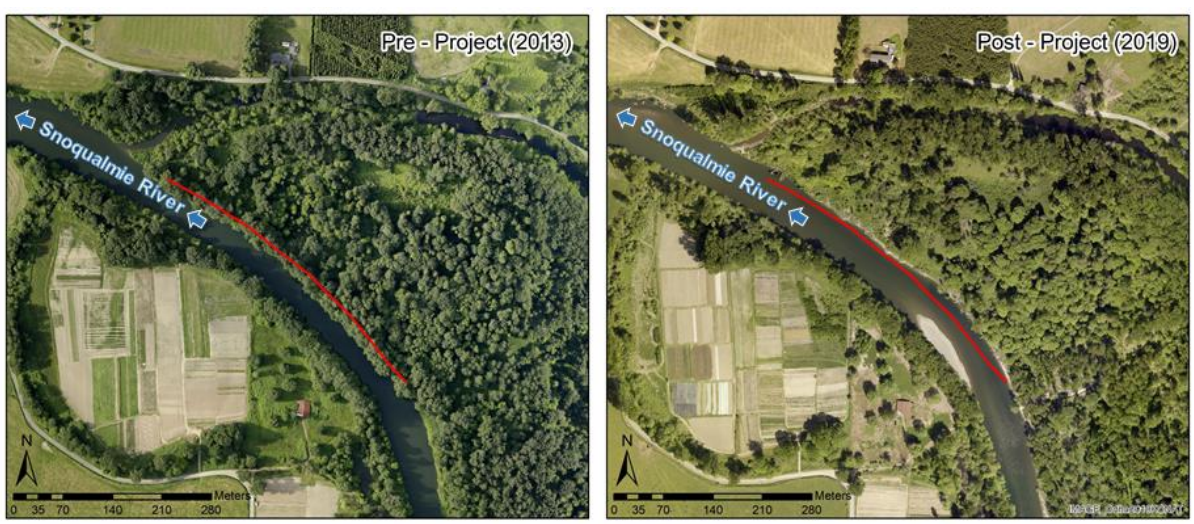

Figure 6. **Upper Carlson project (right bank) during pre-project (2013) and post-project (2019) periods. Red line indicates the pre-project top-of-bank extent of removed revetment. The newly formed gravel bar can be seen in the middle of the post-project image.**

4.2 Increased Edge Habitat Quality and Complexity

Edge habitat quality and complexity was improved across several restoration projects. For example, along the Upper Carlson project reach, there was a net gain of ~864 meters (2835 ft) of mainstem edge habitat due to revetment removal with at least 479 meters (1572 ft) consisting of gravel bars and woody unarmored banks (King County 2018b & in prep.–c). These created and improved edge habitats (restored unarmored banks, bars, backwaters) were wider and shallower, compared to riprap armored banks (Figure 7), resulting in greater low-velocity habitat areas. Additionally, the widths and depths of created and improved edge habitats were similar to controls (i.e., newly formed bars and backwaters were similar to control bars and backwaters), indicating that restored edge habitats had similar characteristics to existing functioning habitats. Edge habitat complexity related to woody unarmored banks has largely been due to increased large wood engagement and recruitment along the project bank. Large trees that were felled during revetment removal were placed along the bank and floodplain terrace to provide near-term sources of large wood as the channel migrated into the forested floodplain (King County 2018b and in prep.–c). Large wood and related logjams create complex edge habitats, increase hydraulic heterogeneity promoting habitat diversity, provide high quality cover, and dissipate hydraulic energy during peak flows (Bilby 1984, Harmon et al. 1986, Bilby and Ward 1991).

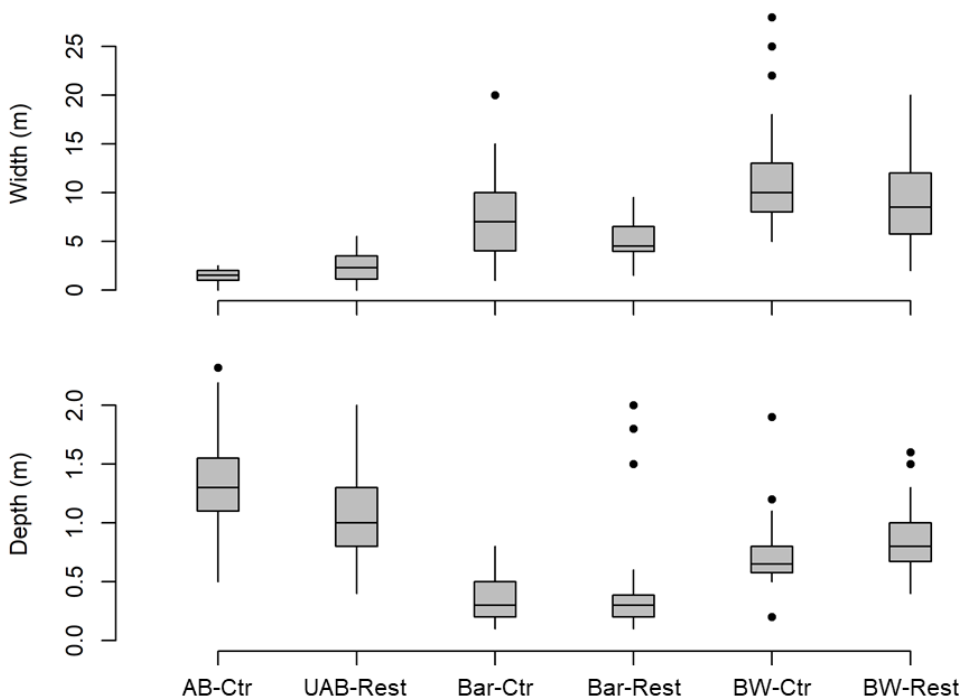

Figure 7. Edge habitat widths and water depths from 2018-2019 surveyed transects across the Upper Carlson project reach. Edge-reach codes include: AB-Ctr (control riprap armored bank), UAB-Rest (restored unarmored bank), Bar-Ctr (control bar), Bar-Rest (restored bar), BW-Ctr (control backwater), and BW-Rest (restored backwater). Note: there were no control transects for unarmored banks. 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.

Edge habitats quality and complexity was also improved at Chinook Bend/Stillwater and the Lower Tolt project reaches. Similar to the Upper Carlson project, bars and backwaters at Chinook Bend/Stillwater had greater low-velocity widths and shallower depth, compared to riprap armored banks (King County in prep–a). Additionally, the Lower Tolt project resulted in channel migration into the right bank undercutting riparian trees and forming new large wood jams, which increased edge habitat complexity (King County in prep - b).

Enhanced bank stabilization projects (Sinnema Quaale and Tolt Pipeline) have also increased edge habitat quality and complexity, by design, through the integration of bioengineering techniques. As previously mentioned, integrating large wood can improve edge habitat complexity by increasing hydraulic heterogeneity and habitat diversity. The Tolt Pipeline protection project installed 700 ballasted wood jacks and 60 engineered log jams throughout the bioengineered revetment bank (King County 2015a & 2019). The installed wood, by design, resulted in increased edge complexity along ~350 meters (1148 ft) of the project reach. Similarly, the Sinnema Quaale project installed log jams and wood structures across ~229 meters (750 ft) of the project reach. The integration of bioengineering techniques, by design, improved edge habitat complexity, compared to solely riprap armored banks. Additionally, the bioengineered revetment banks at both the Sinnema Quaale and Tolt Pipeline projects had greater low-velocity widths and extents, compared to riprap armored banks (King County 2017c & 2019).

4.3 Improvements to an Adjacent Tributary

The Tolt Pipeline project was primarily an enhanced bank stabilization project; however, it included the restoration of the Deer Creek confluence. The restoration of the adjacent tributary confluence included replacing a crushed culvert with a set-back regulated flap gate, improving habitat conditions throughout lower Deer Creek, and creating a floodplain alcove along the mainstem Snoqualmie River. Improvements included re-meandering ~135 meters (443 ft) of Deer Creek upstream of the tributary confluence, increased sediment diversity, creation of a ~1.2-acre floodplain alcove (engaged at flows greater than 7,000 cfs), and the installation of 72 pieces of large wood as discontinuous bioengineered banks throughout lower Deer Creek (King County 2015a & 2019). Reconnecting and restoring Deer Creek provided increased accessibility for juvenile salmonids among tributary habitat areas and improved confluence habitat quality (King County 2019). Specific to accessibility, in years prior to the culvert becoming crushed, juvenile Chinook and coho were frequently observed throughout lower Deer Creek. The culvert eventually became crushed which limited access and connectivity at the confluence. During pre-project monitoring in 2017—2018, juvenile Chinook were not observed upstream of the crushed culvert and juvenile coho were only observed in low abundance. However, once the project was completed in 2018, juvenile Chinook and coho were observed throughout lower Deer Creek at considerably higher abundances compared to pre-project monitored periods (King County 2019).

4.4 Limitations of Remaining Reach-Scale Constraints

Remaining reach-scale constraints can limit the potential of restoration projects. For example, reach-scale channel response and habitat formation along the Chinook Bend/Stillwater project reach were largely achieved only after completion of the second project, which removed some of the remaining constraints. The first project (Chinook Bend) removed ~610 meters (2,000 ft) of riprap rock revetment on the left bank from 2009 to 2011, aiming to improve edge habitat complexity and restore channel and floodplain hydraulics and connectivity. However, response from this riprap removal was limited due in part to armoring remaining throughout the opposite bank and outside bend of the project reach. Remaining armoring throughout the reach limited channel migration as well as reach-scale hydraulic and sediment processes. The second project (Stillwater) removed ~640 meters (2,100 ft) of riprap armoring along the outside bend in 2013. As a result, there were considerable responses across both projects, especially along the lower half of the reach, with increased channel migration, channel splits, erosion, accretion, and habitat formation. These results highlight that remaining reach-scale constraints can limit restoration projects and that a broader reach-scale approach may prove most beneficial for process-based restoration. Additionally, these results suggest that adaptive management for restoration projects should be prioritized in the near-term to address constrained reaches, re-visit remaining constraints (e.g., revealed-buried rock), and address factors that limit habitat improvements.

5.0 JUVENILE SALMONID RESPONSE TO PROJECTS: META-ANALYSIS

Juvenile Chinook and coho have positively responded to improved mainstem edge habitats.
• Across restoration and enhanced bank stabilization projects, juvenile Chinook and coho abundance among improved edge habitats (backwaters, bars, bioengineered banks, and unarmored banks) was consistently greater than degraded riprap armored banks (i.e., positive response to project actions). • Among edge habitat types, backwaters, bars, and unarmored banks showed the greatest juvenile Chinook response while backwaters, bioengineered banks, and unarmored banks showed the greatest coho response. • Juvenile trout showed a mixed response to improved edge habitats, with the most consistent positive response observed among unarmored banks and most consistent negative response observed among backwaters.
Process-based restoration is likely the best approach to maximize habitat improvements for juvenile Chinook.
• The meta-analysis highlights the benefits of improved edge habitats, habitat diversity, and collective improvements across multiple edge habitat types. • While all improved edge habitats can benefit juvenile Chinook, process-based restoration may provide relatively greater benefits, compared to enhanced bank stabilization (although not directly tested in this report). • If bank stabilization is necessary, then bioengineered approaches are better than traditional riprap armored designs. • Improving mainstem habitat conditions is contingent on the degree to which projects restore functioning processes, improve edge habitat conditions, remove reach-scale constraints, integrate bioengineered techniques, and improve adjacent habitat areas.

Project-specific monitoring and analyses have provided useful information; however, there's an ongoing need for a collective evaluation of monitoring observations across restoration and treatment projects. Meta-analysis helps to provide comparisons across different project types, improve overall understandings of patterns and responses, and helps to evaluate similarities or differences in juvenile salmonid responses to project actions. Combining project observations provides better estimates of responses than any given project alone. Across restoration and enhanced bank stabilization projects, the meta-analysis approach in this report aimed to evaluate if the abundance of juvenile salmonids among improved edge habitats (unarmored banks, bars, backwater, bioengineered banks) was consistently greater than abundance among riprap armored banks (degraded habitat condition).

Meta-analysis statistical methods help in summarizing and interpreting monitoring data from a collection of projects and observations. In a meta-analysis, outcomes of various projects are summarized as an index of effect-response, with this index being summarized across all projects (Gurevitch and Hedges 1999). This type of analysis normalizes response results across projects, which helps in evaluating collective, aggregate patterns and observations. In general, a meta-analysis approach is appropriate for this report since there are multiple projects with varying sampling designs and methods used, with all projects having a similar degraded control conditions (i.e., riprap armored banks). Project-related habitat improvements can be categorized and grouped for collective comparison and evaluated based on juvenile salmonid abundance among and between categories.

5.1 Meta-Analysis: Natural Log-Response Ratio

The meta-analysis for projects included in this report uses a natural log response ratio as the metric to evaluate salmonid response to project-related habitat improvements. The natural log response ratio is a useful metric to assess relative response size (Hedges et al. 1999) and has been effectively used for meta-analysis assessments across ecological applications (Smokorowski and Pratt 2007, Whiteway et al. 2010). An advantage of the log response ratio is that the proportional response can be derived from different measures of relative abundance, such as cataraft-based electrofishing and net-seining.

The log-response ratio for this meta-analysis was defined as the proportional effect of the juvenile salmonid abundance among improved edge habitats (i.e., post-project unarmored banks, bars, backwaters, and bioengineered banks) compared to degraded riprap armored banks. Riprap armored banks were either pre-project conditions or when pre-project data was not available, post-project control riprap armored banks were used. Salmonid abundance among edge habitat types was estimated through catch-per-unit-effort (CPUE), which included either juvenile salmonid catch-per-seconds of electrofishing (cataraft-based electrofishing method) or juvenile salmonid catch-per-seconds of netting (net-seining method). The natural log response ratio was calculated using the following formula:

$$Log\ Response\ Ratio = \ln\left(\overline{X_{IEH}} / \overline{X_{RAB}}\right)$$

Where:

$\overline{X_{IEH}}$= average CPUE among post-project improved edge habitats (IEH)

$\overline{X_{RAB}}$ = average CPUE among riprap armored banks (RAB)

The log response ratio is equally affected by changes in $\overline{X_{IEH}}$ and $\overline{X_{RAB}}$ with the distribution of ratio results being normalized compared to the proportional effect-response (Hedges et al. 1999). Across restoration and enhanced bank stabilization projects, there was variation in juvenile salmonid monitoring efforts across pre- and post-project periods (Table 3). When riprap armored bank data was not available for pre-project periods, the juvenile salmonid abundance among control riprap armored banks was used to calculate the log-response ratio. The Lower Tolt restoration project did not have any pre-/post-project riprap armored bank data, so the average of all riprap armored banks across all other projects was used for the log-response ratio. While this results in comparisons across methodologies (i.e., net seining at the Lower Tolt project compared to cataraft e-fishing among riprap armored banks), the combined average is the best estimation available at this time for juvenile salmonid abundance among riprap armored banks across the lower Snoqualmie River.

Table 3. Project completion and juvenile salmonid monitoring periods among select large river projects across the lower Snoqualmie River.

		Juvenile Salmonid Monitoring Periods	
Project	**Project Completion**	**Pre-Project**	**Post-Project**
Chinook Bend/Stillwater Restoration and Floodplain Connection	Chinook Bend (2009 - 2015)* Stillwater (2013)	2009	2011**, 2019
Lower Tolt Restoration and Floodplain Connection	2009	2009	2011, 2019
Upper Carlson Restoration and Floodplain Connection	2014	2014‡	2015‡, 2016 - 2019
Tolt Pipeline Protection and Deer Creek Restoration	2018	2016 - 2018	2019, 2020◊
Sinnema Quaale SR-203 and Snoqualmie Trail Protection	2016	2015‡	2017

* Project completion included multiple phases: upstream revetment and levee removal as well as log piling installation and riparian plantings (2009), downstream revetment and levee removal as well as downstream buried setback levee (2011), additional upstream rock removal (2012), removal of remaining culvert, spoils, and remaining revetment (2015).

** The 2011 post-project monitoring occurred after the primary levee removal at Chinook Bend but before completion of the Stillwater project (2013) and before completion of the additional actions at Chinook Bend (2012-2015).

‡ Snorkel surveys were completed in late summer focusing on coho and trout. Since surveys were conducted after the spring juvenile Chinook rearing period, they were not included in the meta-analysis. All other post-project monitoring used cataraft-based electrofishing from late winter through early summer and were included in the meta-analysis.

◊ Due to Covid-19 and cancelled field work, project monitoring was incomplete and only captured the start of the juvenile salmonid rearing and outmigration period. 2020 data was not used in the meta-analysis.

5.2 Juvenile Salmonid Response to Restoration and Treatment Edge Habitat Types

The meta-analysis included all five projects discussed in Table 1 as well as project-related edge habitats. Across restoration and enhanced bank stabilization projects, a total of 342 sampled transects were used in the meta-analysis. This included post-project bioengineered banks (24 transects), backwaters (42 transects), bars (113 transects), unarmored banks (73 transects), as well as pre-project or control riprap armored banks (90 transects). Not all projects had each representative edge habitat type. For example, only two projects (Tolt Pipeline and Sinnema Quaale) had bioengineered banks and only three projects had backwaters (Chinook Bend/Stillwater, Upper Carlson, Lower Tolt).

Log-response ratios were calculated for juvenile Chinook, coho, and trout (i.e., cutthroat, rainbow, and steelhead) across improved edge habitats (Figure 8 and Appendix A-1). Juvenile Chinook displayed a consistent positive response across all improved edge habitat types, including backwaters, bars, bioengineered banks, and unarmored banks (i.e., abundance was greater among improved edge habitats compared to riprap armored banks). Across improved edge habitats, backwaters (ranging from 0.67–3.80), bars (ranging from 1.17–3.00), and unarmored banks (ranging from 1.73–2.66) showed the greatest juvenile Chinook response. Bioengineered banks also had a positive juvenile Chinook response (ranging from 0.88–1.13), albeit less in magnitude compared to other edge habitat types. These collective log-response ratios suggest that juvenile Chinook abundance among improved edge habitats was consistently greater than riprap armored banks.

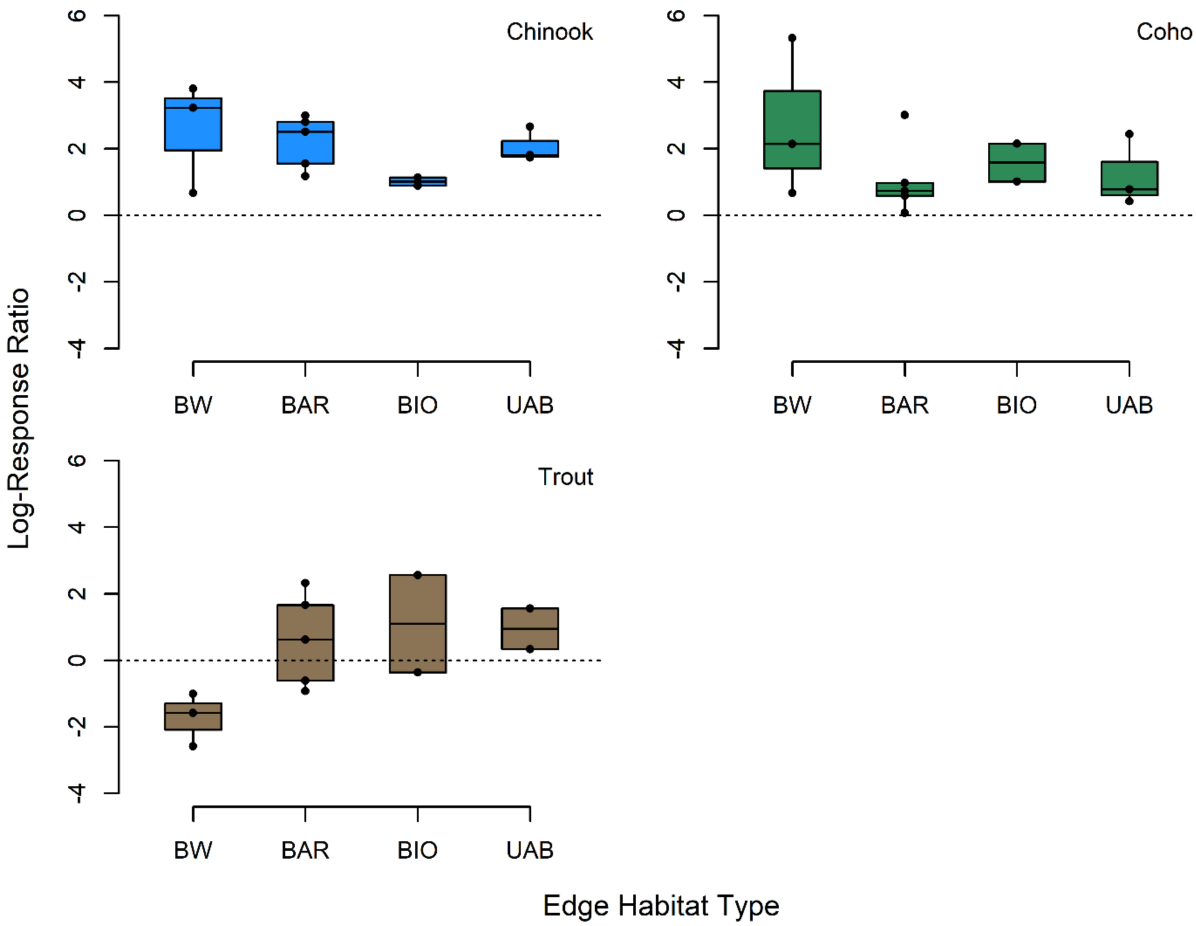

Figure 8. **Natural log-response ratios (proportional effect of the juvenile salmonid abundance among improved edge habitats compared to riprap armored banks) for juvenile Chinook, coho, and trout across improved edge habitat types. Points indicating specific project values. Trout include cutthroat, rainbow, and steelhead. Edge habitat codes include: BW (backwaters), BAR (bars), BIO (bioengineered banks), and UAB (unarmored banks). 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 unconnected points are observations beyond 1.5x the inter-quartile range. Notes: values above zero indicate that the juvenile salmonid abundance among a given post-project edge habitat type is greater than the juvenile salmonid abundance among the riprap armored banks. Values below zero indicate the opposite. Values on or near the zero line indicate that there is no difference in abundance between improved edge habitats and riprap armored banks. Values further away from zero indicate a relatively greater positive or negative response.**

In addition to juvenile Chinook, log-response ratios for juvenile coho also appeared to show a consistent positive response across all improved edge habitat types. However, specific to juvenile coho, backwaters (ranging from 0.66–5.32), bioengineered banks (ranging from 1.01 -2.15), and unarmored banks (ranging from 0.42–2.43) showed the greatest responses. Bars showed less of a consistent response for juvenile coho (ranging from 0.07–

3.01); however, log-response ratios were still positive in value. Similar to juvenile Chinook, these collective log-response ratios suggest that improved edge habitat types had consistently greater juvenile coho abundance, compared to riprap armored banks.

Log-response ratios for juvenile trout showed mixed responses across edge habitat types. Unarmored banks (ranging from 0.33–1.56) showed the most consistent positive response while backwaters (ranging from -1.02–2.59) showed the most consistent negative responses. Both bars and bioengineered banks displayed both positive and negative response values (ranging from -0.92–1.66 and -0.37–2.56, respectively); however, the median across log-response ratios were positive for both edge habitat types.

Juvenile trout observed across project effectiveness monitoring efforts tend to be larger than observed juvenile Chinook and coho. These larger trout may be less dependent on low-velocity areas since they are able to withstand a greater range of flow velocities. Additionally, large spaces among unarmored and riprap armored banks, between roots, wood, and large rocks, may provide suitable holding areas for ambush predation opportunities and for cover from avian predators (further discussed in section 6.0: *Juvenile Salmonid Size Classes and Life-History Patterns, Size-specific Habitat Use, and Seasonal Shifts in Habitat Use*).

Collectively, across restoration and bank stabilization projects, juvenile Chinook and coho displayed consistent positive responses to improved edge habitats. While there is variation in species-specific response to individual edge habitat types, observations indicate that juvenile Chinook and coho abundance among improved edge habitats was consistently greater than riprap armored banks. The benefits of restoration and bank stabilization projects seem apparent since they not only improve edge habitat conditions (discussed in section: *4.0 Project Effects on Aquatic Habitat Conditions),* but also consistently support juvenile Chinook and coho.

It can be difficult to determine if increased juvenile salmonid abundance is a result of increased recruitment, survival, and growth, or because of immigration and redistribution within and across riverine reaches (Gowan and Fausch 1996). Since habitat improvements can benefit juvenile salmonid rearing, foraging, and refuge (SBSRTC 2004, SBSRF 2005), if juveniles are immigrating and redistributing from degraded habitats to improved habitats, there will likely be realized benefits to growth and survival. Additionally, if juveniles immigrate and redistribute to preferred habitats, an increase in watershed-wide juvenile salmonid abundance may occur since there are overall increases in riverine habitat capacity (Gowan and Fausch 1996).

5.3 Juvenile Salmonid Response Across Restoration and Enhanced Bank Stabilization Projects

The meta-analysis highlights the benefits of improved edge habitats, habitat diversity, and collective improvements across multiple edge habitats. Since juvenile Chinook and coho show a considerable response to improved edge habitats, projects which not only support edge habitat improvements but also aim to maximize edge habitat diversity and area, should provide the greatest benefits to juvenile salmonids.

While not directly tested in this report, meta-analysis results suggest that habitat benefits for juvenile Chinook likely vary between restoration and bank stabilization projects. Juvenile Chinook had the greatest response across backwaters, bars, and unarmored banks, which are frequently created and improved by restoration projects. On the other hand, juvenile Chinook had less of a response to bioengineered banks, which is the primary edge habitat type created by enhanced bank stabilization projects. Furthermore, the full benefits of restoration projects may be underestimated in this meta-analysis, since enhanced bank stabilization results in immediate response while restoration results in both immediate and long-term responses. The long-term response and related habitat benefits are not fully captured in this evaluation. There are clearly differences in the goals of restoration projects (promote riverine and floodplain processes) and enhanced bank stabilization projects (minimize detrimental impacts of bank hardening while providing improved edge habitat). Differences in goals as well as observed differences in habitat improvements and juvenile salmonid responses contribute to an inferred difference in habitat benefit between project types. While all improved edge habitat types can benefit juvenile Chinook, if projects aim to maximize habitat improvements, then process-based restoration is likely the best approach. If bank stabilization is necessary, then bioengineered approaches are better than traditional riprap armored designs.

Juvenile coho appeared to show less of a differential response across project types. For example, coho abundance was greatest among backwaters, commonly found at restoration projects, in addition to bioengineered banks, found at enhanced bank stabilization projects. The meta-analysis highlights that juvenile coho showed a positive response to improved edge habitats; however, differences in abundance may align more with specific edge habitats rather than project type. Juvenile coho are known to be associated more with off-channel habitats such as side-channels, beaver ponds, oxbows, and tributaries (Cederholm and Scarlett 1981, Swales and Levings 1989), which may result in under-representation of habitat preference with mainstem-only sampling. Since mainstem edge habitats are particularly important for juvenile Chinook (Levings and Lauzier 1991, Hayman et al. 1996, Beechie et al. 2005), differences in juvenile salmon response across mainstem edge habitats and project types are likely best evaluated through juvenile Chinook abundance.

Juvenile trout appeared to show a mixed response to improved edge habitat types. Furthermore, across several projects and edge habitat types, juvenile trout appeared to be more abundant among riprap armored banks. It's worth noting that the observed trout included multiple size classes and year classes, and were generally larger than juvenile

Chinook and coho (discussed further in section 6.0*: Juvenile Salmonid Size Classes and Life-History Patterns, Size-specific Habitat Use, and Seasonal Shifts in Habitat Use*). These relatively larger trout are likely not preferentially selecting low-velocity edge habitats since they are able to withstand a greater range of flow velocities (higher velocities common among riprap armored bank). Riprap armored banks, especially the spaces between rocks, could provide suitable areas for hiding and ambush predation opportunities. Larger trout likely require larger spaces for hiding and cover. Large wood and vegetation provide similar cover; however, minimal mainstem large wood and degraded riparian areas may result in trout using riprap armored banks.

As previously discussed, improving mainstem habitat conditions is likely contingent on the degree to which projects restore functioning processes, improve edge habitat conditions, address reach-scale constraints, integrate bioengineered techniques, and improve adjacent habitat areas. Restoration projects may require a broader reach-scale approach to better address constraints and support riverine and floodplain processes. Prioritization of near-term adaptive management could help in refining restoration projects to address remaining reach-scale constraints as well as project-specific constraints that weren't fully addressed (e.g., remaining or hidden riprap rock). As highlighted by observed habitat improvements and juvenile salmon responses, enhanced bank stabilization provides greater habitat benefits compared to traditional riprap rock stabilization. If bank stabilization projects aim to improve mainstem habitat conditions and reduce stabilization impacts, then projects will need to integrate bioengineering techniques through the addition of large wood/vegetation as well as improve adjacent habitat areas.

While edge habitat improvements and related juvenile salmonid responses are informative for project evaluation, these elements are only a part of the overall project effectiveness story. As described in section 3.0 *Monitoring Mainstem Aquatic Habitats and Salmonids Across Large River Projects*, multiple monitored metrics and indicators inform project implementation, performance, and effectiveness. Integration of information and observations across metrics and indicators helps in describing and evaluating the cumulative benefits of project actions. However, while many of these monitoring metrics can be informative, metrics which specifically focus on mainstem edge habitat conditions may prove most beneficial for evaluating edge habitat improvements for juvenile Chinook.

6.0 JUVENILE SALMONID SIZE CLASSES AND LIFE-HISTORY PATTERNS, SIZE-SPECIFIC HABITAT USE, AND SEASONAL SHIFTS IN HABITAT USE

Multiple juvenile salmonid size-classes and life histories use project areas.
• There are distinct seasonal modes in size-class frequencies among juvenile Chinook and coho, indicating fry, parr, and yearling life histories. • Juvenile Chinook and coho, specifically among the larger-sized yearling life-history, continue to use mainstem edge habitats throughout fall and winter. • Multiple trout size and year classes were observed among mainstem edge habitats and across seasonal periods.
Juvenile salmonids display size-specific habitat use.
• Smaller juvenile Chinook and coho were most frequent among backwaters and bars, while larger juvenile Chinook and coho were most frequent among unarmored and riprap armored banks. • Smaller trout were most frequent among bars and unarmored banks, while large trout were frequent among bars, unarmored banks, and riprap armored banks.
Juvenile salmonids display seasonal shifts in habitat use.
• Juvenile Chinook and coho primarily use backwaters during spring, when they then shift to using bars and unarmored banks in late spring and early summer. • Juvenile Chinook use riprap armored and bioengineered banks throughout the year (possibly more during winter periods); however, abundance is generally low compared to other edge habitats types. • Trout use backwaters, bars, and unarmored banks somewhat consistently across spring, with abundance among riprap armored and bioengineered banks highest from fall through early spring.

Collective observations across mainstem Snoqualmie River projects can provide useful information about juvenile salmonid life-history patterns, habitat use, and seasonal shifts. Further understanding ecological and behavioral patterns among juvenile salmonids can help to: 1) align habitat improvement strategies with basin-specific salmonid information, 2) refine the development, design, and evaluation of projects, 3) inform monitoring strategies and project effectiveness evaluation, and 4) inform Snoqualmie River salmon recovery and conservation strategies.

The majority of juvenile salmonid monitoring across the lower Snoqualmie River is focused around the rearing and outmigration period of juvenile Chinook (late winter to early summer). This focus has largely been structured around critical early life stages when juvenile Chinook use mainstem channel areas for rearing and refuge. Monitoring observations during these critical periods is important for understanding ecological and behavioral patterns of juvenile Chinook. However, it may also be beneficial to understand patterns throughout the year, since juvenile Chinook and other salmonids can display extended freshwater rearing (King County 2017b, King County 2021).

To provide additional species and life-history information across fall and winter, the following analysis and discussion includes observations from King County (2021), which studied juvenile Chinook with extended freshwater rearing in fall and winter. However, the majority of observations included in the following sections are from projects discussed in this report. The project data includes observation from all sampled transects including all restoration and enhanced bank stabilization transects, all control transects, as well as pre- and post-project periods. Additional data and information from King County (2021) used in this report only included edge habitat transects specific to project reaches (i.e., similar project-related transects surveyed in fall and winter, as part of the study). King County (2021) also used the same sampling methods as the projects included in this report.

6.1 Juvenile Salmonid Size Classes and Life History Patterns

Observations across mainstem river reaches indicated that multiple juvenile salmonid size classes and related life histories used project areas (Figure 9, 10, & 11). Specific to juvenile Chinook (Figure 9), earlier in the year (Feb–Mar) there were two modes in juvenile Chinook sizes classes with smaller sizes representing recently emerged juveniles (fry and parr) and larger sizes representing juvenile yearling Chinook (juveniles hatched a year prior spending up to a year in freshwater habitats). As spring progressed (Apr–May), there was continued emergence of juvenile Chinook, a greater frequency of Chinook parr (grown fry), as well as a relatively low frequency of larger yearling Chinook. By late spring and early summer (Jun–Jul), parr contributed the greatest frequency among juvenile Chinook size classes. During late fall and winter (Oct–Dec), there was a small cohort of larger juvenile Chinook, which remained among freshwater mainstem habitats (yearling life history). Only a small proportion of juvenile Chinook display the yearling life-history (~12% from 2001 to 2019; Matt Pouley, Tulalip Tribes pers. comm.), thus lower juvenile frequencies across fall and winter months would be expected.

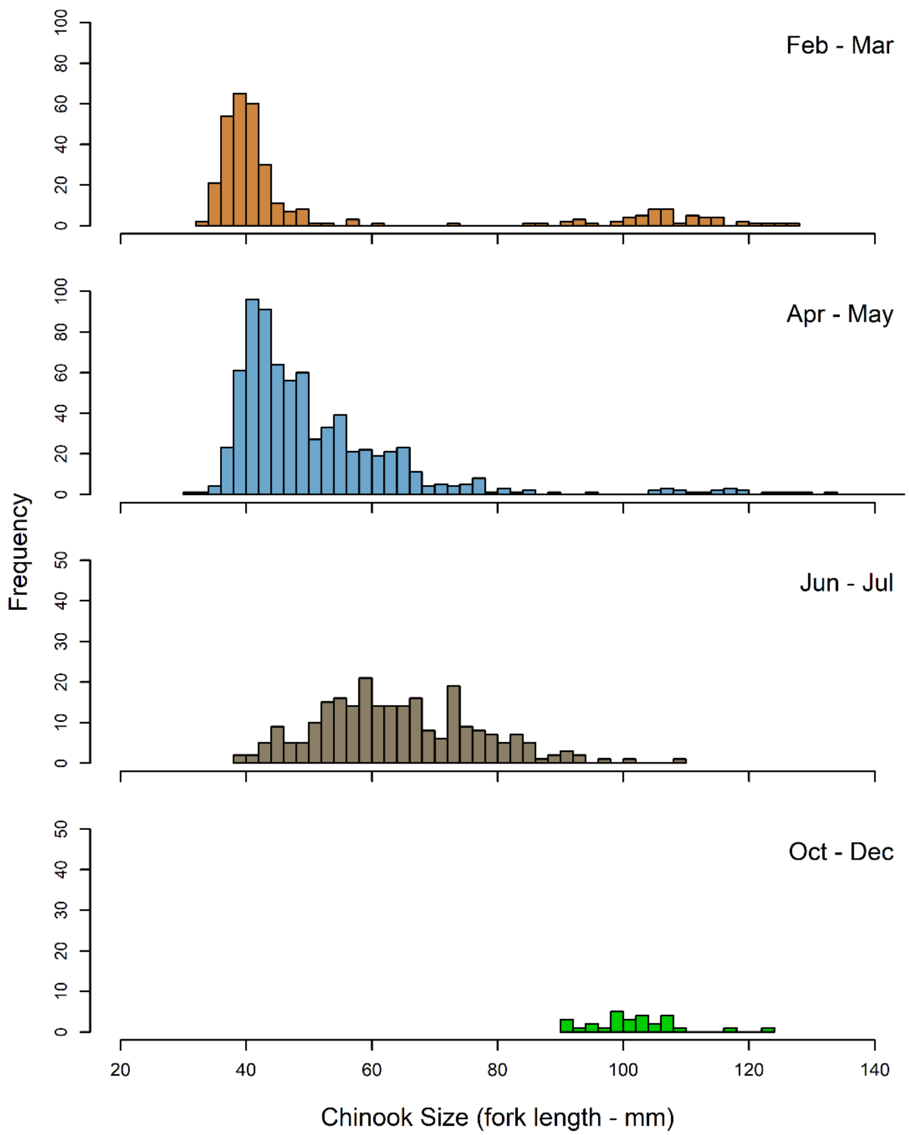

Figure 9. Plots of juvenile Chinook size frequencies across seasonal periods. Notes: vertical axis different for Feb–Mar and Apr–May, compared to other periods, due to high frequencies; plots include observations from all sampled project transects and project-specific observations from King County (2021).

Specific to juvenile coho (Figure 10), earlier in the year (Feb–Mar), monitoring efforts observed few coho. However, similar to juvenile Chinook, there were two modes in juvenile coho size classes including recently emerged smaller juveniles (fry and parr) and larger yearling juveniles. By spring (Apr-May), a large cohort of smaller coho were observed, with less frequent yearling observations. By late spring and early summer (Jun-Jul), yearling coho seem to have left the system and a greater frequency of coho fry and parr were observed. By late fall and early winter (Oct–Dec) a small cohort of larger coho remained in mainstem habitats. Juvenile coho primarily display a yearling life history and are known to overwinter among off-channel and non-mainstem habitats (e.g., side-channels, beaver ponds, oxbows, tributaries, etc.), thus we would expect lower mainstem frequencies in fall and winter.

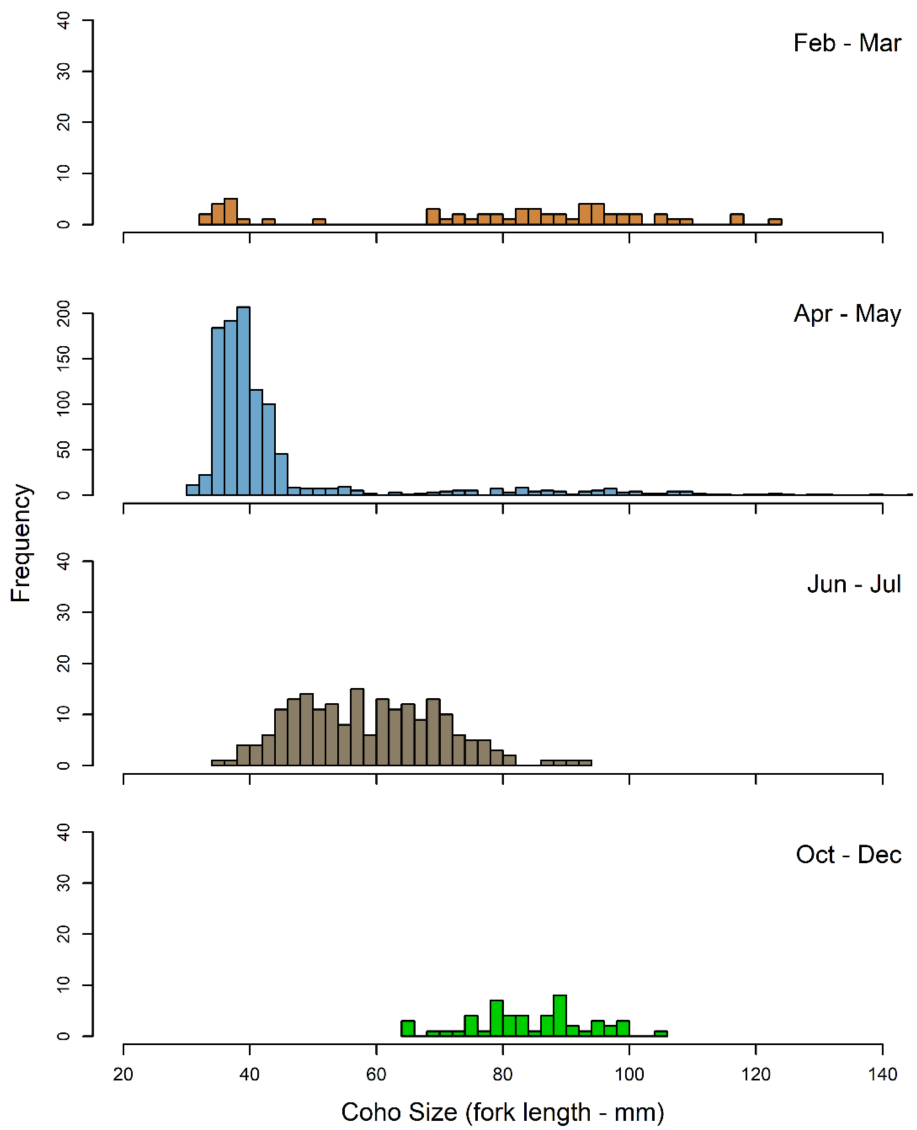

Figure 10. Plots of juvenile coho size frequencies across seasonal periods. Notes: vertical axis different for Apr–May, compared to other periods, due to high frequencies; plots include observations from all sampled project transects and project-specific observations from King County (2021).

Multiple trout size classes were observed across monitoring efforts and seasonal periods (Figure 11). Observed trout were generally larger than juvenile Chinook and coho with the exception of trout fry, which were observed in late spring and early summer (Jun–Jul). The wide distribution of size classes suggests that multiple trout year classes were likely observed. Trout among middle size classes (i.e., 100–200 mm) were frequently observed from February through July. This size class is also observed during late fall and winter across project areas.

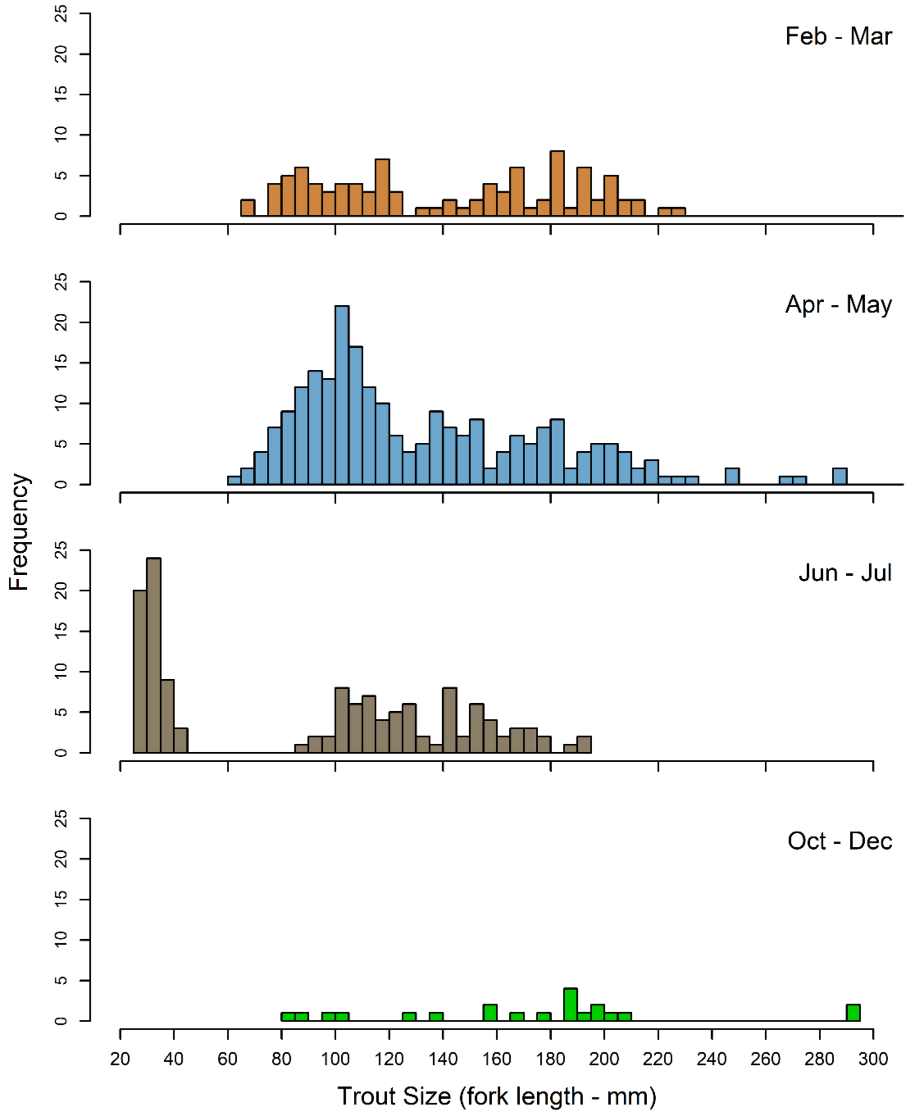

Figure 11. Plots of juvenile trout size frequencies across seasonal periods. Notes: plots include observations from all sampled project transects and project-specific observations from King County (2021).

6.2 Size-Specific Habitat Use

Across the lower Snoqualmie River watershed, distinct size classes and related life histories use specific edge habitat types (Figures 12, 13, and 14). Smaller juvenile Chinook and coho (both fry and parr) were most frequent among backwaters and bars (Figures 12 and 13). Backwaters and bars generally have larger low-velocity areas compared to other edge habitat types (discussed in Table 2), and shallow slow-water habitats provide critical areas for juvenile salmonid rearing and flow refuge (Beechie et al. 2005). This highlights the importance of bars and backwaters for smaller juvenile Chinook and coho, especially during early life stages.

Smaller juvenile Chinook and coho were also observed among unarmored banks, with juvenile Chinook occurring more frequently compared to coho (Figures 12 and 13). Juvenile Chinook and coho, among smaller size classes, were also observed among bioengineered revetment banks and riprap armored banks, but at considerably lower frequencies compared to other edge habitat types.

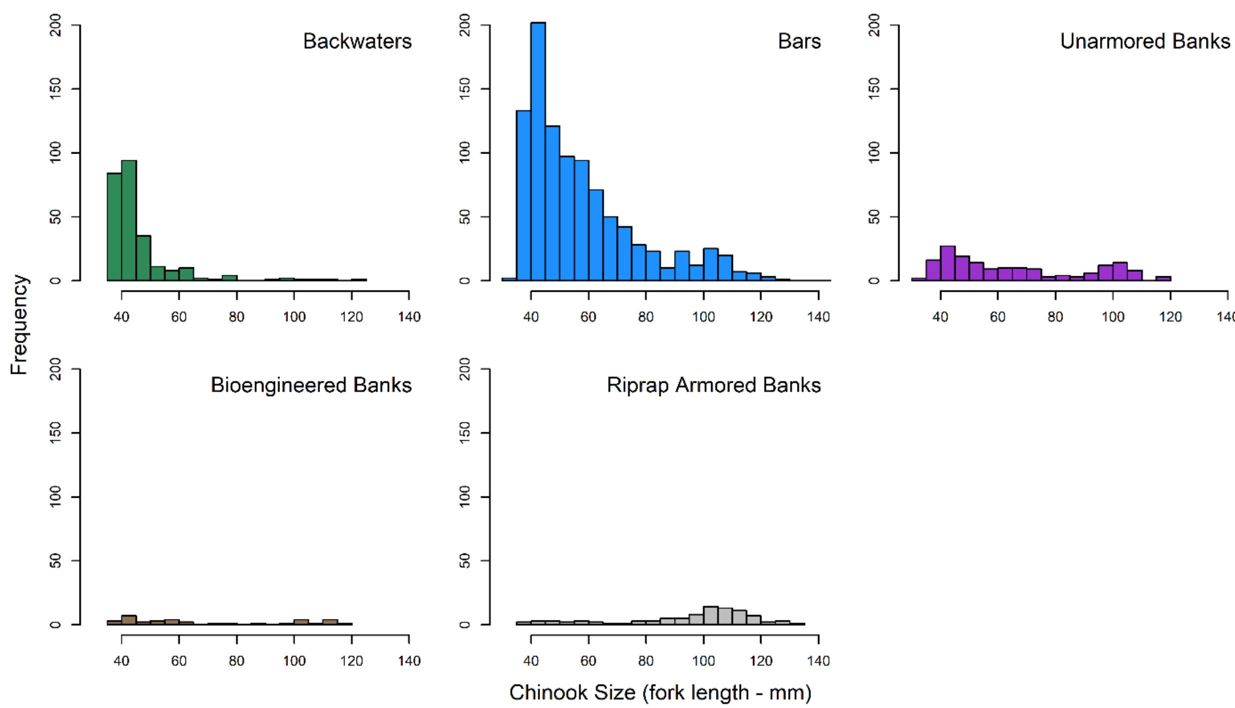

Figure 12. Juvenile Chinook size frequency plots across edge habitat types. Notes: plots include observations from all sampled project transects and project-specific observations from King County (2021).

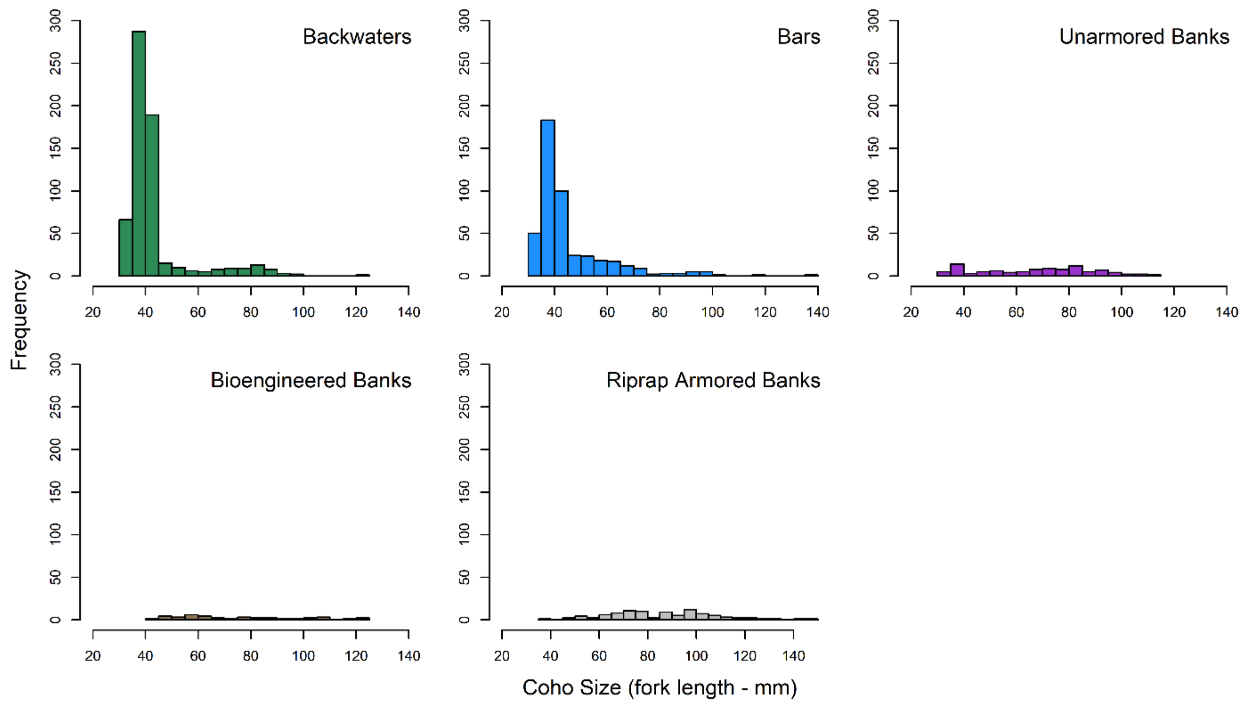

Figure 13. Juvenile coho size frequency plots across edge habitat types. Notes: plots include observations from all sampled project transects and project-specific observations from King County (2021).

Larger juvenile Chinook and coho were most frequent among unarmored banks and riprap armored banks (Figures 12 and 13). Specifically, among riprap armored banks, only the largest Chinook size classes were frequent. Juvenile Chinook and coho size frequency plots suggest that more juveniles were observed among armored banks, compared to bioengineered revetment banks (contrary to meta-analysis results). However, this is a result of frequency plots using a broader data set, which had considerably fewer bioengineered bank transects, compared to riprap armored banks and other edge habitat types. Observations suggest that as juvenile Chinook and coho grow, they are more likely to use bank habitats. Relatively larger juveniles may be able to use bank habitats since larger-sized fish generally have greater swimming abilities and can select higher velocity bank habitats. Bank habitats may be more bioenergetically profitable for larger juveniles focused on drift feeding. Bank habitats may provide enhanced feeding opportunities due to greater prey drift, compared to low-velocity areas. Additionally, large wood and rocks associated with bank habitats may provide resting areas while foraging, due to pronounced velocity gradients.

Larger juvenile Chinook and coho were frequently observed among both riprap armored and unarmored banks; however, this pattern may indicate that habitat availability rather than solely habitat preference could be driving habitat use. For example, juvenile 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 mainstems of the Snoqualmie, Tolt, and Raging rivers have greater than 40% of their banks armored (King County 2018a). Furthermore, bank armoring is concentrated in the mainstem Snoqualmie River across 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.

Specific to trout observations, smaller trout were most frequent among bars and unarmored banks (Figure 14). In addition to smaller trout, a broad range of larger trout size classes were also observed among bars, unarmored banks, and armored banks. Backwaters and bioengineered revetment banks supported low frequencies of trout among variable size classes (primarily between 100–220 mm), with select larger trout observed among bioengineered banks. The greatest frequencies of larger trout were observed among riprap armored banks. As previously mentioned, bank habitats generally have smaller low-velocity areas and larger trout are likely able to withstand a greater range of flow velocities. The prevalence of larger trout among riprap armored banks likely reflects this pattern.

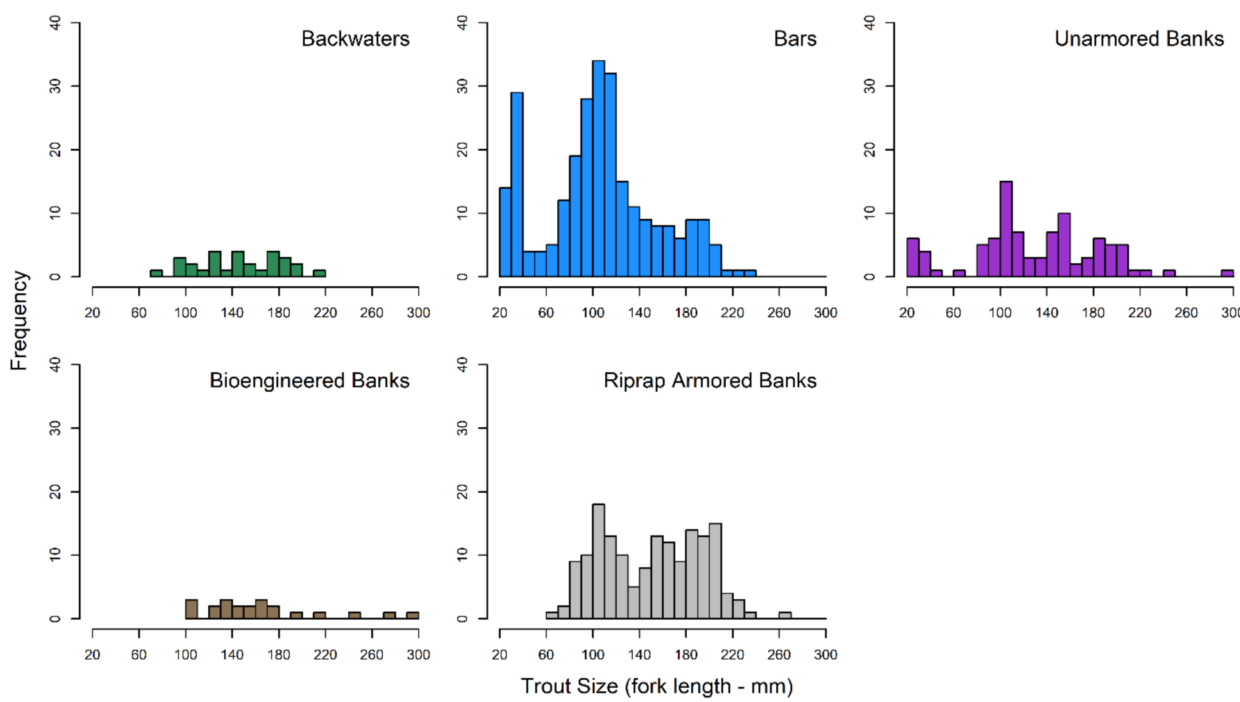

Figure 14. Juvenile trout size frequency plots across edge habitat types. Notes: plots include observations from all sampled project transects and project-specific observations from King County (2021).

6.3 Seasonal Shifts in Habitat Use

There were seasonal shifts in juvenile salmonid habitat use, suggesting that a diversity of edge habitat types is needed to support juvenile salmonids as they grow and transition through early life stages. Juvenile Chinook primarily used backwater habitats during spring with peak abundance occurring from March to May (Figure 15). As juvenile Chinook grew during spring and early summer, they shifted in habitat use from backwaters to bars, with peak abundance occurring around May to June. During spring and early summer, bars may provide warmer areas for optimal growth, since bars are shallow and warm up quicker than other edge habitats. However, bars generally lack large wood and vegetation cover, which likely results in juveniles using bars at night under the cover of darkness. Bars are consistently used year-around. Similar to the relative timing of bar use, juvenile Chinook also shifted from backwaters to unarmored banks. Juvenile Chinook may use mainstem edge habitats throughout summer and fall, 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 were observed among riprap armored and bioengineered banks throughout the year; however, at lower abundances compared to other edge habitats types. Juvenile Chinook used riprap armored banks and bioengineered banks relatively more during winter periods (Dec–Feb); however, low bank abundances across seasons limit interpretation of seasonal shifts. Winter periods are when juvenile Chinook are largest in size and may use bank habitats for holding and overwintering.

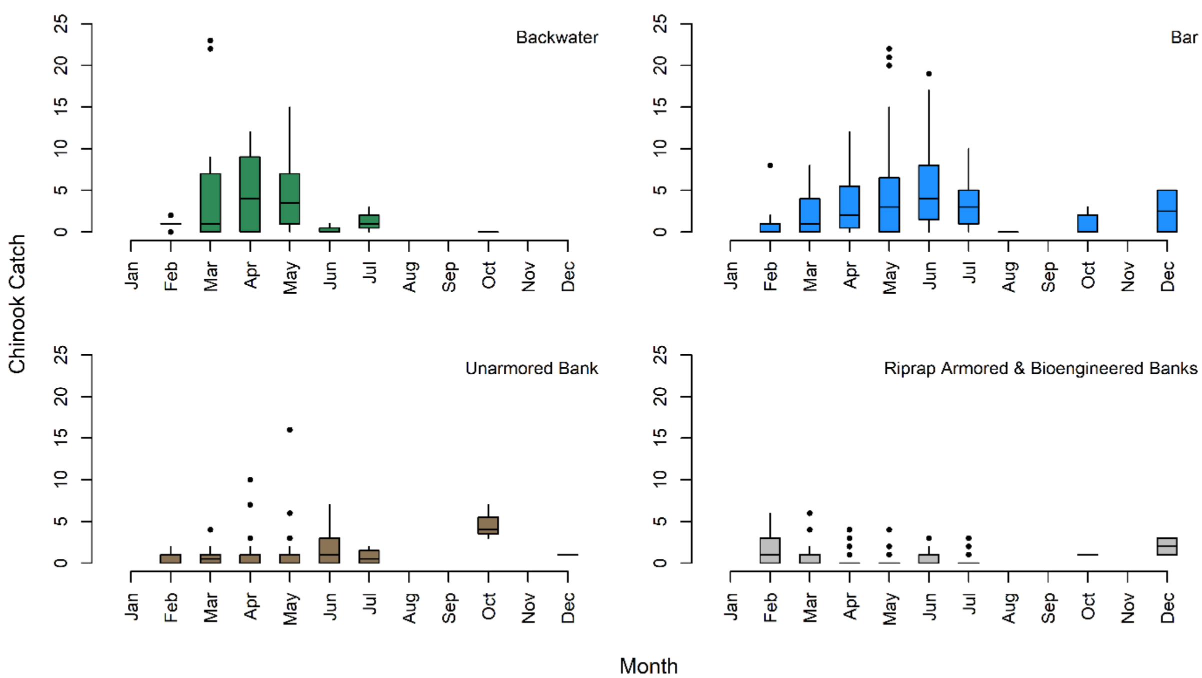

Figure 15. Juvenile Chinook catch across months and edge habitat types. Notes: one backwater point missing (April: 173) and one bar data point missing (April: 50); plots include observations from all sampled project transects and project-specific observations from King County (2021). Boxes indicate the 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.

Similar to juvenile Chinook, juvenile coho primarily used backwaters in spring with peak abundance occurring from April to June (Figure 16). Juvenile coho concurrently used bars and unarmored banks during spring and summer periods. Peaks in juvenile coho abundance occurred from May through August for bars and around July for unarmored banks. Juvenile coho also used bars and unarmored banks during fall, with minimal mainstem observations occurring during winter periods. Juvenile coho were likely infrequent among mainstem edge habitats in winter since they tend to prefer non-mainstem habitats for overwintering (e.g., tributaries, side-channels, ponds, wetland, etc.) (Cederholm and Scarlett 1981, Swales and Levings 1989). Similar to juvenile Chinook, juvenile coho were observed among riprap armored and bioengineered banks throughout the year, albeit at relatively low abundance. Juvenile coho abundance across all bank habitats was relatively lower than bars and backwaters throughout the year.

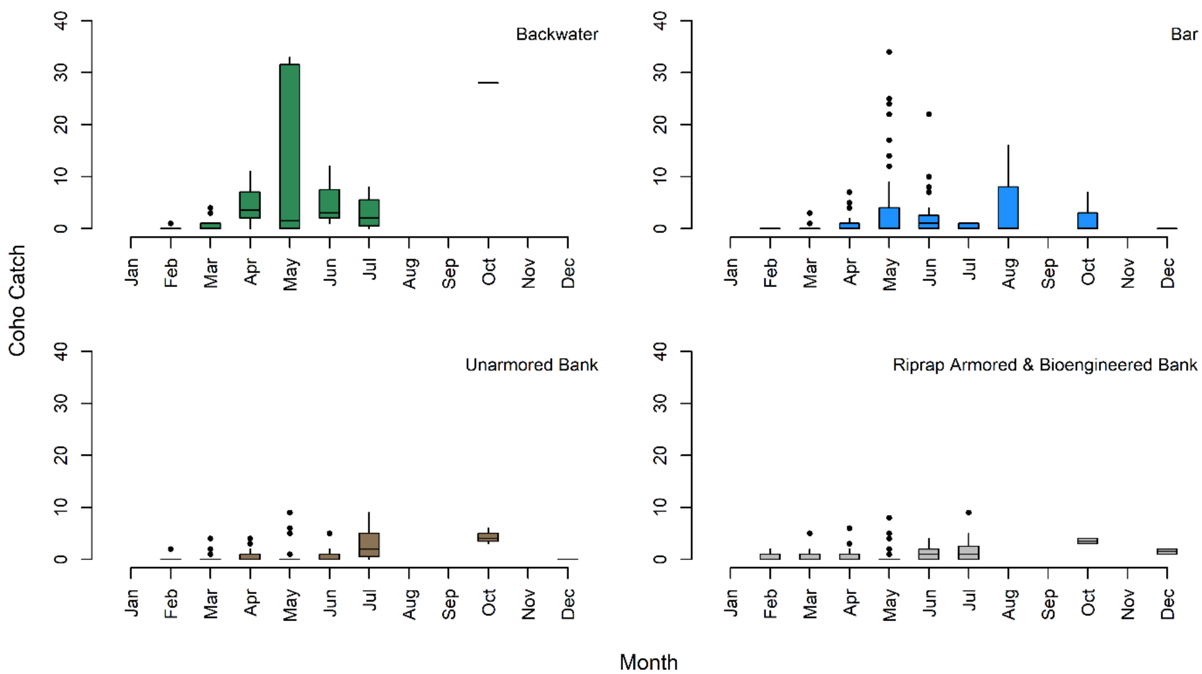

Figure 16. Juvenile coho catch across months and edge habitat types. Notes: three backwater points missing (May: 97, 256, 322) and one bar point missing (May: 83); plots include observations from all sampled project transects and project-specific observations from King County (2021). Boxes indicate the 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.

Trout used backwaters, bars, and unarmored banks somewhat consistently across spring, with the exception of bars, which had peak abundance around late spring and summer (Figure 17). Additionally, bars were used throughout the year but at lower abundance compared to the late spring and summer periods. During fall and winter periods, trout were relatively infrequent among backwaters, bars, and unarmored banks. However, from fall through early spring (Oct–Mar), trout abundance was highest among riprap armored and bioengineered banks. Large spaces between riprap rocks and installed large wood may provide suitable areas for holding and overwintering.

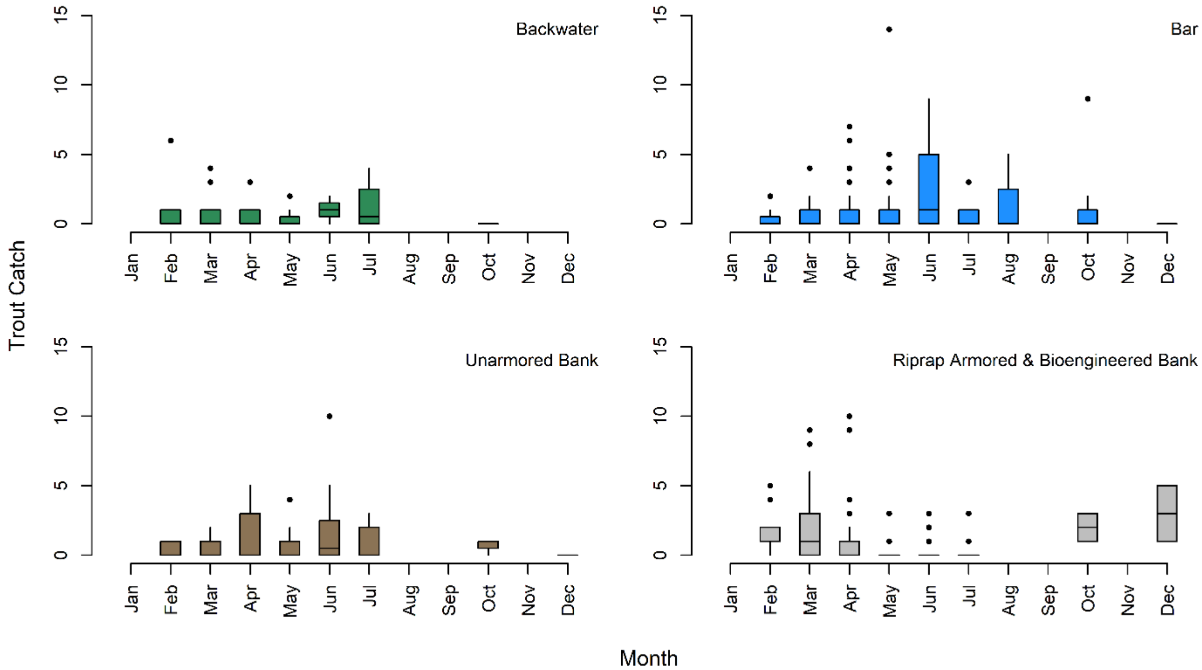

Figure 17. Juvenile trout catch across months and edge habitat types. Notes: plots include observations from all sampled project transects and project-specific observations from King County (2021). Boxes indicate the first quartile, median, and third quartile. The whiskers indicate maximum and minimum values up to 1.5x the inter-quartile range and the points are observations beyond 1.5x the inter-quartile range.

7.0 CONCLUSIONS

Restoration projects and enhanced bank stabilization projects have improved mainstem edge habitats.

Across the lower Snoqualmie River watershed, restoration projects (Chinook Bend/Stillwater, Lower Tolt, and Upper Carlson) have improved and increased aquatic habitats by removing bank armoring and by restoring riverine and floodplain processes. These restoration projects have increased low-velocity edge habitat area and extent, compared to pre-project periods. Improved edge habitats (backwaters, bars, unarmored banks, bioengineered banks) were wider and shallower, compared to degraded riprap armored banks, resulting in greater area for rearing and refuge. Increased edge-habitat area and channel complexity was largely driven by the formation of backwaters, bars, and unarmored banks. Restoration projects also improved edge habitat quality and complexity, by design, through increased large wood integration, engagement, and recruitment.

Enhanced bank stabilization projects (Sinnema Quaale and Tolt Pipeline) have improved edge habitat quality and complexity, by design, through the integration of large wood and vegetation into bank stabilization features (bioengineered revetment banks). Bioengineered banks had greater low-velocity edge habitat widths and extents, compared to riprap armored banks. Additionally, the reconnection and restoration of the Deer Creek confluence, as part of the Tolt Pipeline project, increased tributary accessibility for juvenile salmonids and improved confluence habitat quality and quantity.

Juvenile Chinook and coho have positively responded to improved mainstem edge habitats.

Juvenile Chinook and coho abundance was consistently greater among improved edge habitats, compared to degraded riprap armored banks (i.e., positive response to project actions). Specifically, juvenile Chinook had a positive response, relative to riprap banks, across all improved edge habitat types with the greatest response observed among backwaters, bars, and unarmored banks. Juvenile coho also had a positive response across all improved edge habitat types, with the greatest response observed among backwaters, bioengineered revetment banks, and unarmored banks.

Juvenile trout showed a mixed response across improved edge habitats. Unarmored banks showed the most consistent positive response while backwaters showed the most consistent negative response. Juvenile trout observed across monitoring efforts tend to be larger than juvenile Chinook and coho. Mixed responses could be the result of larger trout being less dependent on low-velocity habitats, since they are able to withstand a greater range of flow velocities. Additionally, the large spaces among unarmored and riprap armored banks, between roots, wood, and large rocks, may provide suitable holding areas for ambush predation opportunities and for cover from avian predators.

Process-based restoration is likely the best approach to maximize habitat improvements for juvenile Chinook.

While not directly tested in this report, meta-analysis results suggest that habitat benefits for juvenile Chinook are likely greater among restoration projects, compared to enhanced bank stabilization projects. Juvenile Chinook displayed the greatest response among backwaters, bars, and unarmored banks, which are frequently created and improved by restoration projects. On the other hand, juvenile Chinook had less of a response to bioengineered banks, which is the primary edge habitat type created by enhanced bank stabilization projects. Furthermore, the full benefits of restoration projects may be underestimated in this meta-analysis since enhanced bank stabilization results in immediate response while restoration results in both immediate and long-term response. The long-term response and habitat benefits of restoration projects are not fully captured in this evaluation. There are clearly differences in the goals of restoration projects and enhanced bank stabilization projects. Differences in goals as well as observed differences in habitat improvements and juvenile salmonid responses contribute to an inferred difference in habitat benefit between project types.

While all improved edge habitat types can benefit juvenile Chinook, if projects aim to maximize habitat improvements, then process-based restoration is likely the best approach. If bank stabilization is necessary, then bioengineered approaches are better than traditional riprap armored designs. The degree to which enhanced bank stabilization projects mitigate armoring impacts and improve habitat conditions is contingent on the extent and magnitude of bioengineering techniques and restoration elements. Integrating large wood and vegetation into bank stabilization features, restoring adjacent habitat areas (e.g., tributary confluences), and correcting fish passage barriers may provide the greatest habitat improvement for enhanced bank stabilization projects.

Juvenile coho also showed a positive respond to improved edge habitats; however, differences in abundance aligned with specific edge habitats rather than project type. Juvenile coho are known to be associated more with off-channel habitats such as side-channels, beaver ponds, oxbows, and tributaries, which may result in under-representation of habitat preference with mainstem-only sampling. Since mainstem edge habitats are particularly important for juvenile Chinook, differences in juvenile salmon response across mainstem edge habitats and project types are likely best evaluated through juvenile Chinook abundance.

Juvenile salmonids display size-specific habitat use and seasonal shifts in habitat use.

Multiple juvenile salmonid size classes and life histories used project areas and related edge habitats. There are distinct seasonal modes in size-class frequencies among juvenile Chinook and coho, indicating fry, parr, and yearling life histories. Juvenile Chinook and coho, specifically among the larger-sized yearling life history, continue to use mainstem edge habitats throughout fall and winter. In addition to juvenile Chinook and coho, multiple trout size and year classes were observed across seasonal periods.

Distinct size classes and related life histories used specific edge habitat types. Smaller juvenile Chinook and coho were most frequent among bars and backwaters. In the Snoqualmie River, bars and backwaters generally have greater low-velocity areas, compared to other edge habitat types, which may be critical when juveniles are smaller. Larger juvenile Chinook and coho were most frequent among unarmored banks and riprap armored banks, suggesting that as juveniles grow and reach larger sizes, they may be more likely to use bank habitats. Smaller trout appeared to be most frequent among bars and unarmored banks while larger trout were frequent among riprap armored banks.

Relatively larger juvenile salmonids may use unarmored and armored bank habitats since they are able to withstand a greater range of flow velocities. Bank habitats may be more bioenergetically profitable for larger juveniles focused on drift feeding. Bank habitats may provide enhanced feeding opportunities due to greater prey drift, compared to low-velocity areas. Additionally, large wood and rocks associated with bank habitats may provide resting areas while foraging, due to pronounced velocity gradients.

Juvenile salmonids display seasonal shifts in habitat use, suggesting that a diversity of edge habitats is needed to support juveniles. Juvenile Chinook and coho primarily used backwaters during spring where they then shift to using bars and unarmored banks during late spring and early summer. Juvenile Chinook used riprap armored banks and bioengineered banks primarily during fall and winter, when they are largest in size. Minimal juvenile coho observations in fall and winter supports the existing literature, which demonstrates that juvenile coho prefer non-mainstem habitats for overwintering. Trout used backwaters, bars, and unarmored banks somewhat consistently across spring, with the exception of bars, which were primarily used around late spring and summer. During winter and early spring, trout abundance was highest among bioengineered revetment and riprap armored banks. Large spaces between riprap rocks and installed large wood may provide suitable areas for holding and overwintering.

Addressing remaining constraints and integrating adaptive management will help projects maximize habitat improvements.

Remaining constraints, including existing shoreline armoring and altered hydraulic, sediment, and wood recruitment regimes, can limit the potential of restoration projects to restore riverine processes. Even among the discussed restoration projects, there are still compromised processes at the watershed scale and riparian forests throughout the lower Snoqualmie River are largely degraded with many years until areas provide a meaningful supply of large wood. The potential of process-based restoration is inherently tied to the extent, magnitude, and scale at which processes are restored. Restoration projects need to take broader reach-scale approaches to ensure that the scale and degree of restorative actions address the extent of constraints and degradation. Larger restoration projects, which address a suite of constraints and incorporate broader reach-scale restoration actions will be most effective in improving mainstem habitats.

Understanding and addressing all reach-scale constraints can be difficult, especially in highly altered and degraded areas. Prioritizing near-term adaptive management will help

to address remaining constraints as well as project elements that fall short of expectations. Near-term adaptive management can provide a direct feedback loop to address factors that limit habitat improvements, helping projects reach full restoration potential. Adaptive management would help ensure that restoration projects are maximizing limited funds and efforts towards achieving the greatest habitat improvements.

Restoration projects need to take aggressive approaches to ensure riverine and floodplain processes are restored. This is especially apparent where constraints upstream, downstream, and across the river remain or are unlikely to be addressed in the near-term. As highlighted with the Lower Tolt project, more aggressive actions were needed to achieve project goals. Aggressive actions include mainstem large wood jams to route flow into created channels, deeper-wider pilot side channel excavation to ensure engagement across a range of flows, and prioritization of remaining reach-scale constraints such as existing and remaining armoring.

Monitoring at appropriate spatial and temporal scales will provide greater estimates of habitat improvements and salmonid responses.

Project interactions and cumulative benefits across projects should be considered when evaluating and monitoring habitat improvements projects. As noted in the Chinook Bend/Stillwater project reach, habitat improvements were likely a result of both projects and the collective restoration of riverine processes. Monitoring efforts should align with a scale and extent inclusive of all projects in a given reach. Additionally, if monitoring efforts aim to evaluate juvenile salmonid responses to mainstem habitat improvement, metrics focused on edge habitat quality and quantity may prove most informative. Using methods that efficiently and effectively capture mainstem edge habitat characteristics will bolster the ability of monitoring efforts to describe project-related habitat improvements.

Monitoring efforts should adopt or continue inter-annual evaluations to capture variability in channel movement, habitat formation, and salmonid populations. Channel movement and habitat formation can influence the overall area, extent, and location of low-velocity edge habitats. Additionally, salmonid populations display inter-annual variability in juvenile and adult abundance, productivity, and survival. Monitoring that captures inter-annual information on habitat and salmonids provides greater estimates of habitat improvements and salmonid responses.

Observations across projects and seasons suggests that juvenile salmonids use mainstem habitats throughout the year. Monitoring efforts that include multi-season sampling will ensure that year-round habitat use is characterized and that all life histories are supported. Additionally, multi-season monitoring will help to better understand habitat conditions throughout juvenile salmonid freshwater residence. In addition to mainstem habitats, monitoring should also include off-channel areas such as side-channels, beaver ponds, oxbows, and tributaries, as these areas are also important for various salmonid life stages.

Supporting habitat and life-history diversity will bolster salmon conservation efforts.

A diversity of edge habitats is needed to support juvenile salmonids as they grow and transition through early life stages. Juvenile salmonids use a variety of edge habitats, display clear shifts in habitat use across seasons, and use specific habitats among each life stage. Projects and strategies that provide a diversity of improved edge habitats and increase edge habitat area will provide the greatest benefits for juvenile salmonids, by improving productivity and increasing overall habitat capacity.

Juvenile salmonids use mainstem habitats throughout the year. Habitat improvement projects will need to consider habitat conditions across seasons to ensure that project address all relevant impairments and constraints. For example, summer and winter habitat conditions, specific to the needs of juvenile salmonid, are largely under-represented in project designs. Accounting for habitat conditions across seasons will help projects provide optimal improvements throughout juvenile salmonid freshwater residence. Additionally, projects which integrate multi-season habitat conditions and support juveniles across life stages will help to maintain life-history diversity. Supporting life-history diversity will help salmonid populations withstand environmental-population variability and will ensure that restoration and conservation efforts are strategic and comprehensive.

8.0 REFERENCES

Beamer, E. M. and R. A. Henderson. 1998. Juvenile Salmonid Use of Natural and Hydromodified Stream Bank Habitat in the Mainstem Skagit River, Northwest Washington. Skagit System Cooperative, La Conner, WA. 51 pp.

Beechie, T. J., M. Liermann, E. M. Beamer, and R. Henderson. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society, 134(3), 717-729.

Beechie, T. J., D. A. Sear, J. D. Olden, G. R. Pess, J. M. Buffington, H. Moir, P. Roni, and M. M. Pollock. 2010. Process-based principles for restoring river ecosystems. Bioscience 60:209-222.

Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry 82:609–613.

Bilby, R. E., and J. W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Can. J. Fish. Aquat. Sci. 48, 2499-2508, 1991.

Bisson P. A., and D. R. Montgomery. 1996. Valley segments, stream reaches, and channel units. In: Methods in Stream Ecology (Eds F.R. Hauer & G.A. Lanberti), pp. 23–52. Academic Press, San Diego, CA.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Bradford, M., and S. P. Higgins. 2001. Habitat-, season- and size-specific variation in diel activity patterns of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences. 58:365–374.

Cederholm, C. J. and W. J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981 In E.L. Brannon and E.O. Salo, editors. Salmon and Trout Migratory Behavior Symposium, June 1981.

Crozier, W. W., and G. J. A. Kennedy. 1994. Application of semi-quantitative electrofishing to juvenile salmonid stock surveys. Journal of fish biology 45.1: 159-164.

Federal Register. 1999. Endangered and Threatened Species; Threatened Status for Three Chinook Salmon Evolutionarily Significant Units (ESUs) in Washington and Oregon, and

Endangered Status for One Chinook Salmon ESU in Washington. Fed. Regist. 64(56):14308-14328.

Gowan, C., and K. D. Fausch. 1996. Long-term demographic responses of trout populations to habitat manipulation in six Colorado streams. Ecological Applications 6: 931–946.

Gurevitch J, and L. V. Hedges. 1999. Statistical issues in ecological meta-analyses. Ecology 80:1142–49

Guy, C. S. and M. L. Brown. 2007. Analysis and interpretation of freshwater fisheries data. American Fisheries Society.

Haring, D. 2002. Salmon Habitat Limiting Factors Analysis, Snohomish River Watershed, Water Resource Inventory Area 7. Washington State Conservation Commission, Olympia, WA.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15: 133-302.

Hayman, R. A., E. Beamer, and R. E. McClure. 1996. FY 1995 Skagit River Chinook Restoration Research. Progress Report No. 1. Skagit System Cooperative, LaConner, WA.

Hedges, L. V., J. Gurevitch, and P. S. Curtis. 1999. The meta-analysis of response ratios in experimental ecology. Ecology 80:1150–56.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile Chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116.2: 185-195.

King County. 2002. Snoqualmie Watershed Aquatic Habitat Conditions Report: Summary of 1999-2001 Data. Prepared by Fran Solomon and Melissa Boles, Water and Land Resources Division. Seattle, Washington.

King County. 2011. Snoqualmie at Fall City Reach Restoration Assessment. Prepared by Dan Eastman, Todd Hurley, Will Mansfield, Josh Latterell, Chase Barton, Tenzing Thinley, and Mary Maeir. King County Department of Natural Resources and Parks, Seattle, Washington

King County. 2015a. Instream Project Design Checklist – Tolt Pipeline Protection Project. Prepared by Chase Barton and Phyllis Meyers, Water and Land Resources Division. Seattle, Washington.

King County. 2015b. Instream Project Design Checklist – Sinnema Quaale Upper Revetment Reconstruction. Prepared by Chase Barton and Phyllis Meyers, Water and Land Resources Division. Seattle, Washington.

King County. 2017a, Chinook Bend Floodplain Reconnection Project - Year 5 (2014) Monitoring and Maintenance Report. Prepared by Josh Latterell and Dan Eastman, Water and Land Resources Division. Seattle, Washington.

King County. 2017b. Snoqualmie River Juvenile Yearling Chinook Habitat Use and Distribution' Prepared by Josh Kubo, Water and Land Resources Division. Seattle, Washington.

King County. 2017c. Sinnema Quaale Upper Revetment Repair Project 2015 & 2017 Juvenile Salmonid and Low Velocity Habitat Sampling. Prepared by Chris Gregersen, Water and Land Resources Division. Seattle, Washington.

King County. 2018a. Aquatic Habitat Conditions in the Lower Snoqualmie, Tolt, and Raging Rivers. Prepared by Josh Kubo, Water and Land Resources Division. Seattle, Washington.

King County. 2018b. Upper Carlson Floodplain Reconnection Project Year 3 (2017) Monitoring Report. Prepared by Josh Latterell, Dan Eastman, Todd Hurley, and Laura Hartema, Water and Land Resources Division. Seattle, Washington.

King County. 2019. Tolt Pipeline Protection/Winkelman Revetment Reconstruction Project: Aquatic Habitat and Juvenile Salmon Monitoring Results. Prepared by Josh Kubo and Aaron David, Water and Land Resources Division. Seattle, Washington.

King County. 2020. Upper Carlson Floodplain Restoration Project: Fish and Aquatic Habitat Monitoring. Prepared by Aaron David and Josh Kubo, Water and Land Resources Division. Seattle, Washington.

King County. 2021. Juvenile Chinook with Extended Freshwater Rearing – Habitat Use, Distribution, and Seasonal Shifts. Prepared by Josh Kubo, Water and Land Resources Division. Seattle, Washington.

King County. In Preparation – a. Chinook Bend Floodplain Reconnection Project - Year 10 (2019) Monitoring and Maintenance Report. Prepared by Jo Wilhelm, Josh Latterell, Dan Eastman, and Ashley Gould, Water and Land Resources Division. Seattle, Washington.

King County. In Preparation – b. Lower Tolt Floodplain Reconnection Project – Effectiveness Monitoring Report: Year 10 (2019). Prepared by Jo Wilhelm, Laura Hartema, Todd Hurley, Josh Kubo, Josh Latterell, and Ashley Gould, Water and Land Resources Division. Seattle, Washington.

King County. In Preparation – c. Upper Carlson Floodplain Reconnection Project Year 5 (2019) Monitoring Report. Prepared by Josh Latterell, Dan Eastman, Todd Hurley, and Laura Hartema, Water and Land Resources Division. Seattle, Washington.

Knudsen, E. E., and S. J. Dilley. 1987. Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams. North American Journal of Fisheries Management 7:351–356.

Levings, C. D. and R. B. Lauzier. 1991. Extensive use of the Fraser River basin as winter habitat by juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Zool. 69:1759-1767.

Lowery, E. D., J. N. Thompson, J. P. Shannahan, E. J. Connor, D. Pflug, B. Donahue, C. E. Torgersen, and D. A. Beauchamp. 2013. Seasonal distribution and habitat associations of salmonids with extended juvenile freshwater rearing in different precipitation zones of the Skagit River, WA. Report submitted to the Skagit River Flow Committee. University of Washington.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42.

Metcalfe, N. B., N. H. C. Fraser, and M. D. Burns. 1999. Food availability and the nocturnal vs. diurnal foraging trade-off in juvenile salmon. Journal of Animal Ecology. 68:371–381.

NRC (National Research Council). 1992. Restoration of aquatic ecosystems: science, technology and public Policy. National Academy Press, Washington, D.C., USA.

Quigley, J. T. and D. J. Harper, 2004. Streambank Protection with Riprap: An Evaluation of the Effects on Fish and Fish Habitat. Fisheries and Oceans Canada, Vancouver, B.C., 92 pp.

Smokorowski, K. E. and T. C. Pratt. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems – a review and meta-analysis. Environmental Reviews 15(NA): 15-41.

SBSRF (Snohomish Basin Salmon Recovery Forum). 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Surface Water Management Division, Everett, WA.

SBSRTC (Snohomish River Basin Salmonid Recovery Technical Committee). 2004. Snohomish River Basin Ecological Analysis for Salmonid Conservation. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki, 1996. An Ecosystem Approach to Salmonid Conservation. TR-4501-96-6057. ManTech Environmental Research Services Corporation, Corvallis, OR.

Swales, S., and C. D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Can. J. Fish. Aquat. Sci. 46: 232-242.

Van Den Avyle, M. J. and R. S. Hayward. 1999. Dynamics of exploited fish populations. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland. 1999; 5:127-66.

Ward, J. V., and J. A. Wiens. 2001. Ecotones of Riverine Ecosystems: Role and Typology, Spatio-Temporal Dynamics, and River Regulation. Ecohydrology & Hydrobiology 1(1-2):25-36.

Whiteway, S. L., P. M. Biron, A. Zimmermann, O. Venter, and J. W. A. Grant. 2010. Do in-stream restoration structures enhance salmonid abundance? A meta-analysis. Canadian Journal of Fisheries and Aquatic Sciences 67:831–841.

Zale, Alexander V., Donna L. Parrish, and Trent M. Sutton. 1996. Fisheries techniques, 3rd edition. Bethesda, Maryland: American Fisheries Society.

Appendix: A

Restoration and Enhanced Bank Stabilization Log-Response Ratios

Table A-1: Natural log-response ratios (proportional effect of the juvenile salmonid abundance among improved edge habitats compared to riprap armored banks) for juvenile Chinook, coho, and trout across improved edge habitat types.

		Log - Response Ratio		
Project	**Edge Habitat Type**	**Chinook**	**Coho**	**Trout**
Chinook Bend/Stillwater Restoration and Floodplain Connection	Bar	1.17	0.59	-0.92
	Backwater	0.67	2.14	-2.59
	Unarmored Bank	1.81	0.78	NA*
Lower Tolt Restoration and Floodplain Connection**	Bar	2.80	3.01	1.66
	Backwater	3.80	5.32	-1.02
	Unarmored Bank	2.66	2.43	1.56
Upper Carlson Restoration and Floodplain Connection	Bar	2.51	0.07	0.62
	Backwater	3.22	0.66	-1.59
	Unarmored Bank	1.73	0.42	0.33
Tolt Pipeline Protection and Deer Creek Restoration	Bar	1.56	0.97	-0.62
	Bioengineered Revetment	1.13	1.01	-0.37
Sinnema Quaale SR-203 and Snoqualmie Trail Protection	Bar	3.00‡	0.73	2.32
	Bioengineered Revetment	0.88‡	2.15	2.56

* No trout were observed post-project thus log-response ratio could not be calculated.

** No riprap armored banks were surveyed for this project so the average of all riprap armored banks across all other projects was used for the log-response ratio (including pre-project, post-project, and control riprap armored banks). While this results in comparisons across methodologies (i.e., net seining among improved Lower Tolt edge habitats compared to cataraft e-fishing among riprap armored banks), the combined average is the best estimation of juvenile salmonid abundance among riprap armored banks that is specific to the Snoqualmie River watershed and available at this time.

‡ No Chinook were observed among riprap armored banks so the average Chinook abundance among all riprap armored banks across all other projects were used for the log-response ratio (including Chinook abundance across pre-project, post-project, and control riprap armored banks).

Appendices: B – F

Snoqualmie River Project-Specific Observations: Mainstem Aquatic Habitats and Juvenile Salmonids

As highlighted in section 3.0 *Monitoring Mainstem Aquatic Habitats and Salmonids Across Large River Projects,* a variety of elements are monitored to inform Snoqualmie River project goals and objectives. These include, but are not limited to habitat conditions, salmonid responses, channel characteristics and processes, riparian and floodplain vegetation condition, large wood presence and condition, riverine and floodplain connectivity, flood risk reduction, and channel migration hazards. While all of these elements are important for project evaluation and characterization, the following project-specific observations are focused on mainstem aquatic habitat conditions and juvenile salmonid responses.

Data and information included in the following project-specific observations are summarized from draft and finalized monitoring reports for projects discussed throughout this report. These monitoring reports have been prepared by King County's Ecological Restoration and Engineering Services unit, River and Floodplain Management section, as well as the Science and Technical Support Section. Data and information in the following sections include project goals, objectives, evaluations, and observations specific to mainstem aquatic habitat conditions and juvenile salmonid responses. Information included among draft monitoring reports may be subject to updates as reports becomes finalized.

Appendix B: Chinook Bend/Stillwater Restoration and Floodplain Connection

Data and infromation from King County 2017a and King County (in prep.–a).

Where is the project and when was it completed?

The project site is located in the Snohomish River basin near the City of Carnation, Washington. The project reach is located on the Snoqualmie River between RM 20.8–21.8, downstream of the Stossel Bridge NE Carnation Farm Rd (Figure B-1). The project was completed in phases between 2011 and 2015 (refer to Table 3).

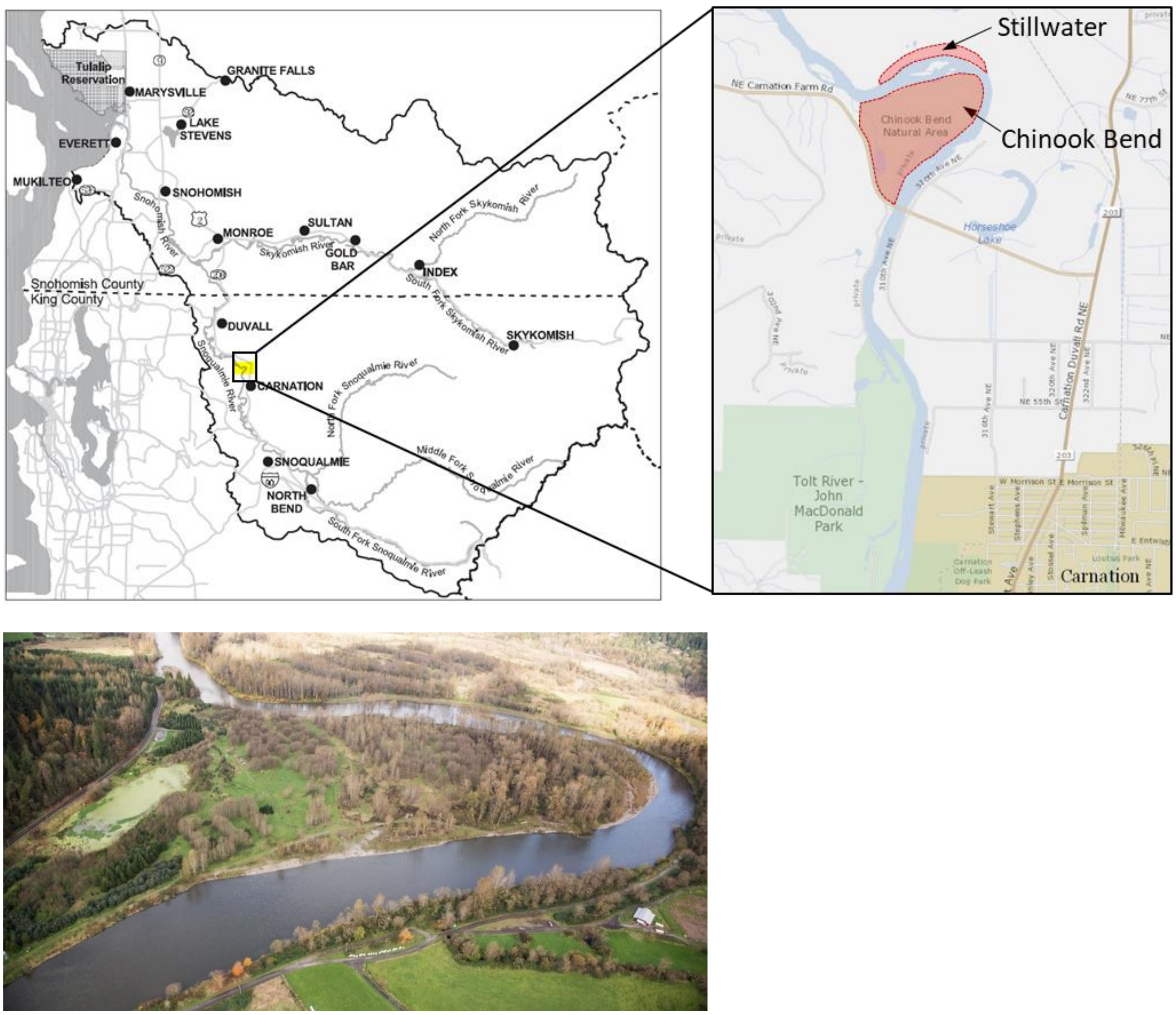

Figure B-1: Vicinity maps. Top left panel is from Snohomish River Basin Salmon Conservation Plan (2005) and top right panel showing project area. Bottom photo is of the Chinook Bend/Still was project reach, looking downstream. Photo from October 29, 2014. Discharge at USGS 12149000 was 7,500 cfs (212 cms).

What was the purpose?

The overall project goal was to enhance fluvial processes in the river and floodplain of the Chinook Bend Natural Area and the Stillwater Unit of the Snoqualmie Wildlife Area to achieve the following results:

- Allow more frequent overbank flooding within the Natural Area and the Wildlife Area;
- Allow the river to migrate laterally through the floodplain; and
- Promote the formation of complex riverine and floodplain habitat for rearing and spawning salmonids.

What actions were taken?

Chinook Bend project area

- Removal of ~1500 feet of rock revetment along the left (west) bank of the Snoqualmie River in the upstream portion of the project reach, and ~500 feet of revetment in the downstream reach.
- Installed live cottonwood piles in a staggered pattern to rack floating wood, form jams, create roughened bank before channel encounters them. The structures should deflect high velocity flows to the east, toward the primary overbank flow path (east). Installed at least 75 feet from OHWM (ordinary high-water mark). Densely planted around them.
- Enhanced and maintained native plant communities throughout the floodplain.
- Left ~530 feet of revetment in place along the left bank downstream from Stossell Bridge. Constructed a 600-ft-long, buried setback revetment to protect Carnation. Aimed to deflect high velocity flow and associated potential for erosion and channel formation, from the Carnation wastewater outfall and Camp Korey property.

Stillwater project area

- Removal of ~2100 feet of rock revetment on the right (northeast) bank of the Snoqualmie.
- Enhanced and maintained native plant communities throughout the floodplain.

What were the goal(s) specific to mainstem aquatic habitats and juvenile salmonids?

Goal: Promote the formation of complex riverine and floodplain habitat for rearing salmonids.

Performance Measure/Indicator:

- The summed area of 'edge habitat' (bar, bank, backwater and side channel units) increases relative to pre-project conditions.
- Juvenile salmon presence and abundance is greater among restored edge habitats (bar, unarmored bank, backwater) compared to riprap armored banks.

Are goals being met and what were mainstem aquatic habitat and juvenile salmonid observations?

Has there been increases in juvenile salmonid rearing habitat?

Low-velocity edge habitats were mapped at three flows in 2009, four flows in 2011, and four flows in 2019 (Table B-1). Comparison of edge habitat to flow relationships before and after restoration is challenging because sampled flows did not exactly align across years. Total edge habitat area for a given flow range appeared to increase after restoration (Figure B-2). Generally, total edge habitat area was higher at low flows (~1500 cfs), decreased as flow increased (~1500 to 7,500 cfs), and then increased again when flows began engaging the floodplain (approximately 13,000 cfs post-project) (Figure B-3). More samples at flows between 5,000 and 10,000 cfs would help validate these range patterns.

Increases in edge habitat area for a given flow were primarily driven by changes in bar and bank habitat (Figure B-4). Bar and bank edge habitat area was generally greater after the restoration project, particularly during lower flows. Compared to bank edge habitat, the area of bar edge habitat declined more slowly with increasing flow. In 2019 there were large areas of bank edge habitat at flows under 1,500 cfs, but bank edge habitat area was generally low for all other sampling events. Backwater edge area appeared relatively consistent across sampled flows, while side channels only became engaged above 7,000 cfs.

The location and extent of edge habitat areas appears to be largely associated with depositional bars. Changes in hydraulic and sediment dynamics across the Chinook Bend project reach likely influenced the formation of bars as well as the frequency of related channel bifurcations. The project reach has become more complex compared to pre-project conditions with a greater number of channel bifurcations, increased deposition, and increase in the frequency and size of low-velocity habitat areas. Increased channel complexity helps to support a suite of edge habitat types and increases the availability of low-velocity edge habitat areas. The availability and diversity of these edge habitats supports juvenile salmon as they transition through early life-stages.

Table B-1: Discharges during edge habitat mapping.

Approx. Flow percentile	Method	Discharge (cfs)			Survey dates		
		2009	2011	2019	2009	2011	2019
<5th	Field survey	No survey	990	1,175 & 1,350	None	Oct 4	March 6 & July 23
20th	Field survey	2,260	2,150	2,700	Mar 3	Aug 2	May 28
50th	Field survey	3,720	3,440	4,750	Mar 26	July 12	April 16
90th	Field survey	7,490	7,280	No survey	Mar 7	May 18	None
>95th	Oblique	Estimate	16,400	No survey	None	Dec 29	None

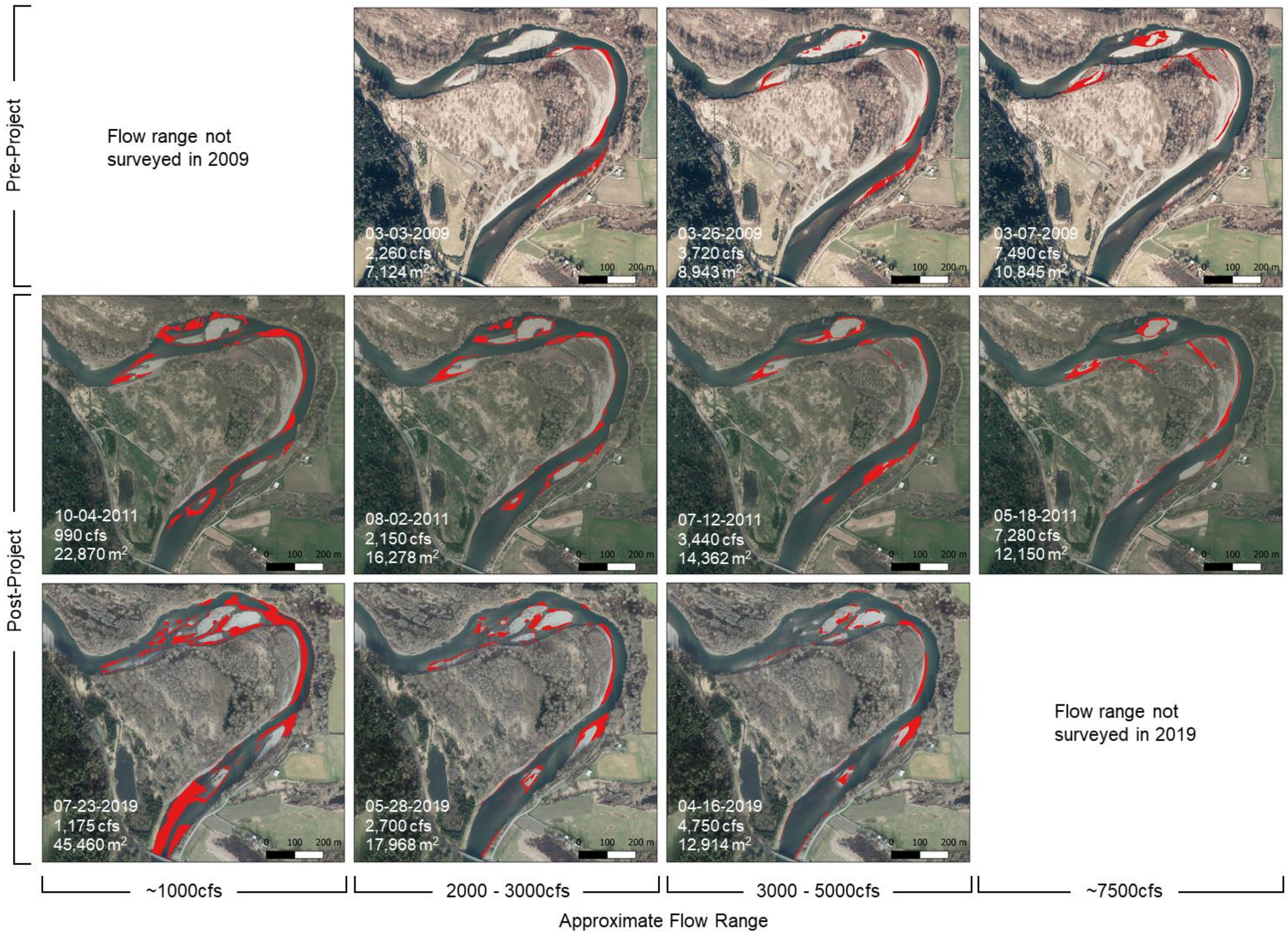

Figure B-2: Low-velocity edge habitat areas (red shapes) before (2009) and after (2011 & 2019) Chinook Bend/Stillwater project completion. Aerial imagery corresponds with survey years. Survey dates, river flow (cubic-feet-per-second), and total area (square meters) of low-velocity habitat are shown in the corner of each map. River flows are for USGS gage 12149000 Snoqualmie near Carnation, WA. Note that the March 3, 2009 survey did not fully map all low-velocity habitat areas.

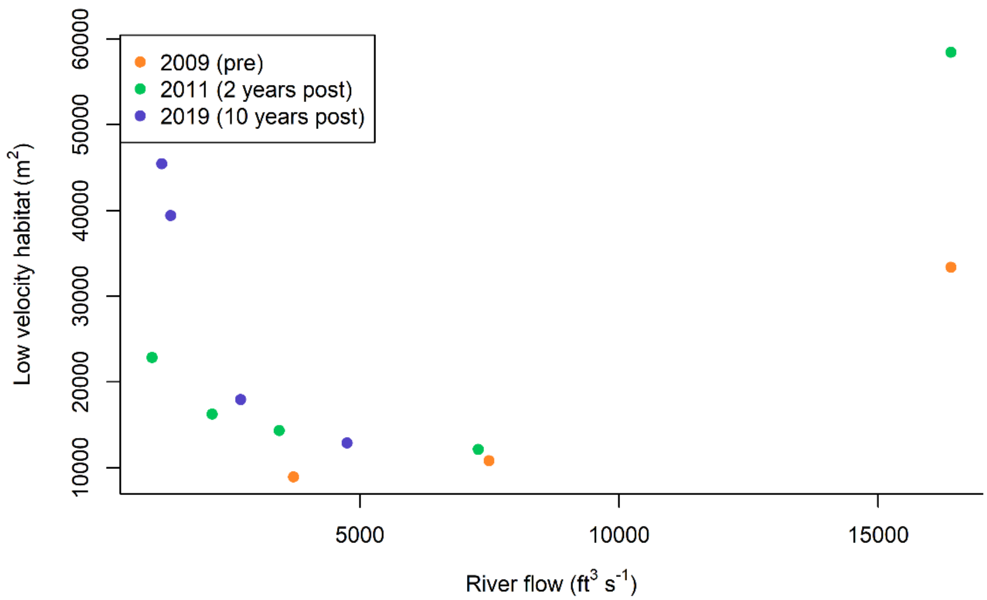

Figure B-3: Total low-velocity edge habitat area (m2) as a function of discharge (ft3 s-1) across pre-project (2009) and post-project (2011 & 2019) surveys.

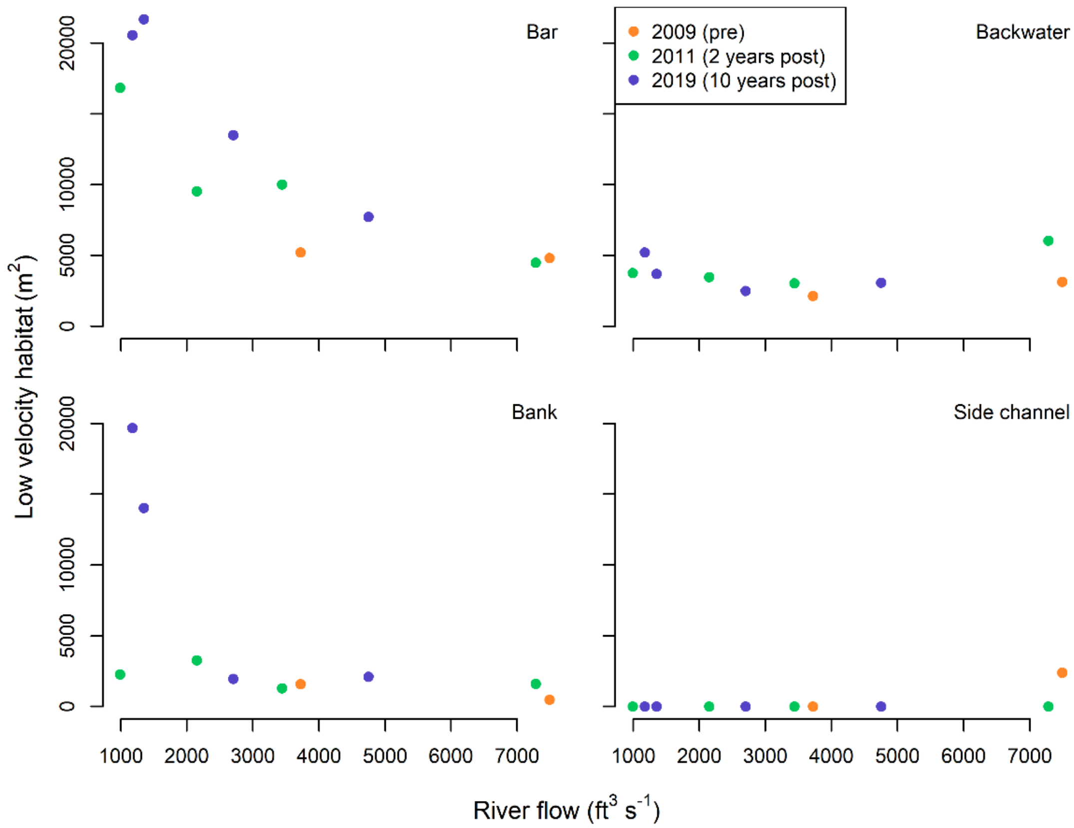

Figure B-4: Low-velocity edge habitat area (m2) across edge habitat types as a function of discharge (ft3 s-1) across pre-project (2009) and post-project (2011 & 2019) surveys. Floodplain low-velocity habitat was excluded from this comparison because it was only measured from aerial photos once in 2011 during a high flow event.

What are the edge habitat characteristics across the project reach?

Measurements across project transects surveyed in 2019 (refer to Figure B-5) indicated that bars and backwaters generally had greater low-velocity edge widths than armored and unarmored banks (Figure B-6). Additionally, bars and backwaters had considerably shallower depths than armored and unarmored banks.

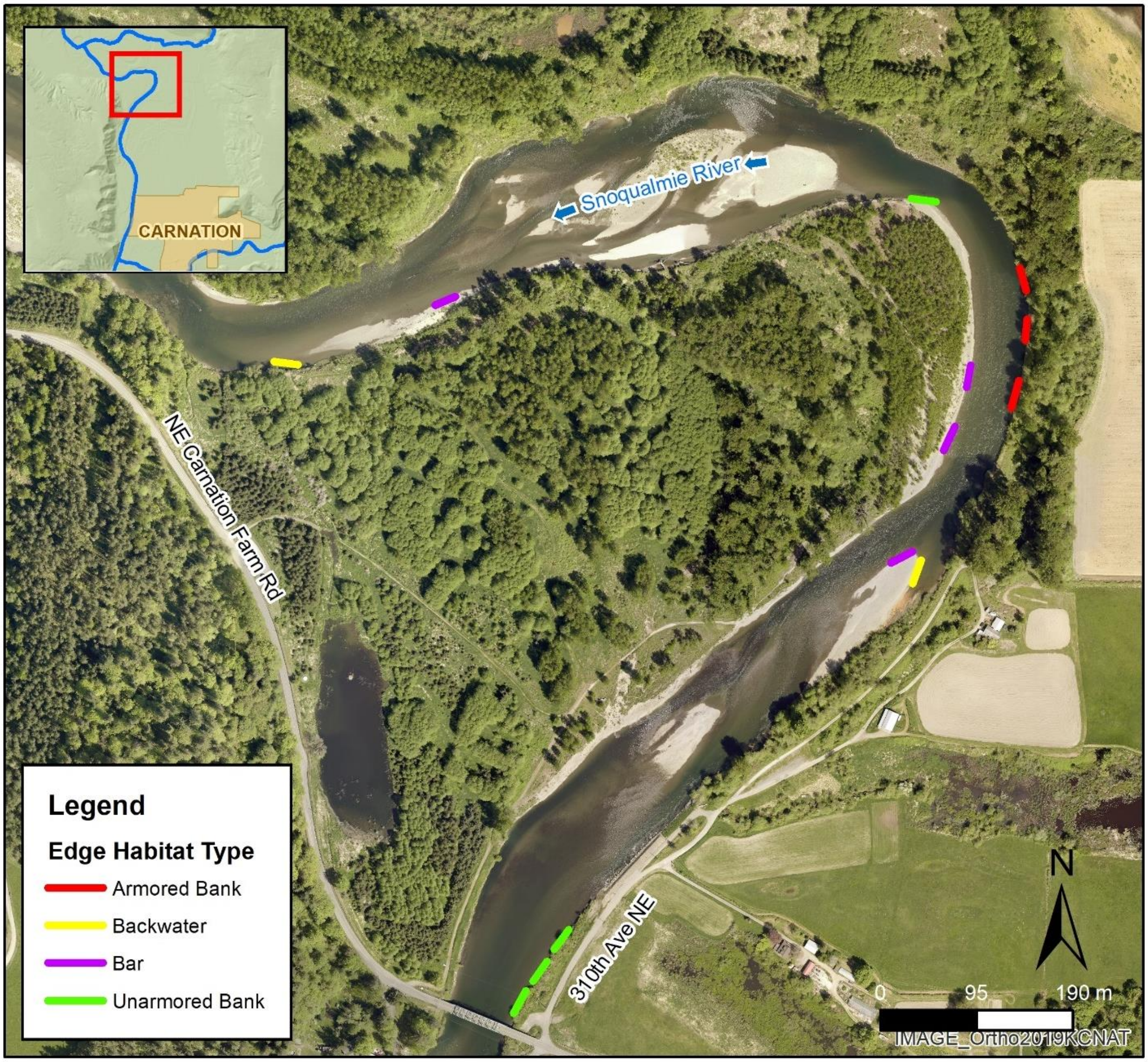

Figure B-5: Electrofishing transects surveyed in 2019 across the Chinook Bend project reach located on the Snoqualmie River. Aerial imagery from 2019.

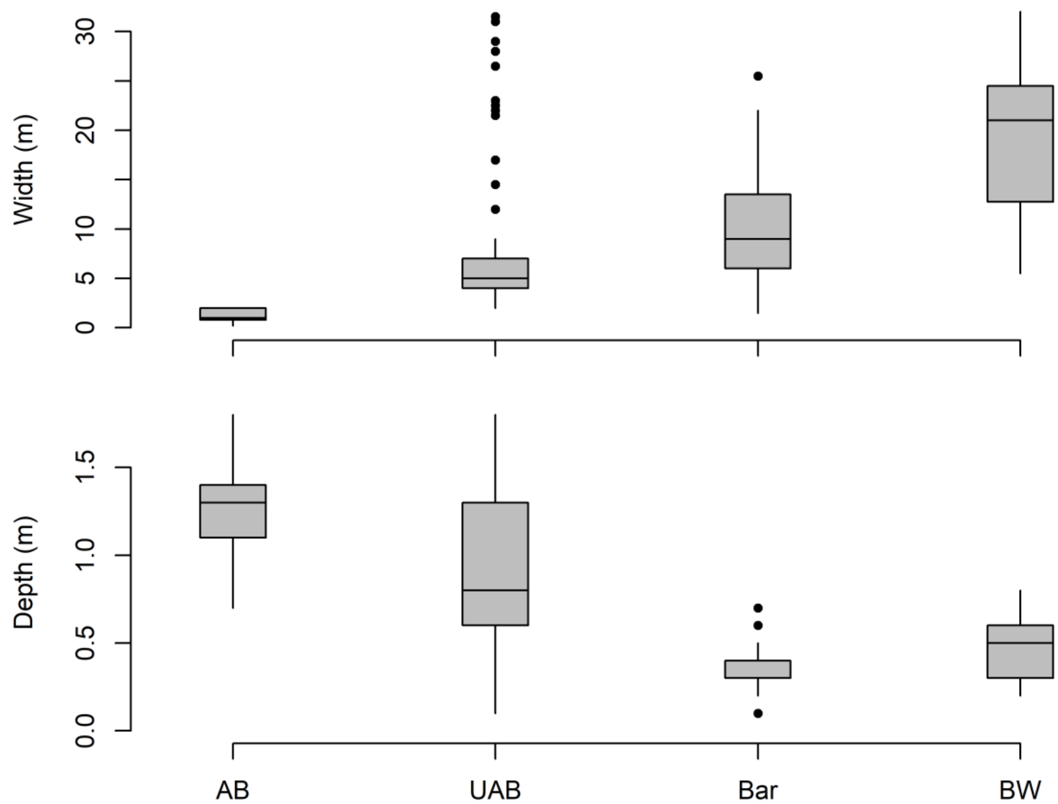

Figure B-6: Edge habitat low-velocity widths and water depths from 2019 surveys along the Chinook Bend project reach. Habitat codes include AB (armored bank), UAB (unarmored bank), and BW (backwater). Boxes indicate the first quartile, median, and third quartile. The whiskers indicate maximum and minimum values up to 1.5x the inter-quartile range and the points are observations beyond 1.5x the inter-quartile range.

What were juvenile salmonid observations, and are juvenile salmonid abundances among project-related edge habitats relatively greater than abundances among riprap armored banks?

Seining and snorkeling was done on a limited basis pre-project (2009) and post-project (2011). However, these methods were unable to reliably sample juvenile salmonids within the project reach and are thus not reported. Cataraft electrofishing was adopted for the 10-year post-project monitoring effort because this approach was effective at sampling juvenile salmonids across large-river restoration projects.

During 2019, a total of 317 fish from 10 different species were observed in the Chinook Bend project reach (Table B-2). Juvenile Chinook and coho salmon fork length frequencies indicated that multiple life-history types were present during project monitoring. Earlier in the season (March) we observed a cohort of smaller sub-yearling Chinook (hatched that winter) as well as a cohort of larger yearling Chinook (hatched the prior year) (Figure B-7).

These two cohorts are indicated by the bimodal peaks in fork length frequencies during March, with the shorter fork lengths representing sub-yearling Chinook and the longer fork lengths representing yearling Chinook. Later in the season (May and July), we only observed sub-yearling Chinook. Throughout the sample season, we primarily observed sub-yearling coho; however, a few yearling coho were also observed in March and May.

Table B-2: Species list and counts for fish observed within the Chinook Bend project reach (2019).

Species code	Common name	Scientific name	Fish Counts
CHK	Chinook salmon	*Oncorhynchus tshawytscha*	58
COH	Coho salmon	*Oncorhynchus kisutch*	60
COT	Sculpin (unknown)	*Cottus sp.*	166
CUT	Cutthroat trout	*Oncorhynchus clarki*	1
DAC	Dace (unknown)	*Rhinichthys sp.*	3
GSF	Green sunfish	*Lepomis cyanellus*	5
LSS	Large scale sucker	*Catostomus macrocheilus*	3
MWF	Mountain whitefish	*Prosopium williamsoni*	1
PMM	Peamouth minnow	*Mylocheilus caurinus*	1
RBT	Rainbow trout	*Oncorhynchus mykiss*	19

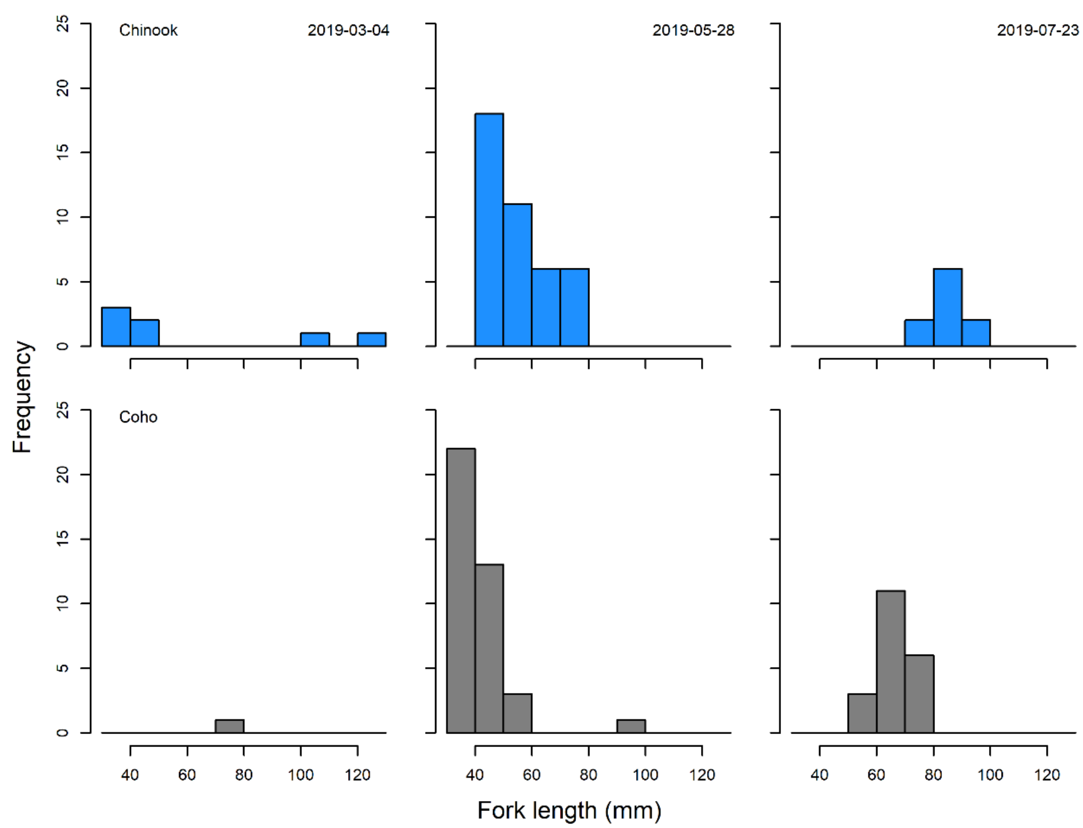

Figure B-7: Fork length frequencies of juvenile Chinook and coho salmon sampled in 2019 throughout the Chinook Bend project reach.

In 2019, juvenile Chinook salmon were more abundant along bars and unarmored banks and were less abundant along riprap armored banks and in backwaters (Figure B-8). Juvenile coho salmon were most abundant in backwaters and were slighltly more abundant along unarmored banks than riprap armored banks. The median abundances of Chinook and coho salmon along unarmored banks, bars, and backwaters were only slightly greater than riprap armored banks due in part to large numbers of zero-catches. However, both Chinook and coho salmon were observed more frequently along unarmored banks, bars, and in backwaters compared to riprap armored banks. Chinook salmon were observed in 60% of transects along unarmored banks, 62% of transects along bars, and in 80% of transects in backwaters. Coho salmon were observed in 50% of transects along unarmored banks and in 80% of surveyed transects in backwaters, but were not observed along bars. In comparison, both Chinook and coho salmon were only observed in ~44% of transects along riprap armored banks.

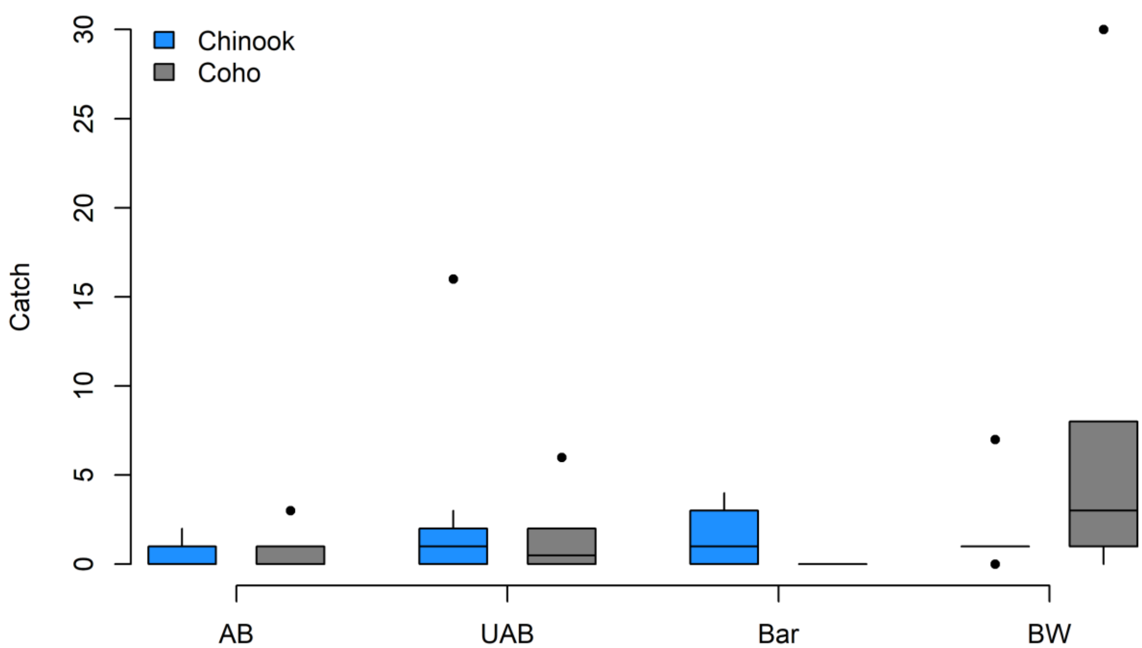

Figure B-8: Juvenile Chinook and coho abundance (catch per 25m transect) among edge habitat types across the Chinook Bend project reach. Habitat codes include: AB (riprap armored bank), UAB (unarmored bank), and BW (backwater). Boxes indicate the first quartile, median, and third quartile. The whiskers 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.

Appendix C: Lower Tolt Restoration and Floodplain Connection

Data and infromation from King County (in prep.–b).

Where is the project and when was it completed?

The project site is located at the confluence of the Tolt and Snoqualmie Rivers, in the Tolt River-John MacDonald Park, a 574-acre (232 hectare) regional park operated by King County (Figure C-1). The project is located along RM 0–0.5 of the Lower Tolt River just downstream of SR 203 Bridge–Fall City Carnation Road NE. The project was completed in 2009.

Figure C-1: Top panel showing the Lower Tolt restoration project vicinity map. Bottom panel is an oblique aerial photo of the lower Tolt restoration project (October 29, 2014, 12:28 PM)

What was the purpose?

- The Lower Tolt Floodplain Reconnection Project was a joint effort by King County and the City of Seattle to remove a levee at the confluence of the Tolt and Snoqualmie rivers (hereafter the Lower Tolt), for the benefit of threatened salmonids.
- To restore the physical processes and functions that create beneficial fish habitat to the lower reaches of the Tolt River and its floodplain and to enhance spawning and rearing habitat for Chinook, chum salmon, steelhead trout and other salmonids
- Restoration of the Lower Tolt reach will contribute to meeting basin-wide recovery goals for Chinook salmon.

What actions were taken?

- Removal of 2,460 feet of existing levee on the right bank and built a new setback 800 feet to the north. Left 700 feet of existing levee in place to ensure structural integrity of bridge.
- Excavated a new channel outlet in the floodplain.
- Planted native vegetation in the floodplain and all areas disturbed during construction.
- Placed large wood (LW) in the floodplain to direct water to desired flow routes, to diffuse energy, and to encourage formation of habitat features.
- Excavated two pilot channels near the upstream end of the project site.

What were the goal(s) specific to mainstem aquatic habitats and juvenile salmonids?

Goal: Restore salmonid rearing habitat in the lower Tolt River by returning the complexity, diversity, and morphology of habitats characteristic of an unconstrained channel.

Performance Measure/Indicator:

- Edge habitat extent and area (edge habitat increases and resembles natural conditions; existing off-channel habitat is improved).
- Fish use (juvenile salmonids use edge habitats for rearing) and increased relative abundance (post-project conditions support greater abundances than pre-project conditions).

Are goals being met and what were mainstem aquatic habitat and juvenile salmonid observations?

Has there been increases in juvenile salmonid rearing edge habitat?

Changes in edge habitat and fish use were chosen as indicators of whether the project is successfully restoring rearing habitat in the Lower Tolt River. An increase in the area and diversity in edge habitat types is indicative of added complexity and diversity of the channel, though the value of edge habitat to fish may vary among habitat types and be further modified by the presence of cover. An assessment of fish use in each habitat type helps us to understand the relative importance of edge habitats for rearing.

Since project implementation, the channel response to levee removal has been limited to the lower half of the project site. There, the channel is migrating into the unarmored right bank and the left bank gravel bar, undercutting cottonwood trees and forming logjams. Two large gravel bars have formed, and at some high flow levels, these gravel bars are flanked by flowing side channels and contain backwater features. Though new logjams have formed and the gravel bars could trap floating wood from upstream, relatively little wood has accumulated. In fact, wood loading has steeply declined from pre-project (post January 2009 flood) conditions. Edge habitat –the intended product of these changes– has increased over pre-project levels, owing to the formation of new side channels and backwaters associated with gravel bars and logjams

Initial target flow ranges for pre- and post-project edge habitat surveys were determined based on flow percentiles from the Tolt River USGS flow gage (USGS Station 12148500) (Table C-1). Specific flow targets among each percentile range were subsequently established during pre-project surveys in 2009 with the addition of a moderate flow target (461-590cfs) being established in 2011. Edge habitat was successfully mapped at two target flow ranges in 2009, four in 2011, three in 2014, and two in 2019 (Table C-1). While edge habitat was mapped four times in 2019, low-flow conditions during the 2019 sample period resulted in only two target flow ranges being represented.

Table C-1: Target and actual Discharges at which edge habitats were mapped before (2009) and after (2011, 2014, 2019) project completion.

Target Range in cfs (cms)	Discharge (cfs/cms)				Survey dates			
	2009	2011	2014	2019	2009	2011	2014	2019
Supplemental	1,320 (37.4)	1,323 (37.4)	1,340 (37.9)	none	May 14	Dec.29	Apr. 24	none
>700 (19.8)	760 (21.5)	725 (20.5)	775 (21.9)	950 (26.9)	May 07	Nov. 17	Apr. 29	Apr. 09
461-590 (13-16.7)	none	480 (13.6)	434 (12.3)	none	none	Oct.24	May 28	none
0-350 (0-9.9)	156* (4.4)	142 (4.0)	none	338 (9.6); 256 (7.2); 185 (5.2)	Oct. 15	Oct. 03	none	May 20; Mar. 06; Jun. 17

*In 2009, slow-water habitat was abundant during the low-flow survey, but it was not measured. Mapping during this survey was not consistent with other surveys. Thus, these data were not used.

Edge habitat area increased from 2009 to 2011 across all measured flow levels in response to post-project channel migration and bar formation, as well as the presence of a constructed outlet channel (Figures C-2 and Figure C-3). Surveys in 2011 indicated that the overall area of low-velocity habitat was highest at low discharge, declined as discharge increased, and then increased abruptly once water surface elevations begin to exceed the elevation of bars in the active channel (Figure C-2). This allowed flows to pass into side channels and backwaters, and to form large areas of shallow, exposed bar habitat as well.

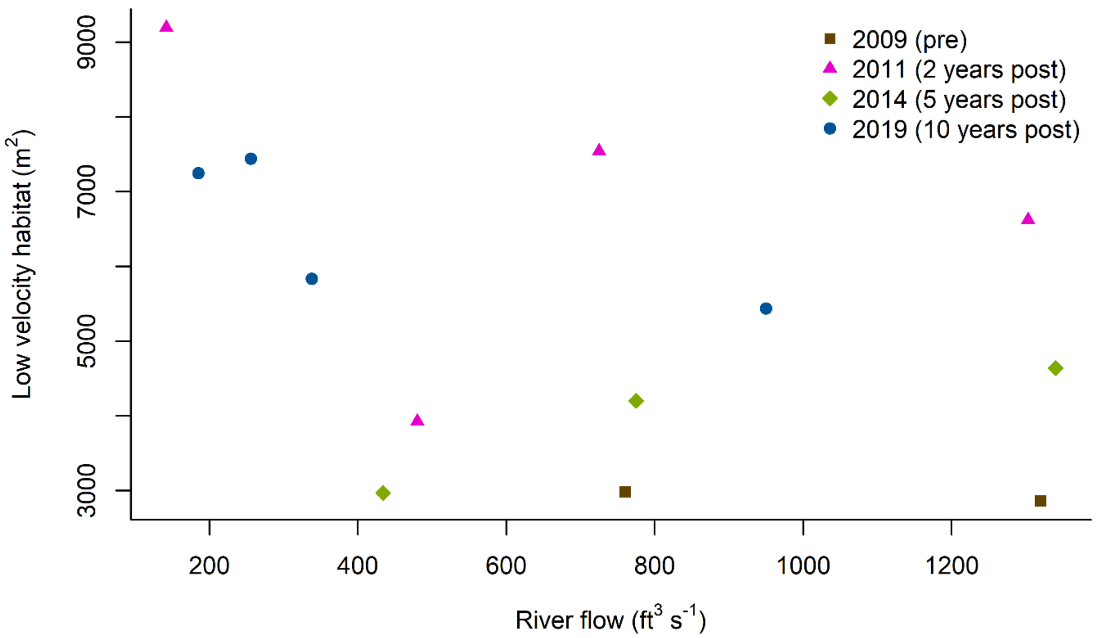

Figure C-2: Low velocity edge habitat area as a function of discharge before (2009) and after (2011, 2014, 2019) the project was completed.

Edge habitat declined from 2011 to 2014; the magnitude of the decline varied with discharge (Figure C-2 & Figure C-4). The largest decline occurred between 700-800 cfs (19.8-22.6 cms), because in 2014, that discharge level no longer created extensive backwaters and side channels along the right bank. It is likely that either the gravel bars aggraded, or the thalweg incised from 2011-2014, though no bathymetric surveys exist from 2014 to substantiate either explanation. Regardless, the result was a steep decline in edge habitat availability in that discharge range. Of the different habitat types, backwaters experienced the most notable decline in area from 2011 to 2014 across the range of sampled discharges.

Edge habitat increased from 2014 to 2019 across a range of flows (Figure C-2 and Figure C-5). The largest increase in low-velocity area occurred at lower flows (below 450 cfs); however, an increase in low-velocity area also occurred at higher flows (775–950 cfs). The increase in low-velocity area appeared to be primarily associated with bars and backwaters. Specifically, in 2019 during lower flows a large amount of low-velocity bar habitat was present and during higher flows a large backwater formed on the left bank of the Tolt River near the confluence with the Snoqualmie River.

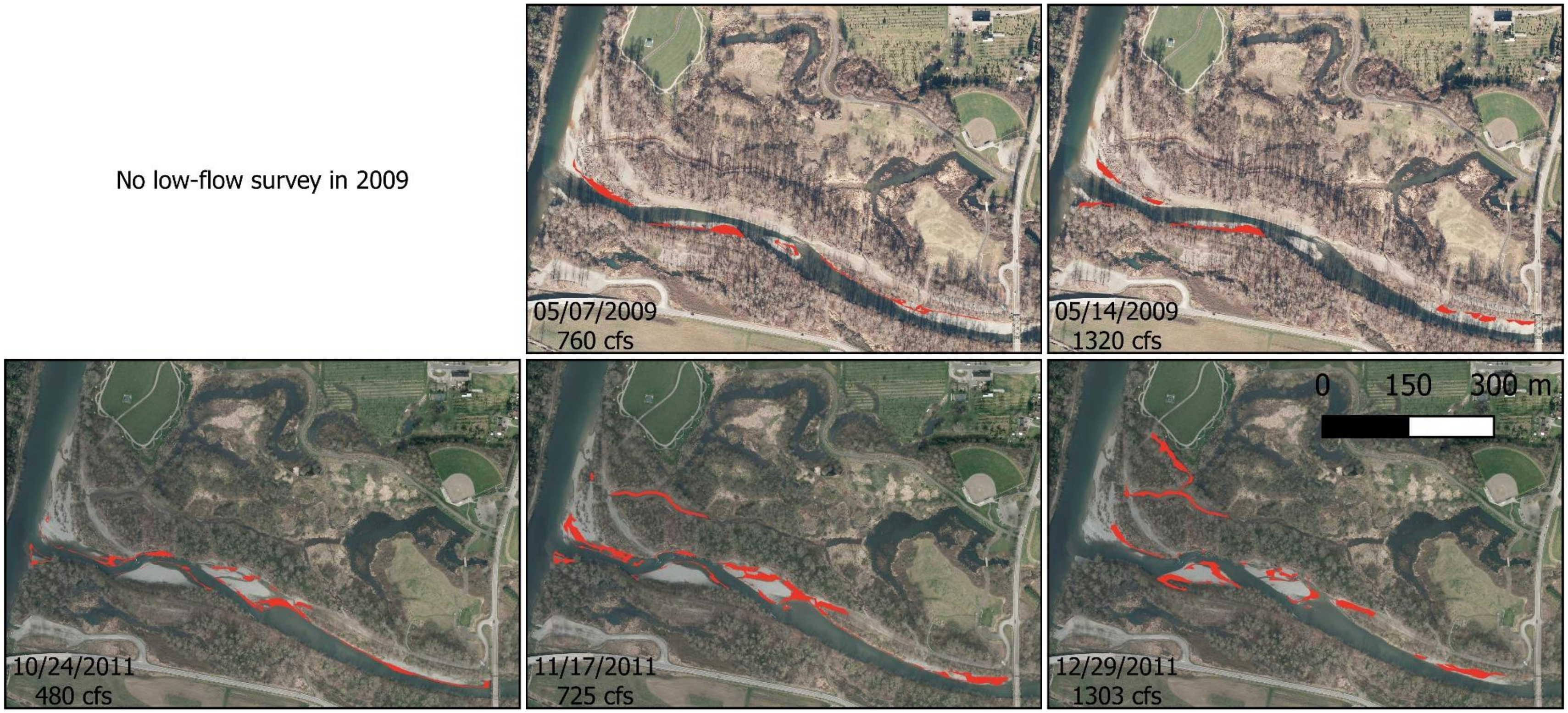

Figure C-3: Edge habitat areas before (2009) and Two years after (2011) the Lower Tolt project completion. Low-velocity edge habitat areas area shown in red. Reported flows were downloaded from USGS gage 12148500 Tolt River near Carnation, WA. Aerial imagery corresponds to the survey year.

Figure C-4: Edge habitat areas two years (2011) and five years (2014) after project completion. Low-velocity edge habitat areas are shown in red. Reported flows were downloaded from USGS gage 12148500 Tolt River near Carnation, WA. Aerial imagery corresponds to the survey year.

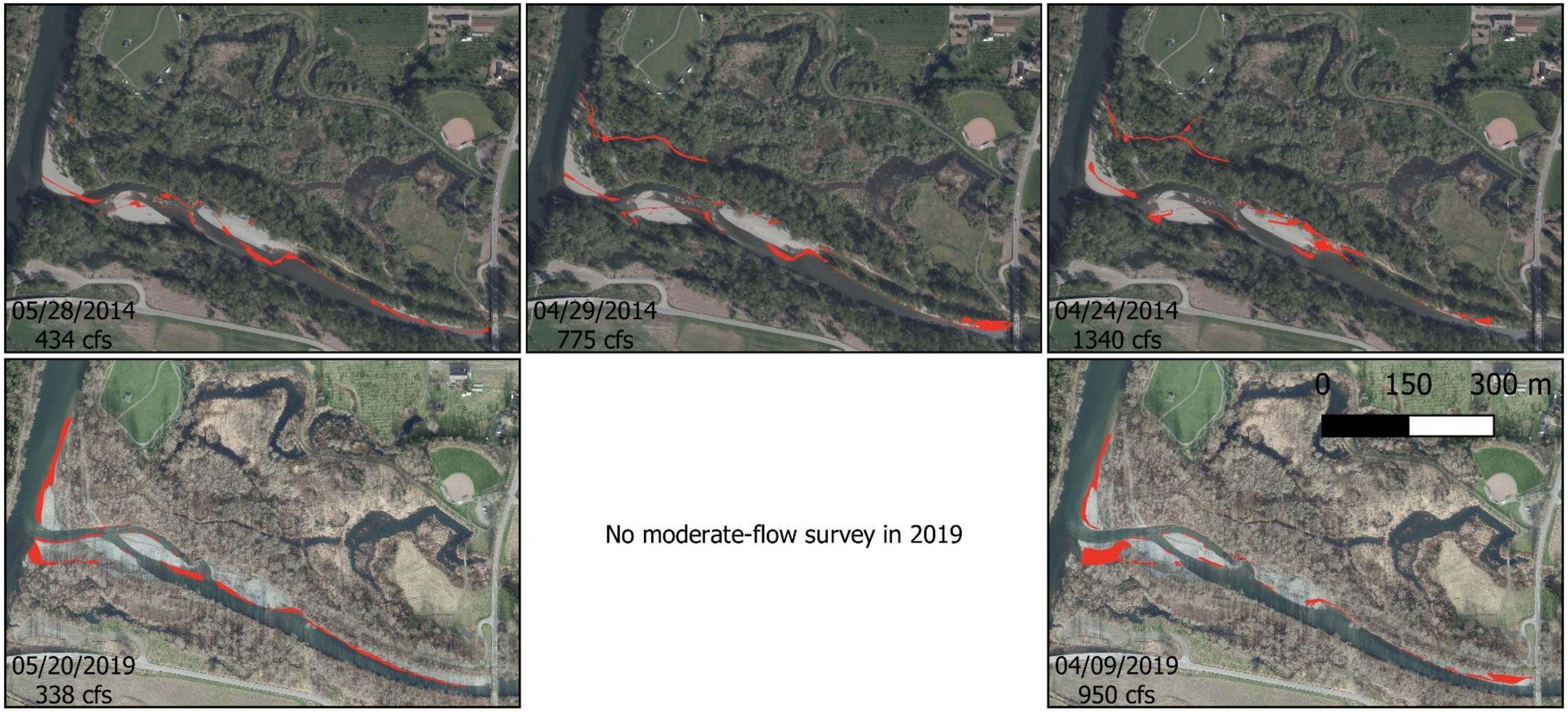

Figure C-5: Edge habitat area five years (2014) and ten years (2019) after project completion. Low-velocity edge habitat areas are shown in red. reported flows were downloaded from USGS gage 12148500 Tolt River near Carnation, WA. Aerial imagery corresponds to the survey year.

Inter-annual changes in low-velocity edge habitat area across the Lower Tolt project reach were primarily driven by changes in bar, backwater, and side-channel habitats (Figure C-6). These edge habitats generally had greater low-velocity areas during post-project periods. During lower flows, bars and backwaters had greater low-velocity habitat area compared to pre-project surveys. Additionally, during higher flows, backwaters and side-channels had greater low-velocity habitat area compared to pre-project surveys. As flows increased, the overall edge habitat area shifted from predominantly bars to backwaters and side channels. The area of bar edge habitat declined with increasing flow while side-channels became engaged above ~700cfs and backwaters above ~900cfs. Bank edge low-velocity areas appeared relatively invariant to changes in flow and represented a small amount of low-velocity habitat area across the project reach. Increases in backwater and side-channel habitat are notable as these habitat types were not present in measurable quantities prior to project completion.

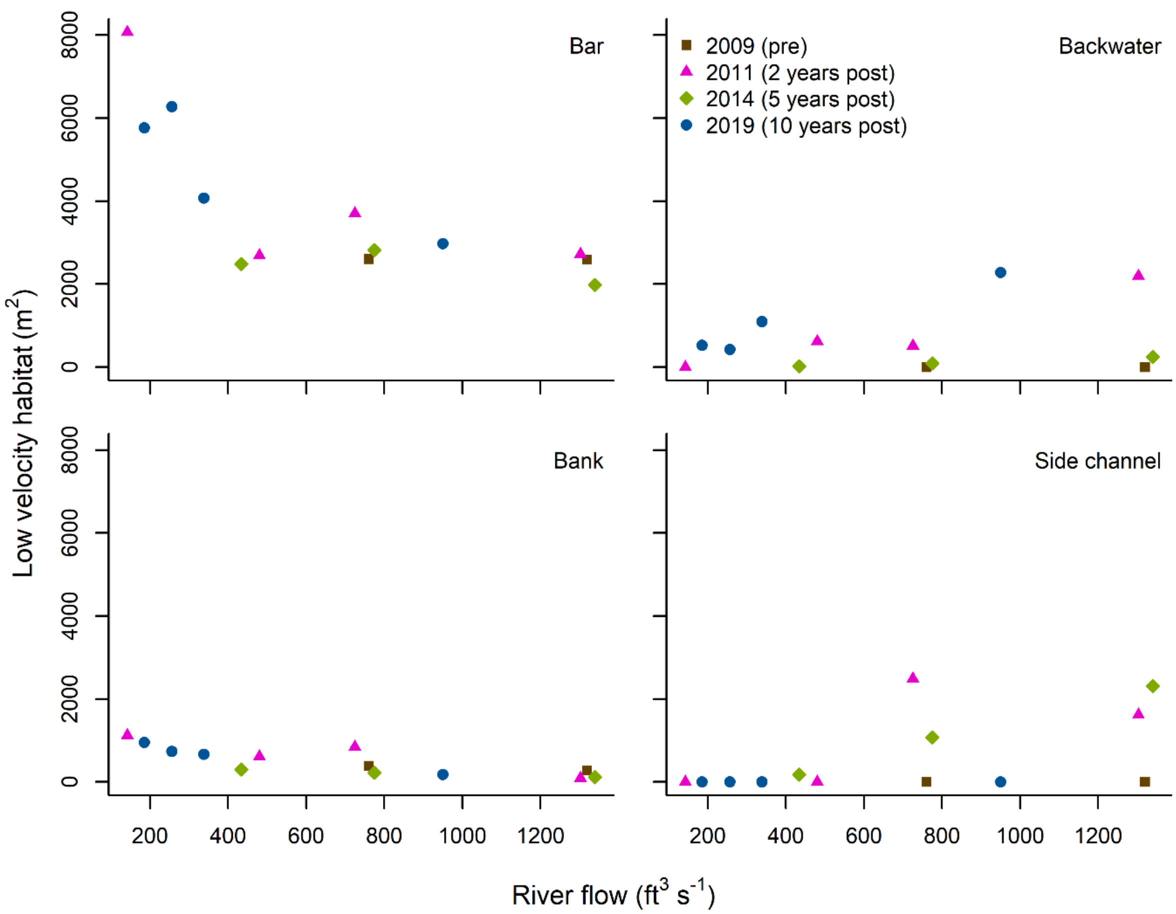

Figure C-6 Low velocity edge habitat area as a function of discharge, separated by edge habitat type, before (2009) and after (2011, 2014, and 2019) the project was completed.

Observations across all post-project surveys indicate that low-velocity edge habitat has increased since the completion of the Lower Tolt project. Inter-annual changes in the cumulative area, extent, and location of low-velocity habitat areas highlight that channel movement and related habitat formation is dynamic in the Lower Tolt. The location and extent of edge habitat areas appeared to be largely associated with depositional bars, channel obstructions, and side-channel connectivity. Changes in hydraulic and sediment dynamics as well as related channel movement across the Lower Tolt project reach likely influenced the frequency of channel bifurcations, the connectivity of side-channel areas, as well as the formation of bars and backwaters. Increased channel complexity helps to support a suite of edge habitat types and increases the availability of low-velocity edge habitat areas. The availability and diversity of these edge habitats supports juvenile salmon as they transition through early life stages.

What were juvenile salmonid observations and are juvenile salmonids using project-related edge habitats?

Fish habitat preferences are important to validate, as this knowledge helps to prioritize selection and design of restoration projects. Another reason to estimate juvenile salmonid densities in specific habitat types is to translate edge habitat maps into estimates of habitat capacity—the approximate number of fish the river can support under certain conditions. Restoration projects are generally expected to increase habitat capacity by increasing the area and quality of habitat.

A single survey—May 14, 2009—was conducted prior to project implementation. Four surveys were conducted two years after project completion in 2011 (April 25, May 14, May 27, September 7) and four surveys were conducted 10 years after project completion in 2019 (Mar 6, April 6, May 20, June 17) (Table C-2).

Table C-2: Count of seine surveys across edge habitat types.

Year	Month/Day	Edge Habitat Type			Totals
		Banks	Bars	Backwaters	
2009	May 14th	2	6		8
2011	April 25th	3	4	1	8
	May 14th	2	6	1	9
	May 27th	3	3	1	7
	September 7th	4	4		8
2019	March 6th	3	9	3	15
	April 6th	1	6	3	10
	May 20th	2	8	2	12
	June 17th	3	9	1	13

A total of 2,177 fish from 12 different species were observed in the Lower Tolt project reach between in 2009, 2011, and 2019 (Table B-3). Juvenile Chinook and coho salmon fork length frequencies indicated that multiple life-history types were present during

project monitoring. Earlier in the season (Mar–Apr) we observed a cohort of smaller sub-yearling Chinook (hatched that winter) as well as two cohorts of coho including a sub-yearling cohort as well as a yearling cohort (hatched the prior year) (Figure C-7). These two coho cohorts are indicated by the bimodal peaks in fork length frequencies during Mar-Apr, with the shorter fork lengths representing sub-yearling coho and the longer fork lengths representing yearling coho. Later in the season (May-Jun) we continued to observe sub-yearling Chinook and observed both sub-yearling and yearling coho. However, yearling coho were relatively infrequent later in the season.

Table C-3: Species list and counts for fish observed within the lower Tolt project reach (2009, 2011, & 2019).

Species code	Common name	Scientific name	Fish Counts
CHK	Chinook salmon	*Oncorhynchus tshawytscha*	536
RBT	Rainbow trout	*Oncorhynchus mykiss*	96
COH	Coho salmon	*Oncorhynchus kisutch*	1108
COT	Sculpin (unknown)	*Cottus sp.*	182
TRT	Trout (unknown)		56
CHM	Chum salmon	*Oncorhynchus keta*	27
DAC	Dace (unknown)	*Rhinichthys sp.*	36
STH	Steelhead	*Oncorhynchus mykiss*	3
MWF	Mountain whitefish	*Prosopium williamsoni*	3
LMP	Lamprey (unknown)		2
TOR	Torrent sculpin	*Cottus rhotheus*	24
MIN	Minnow (unknown)	Cyprinidae	2
RIF	Riffle sculpin	*Cottus gulosus*	30
LND	Longnose dace	*Rhinichthys cataractae*	67
LSS	Large scale sucker	*Catostomus macrocheilus*	3
PRK	Prickly sculpin	*Cottus asper*	2

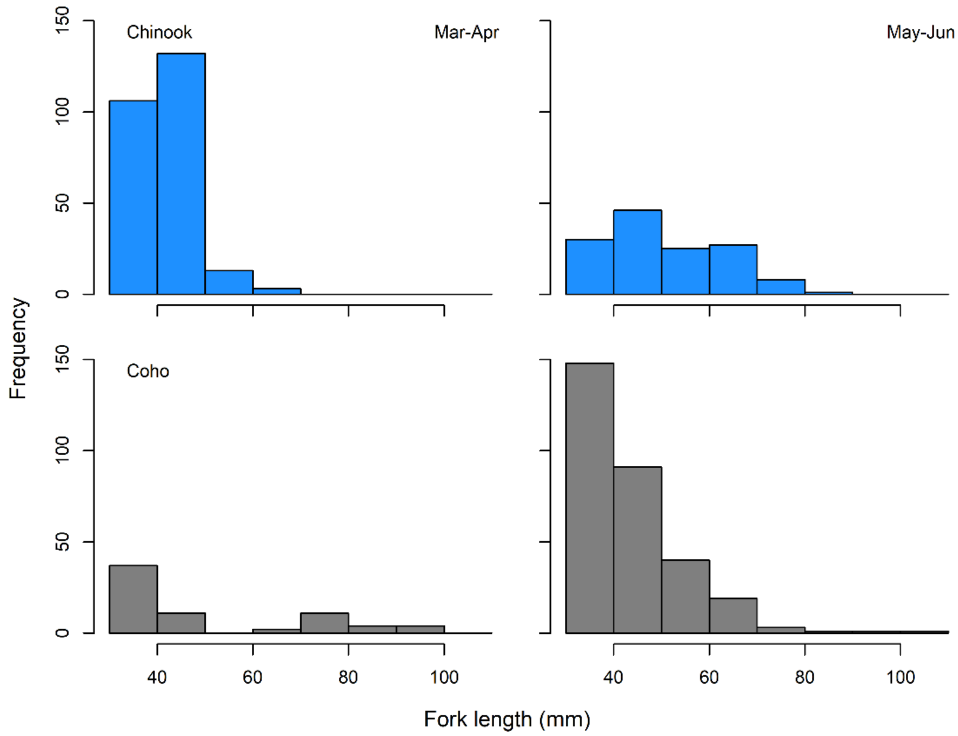

Figure C-7: Fork length frequencies of juvenile Chinook and coho salmon sampled during 2009, 2011, and 2019 throughout the lower Tolt project reach.

In 2009 (pre-project), juvenile Chinook were not observed across the project reach but juvenile coho and trout were observed along both bars and banks (Figures C-8 and Tables C-4, C-5, and C-6). Juvenile coho abundance was relatively similar between bars and banks while juvenile trout abundance was higher along banks. Compared to 2009, juvenile Chinook and trout abundance in 2011 increased among all habitat types while juvenile coho abundance increased along bars and were observed in backwaters. In 2011, Chinook abundance was highest along bars, coho abundance was highest within backwaters, and trout abundance was highest along banks.

Compared to 2009 and 2011, juvenile Chinook abundance in 2019 was greater across all habitat types. Across habitat types, the greatest increases in juvenile Chinook abundance was observed along bars and backwaters. In 2019, juvenile Chinook abundance was highest within backwaters. Juvenile coho abundance in 2019 was relatively similar to abundances in 2011 with the exception of backwaters where coho abundance was lower than in 2011. In 2019, juvenile coho abundance was highest within backwaters. Juvenile trout abundance increased from 2011 to 2019 along bars while banks and backwaters had similar abundances between years. In 2019, juvenile trout abundance was highest along bars.

Observations across survey years suggest that the Lower Tolt restoration project increased juvenile salmonid abundance across all habitat types. These observations as well as project-related increases in low-velocity edge habitat areas highlight the benefits of the Lower Tolt restoration project in creating and maintaining juvenile salmonid rearing

habitats. Additionally, since the abundance of juvenile salmonids varied across edge habitat types, observations suggest that a suite of low-velocity edge habitats are needed to support juvenile salmonids in the Lower Tolt project reach. However, inferences regarding the benefits of the Lower Tolt restoration project should be cautioned by the fact that only a single pre-project fish survey was conducted, and no control reach was sampled.

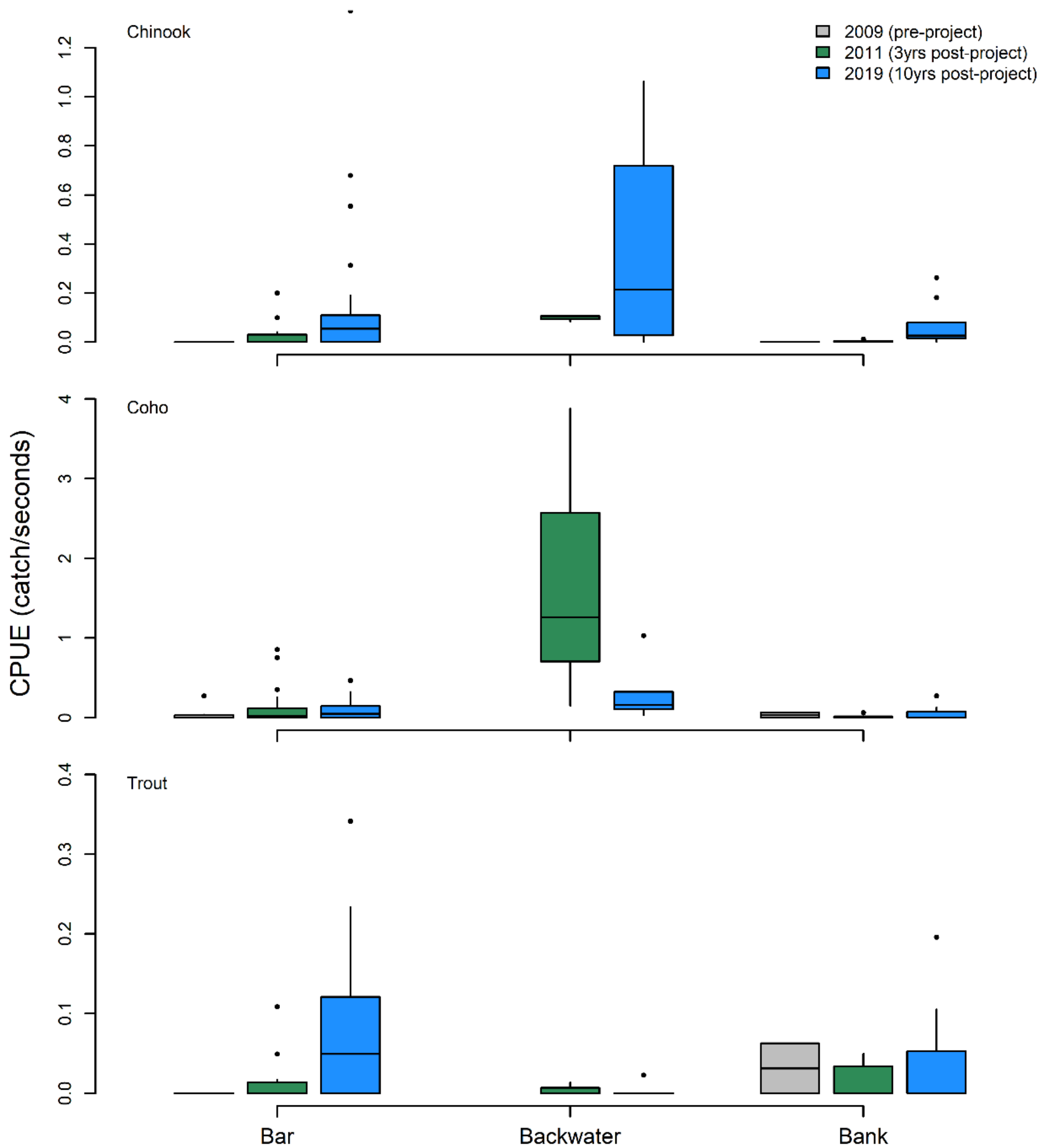

Figure C-8: The relative abundance (catch per seconds of seining) of juvenile Chinook, coho, and trout among habitat types and sample years. Three data points are not displayed in the figure due to scaling of the y-axis. These values include a 2019 Chinook abundance of 3.93 catch/seconds in backwaters, a 2011 coho abundance of 3.88 catch/seconds in backwaters, and 2019 coho abundance of 5.82 catch/seconds in 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.

Table C-4: Summary results of seine surveys for juvenile Chinook salmon.

Timing	Survey date	Total seine sets	Chinook captured	Mean Chinook Per Seine Set		
				Backwater	Bank	Bars
Pre-Project	5/14/2009	9	0		0.0	0.0
3 Years Post Project (2011)	4/25/2011	8	30	8.0	1.0	4.8
	5/13/2011	9	14	7.0	0.0	1.1
	5/27/2011	7	10	8.0	0.0	0.7
	9/7/2011	8	0		0.0	0
10 Years Post Project (2019)	3/6/2019	15	111	8	1.7	9.1
	4/6/2019	10	253	61	10	10
	5/20/2019	12	98	24.5	5.3	3.5
	6/17/2019	13	20	1	1.7	1.3

Table C-5: Summary results of seine surveys for juvenile coho salmon.

Timing	Survey date	Total seine sets	Chinook captured	Mean Coho Per Seine Set		
				Backwater	Bank	Bars
Pre-Project	5/14/2009	9	4		2.0	0.0
3 Years Post Project (2011)	4/25/2011	8	27	11.0	0.7	4.5
	5/13/2011	8	462	322.0	0.7	23
	5/27/2011	7	126	97.0	1.5	8.7
	9/7/2011	8	1		0.3	0.25
10 Years Post Project (2019)	3/6/2019	15	11	2.7	0	0.3
	4/6/2019	10	31	6	3	1.7
	5/20/2019	12	359	144.5	7	7
	6/17/2019	13	69	12	0.7	6.1

Table C-6: Summary results of seine surveys for trout (rainbow and steelhead).

Timing	Survey date	Total seine sets	Chinook captured	Mean Trout Per Seine Set		
				Backwater	Bank	Bars
Pre-Project	5/14/2009	9	0		0.0	0.0
3 Years Post Project (2011)	4/25/2011	8	10	1.0	2.7	0.5
	5/13/2011	8	3	0.0	0.7	0.3
	5/27/2011	7	4	0.0	0.5	2
	9/7/2011	8	10	0.0	0.5	4
10 Years Post Project (2019)	3/6/2019	15	4	0	0	0.4
	4/6/2019	10	17	0	4	2.2
	5/20/2019	12	36	0.5	1	4.1
	6/17/2019	13	67	0	3.7	6.2

This page intentionally left blank.

Appendix D: Upper Carlson Restoration and Floodplain Connection

Data and information from King County (2018b & 2020) and King County (in prep.–c).

Where is the project and when was it completed?

The project is located on 50 acres of public land located on the right bank of the Snoqualmie River between River Miles 32 and 33, less than two miles downstream of the SR 202 bridge in Fall City (Figure D-1). The project was completed in 2009.

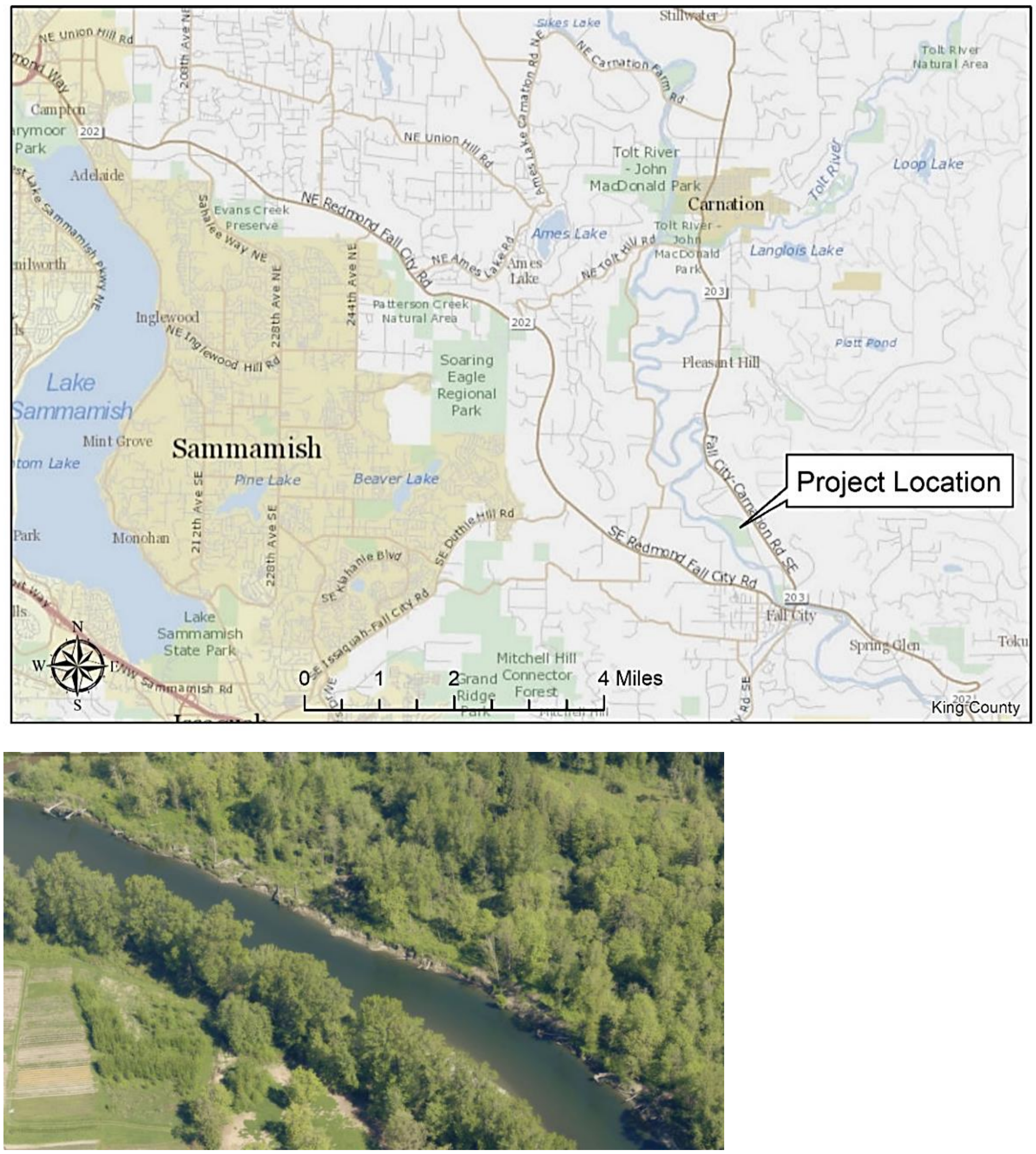

Figure D-1: Top panel showing the Upper Carlson restoration project vicinity map. Bottom panel shows the right bank Upper Carlson project looking north-east.

What was the purpose?

The goal of the project was to restore natural floodplain functions and processes that create riverine habitat and promote salmon recovery.

The project addressed high priority needs for the threatened Snoqualmie Chinook salmon identified in the Puget Sound Salmon Recovery Plan (2007) and for threatened steelhead and other species. The Upper Carlson project was identified as a high priority project in the Snoqualmie at Fall City Reach Restoration Assessment (King County 2011). The project addressed four of the Snohomish Basin Salmon Conservation Plan's (SBSRF 2005) highest priority ecological actions in the Upper-Mainstem Snoqualmie River sub-basin:

- Reconnection of off-channel habitats
- Restoration of shoreline condition
- Restoration of hydrologic and sediment processes
- Riparian enhancement

What actions were taken?

- Levee removal and wood placement: The project removed 1,600 feet of levee and revetment along the right bank. In addition, mature cottonwood trees growing on the levee were pushed over into the floodplain to mimic natural recruitment of trees from bank erosion.
- Buried revetment: The project constructed a setback protection structure along approximately 1,100 feet of Neal Road to protect property and infrastructure. It consisted of a 600-foot-long rock revetment, one large wood structure water ward of the revetment to recruit and retain wood, and three engineered log jams (ELJs).
- Spoils: The project distributed native spoils onsite in the following areas: unvegetated areas; areas with primarily invasive species; within placed log clusters; and at local farms in the form of "farm pads."

What were the goal(s) specific to mainstem aquatic habitats and juvenile salmonids?

Goal: Promote channel aggradation and form bar habitat along the left bank.

Performance Measure/Indicator: By 2019 or after three 2-yr recurrence-interval floods, a meander will form in response to bank retreat, with a point bar on the left bank and lateral scour on the right bank.

Goal*:* Promote formation of complex, woody right-bank edge habitat.

Performance Measure/Indicator: By 2017, there will be a minor increase in the amount and complexity of edge habitat, so that it increases above baseline and resembles the

reference site. After 2017, a rapid increase will occur and become similar to the downstream reference by 2022 to 2024.

Goal: Support juvenile salmonids across project-specific edge habitat types.

Performance Measure/Indicator: Upon formation of new edge habitats, and increases in woody, submerged overhead cover along the right bank, juvenile Chinook salmon relative abundance will be higher in those habitats than along rip-rap banks.

Are goals being met and what were mainstem aquatic habitat and juvenile salmonid observations?

Is the channel aggrading and forming bars?

The channel has aggraded by two to five feet (0.6-1.5 m) throughout most of the project site and up to 12 feet (3.7 m) in some places. A new, one-acre (0.4 ha) gravel bar formed on the left bank, creating bar edge habitat and a backwater feature.

Is complex woody edge habitat forming?

There was a net gain of approximately 864 meters (0.54 miles) of edge habitat in the project site. Gravel bars and woody banks now compose approximately 479 meters (1,572 ft) of the total edge habitat. The amount of edge habitat per unit channel length is similar to the downstream reference site. Six logjams are present in the channel and the overall quantity of instream wood increased by 111 pieces, approximately 25% as many as at the reference site.

What are the edge habitat characteristics across the project reach?

Measurements across restoration and control transects (refer to Figure D-2) indicated that bars and backwaters generally had greater low-velocity edge widths compared to armored and unarmored banks (Figure D-3). Additionally, bars and backwaters had considerably shallower depths compared to armored and unarmored banks. The depths and widths of the Upper Carlson unarmored restoration bank (UAB-Rest) and restoration-related backwater and bar habitats (BW-Rest & Bar-Rest) were similar to depths and widths measured along control edge habitats (AB-Ctr, Bar-Ctr, & BW-Ctr).

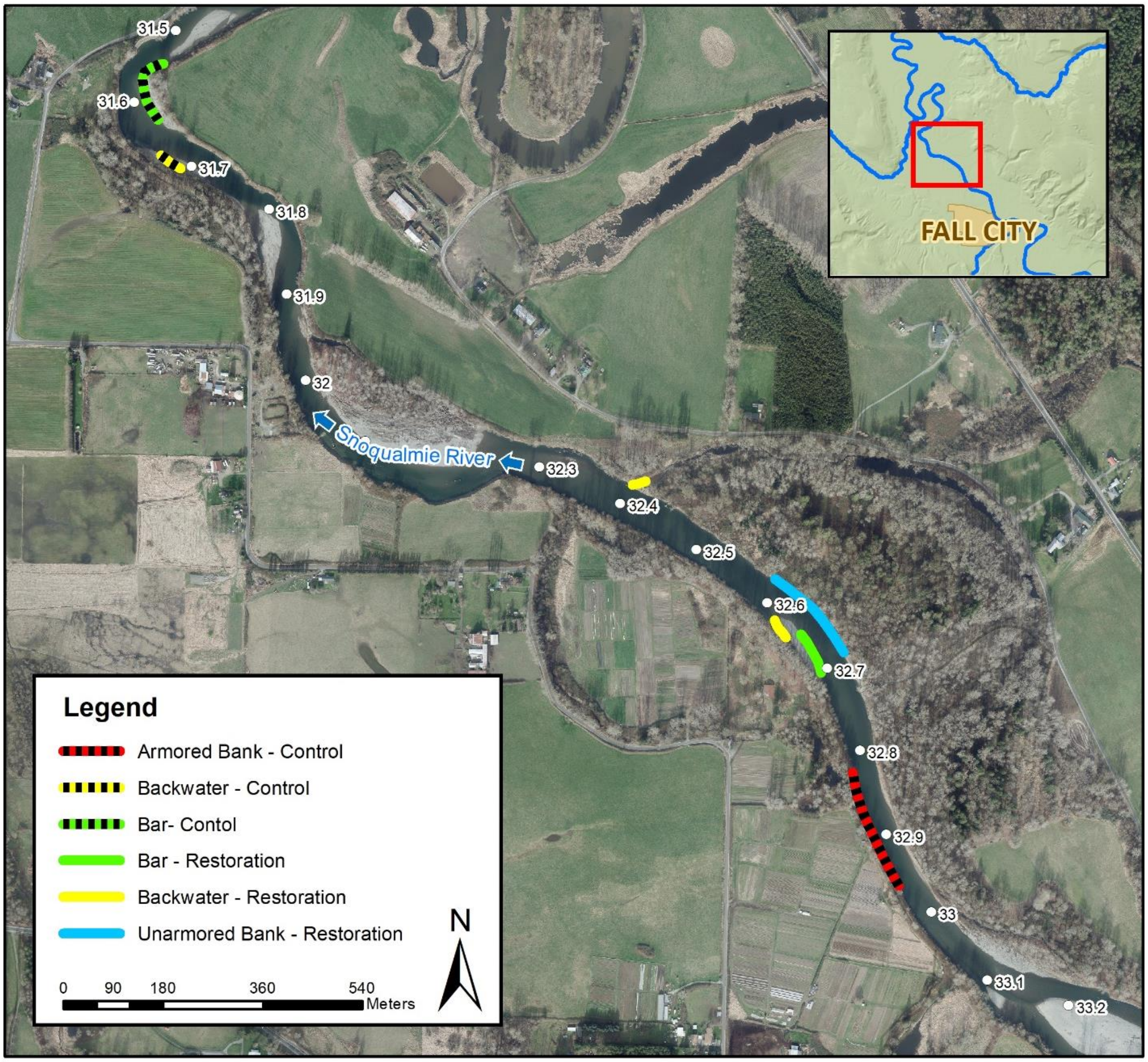

Figure D-2: Edge habitat sampling areas across the Upper Carlson project reach located on the Snoqualmie River. Aerial imagery from 2017.

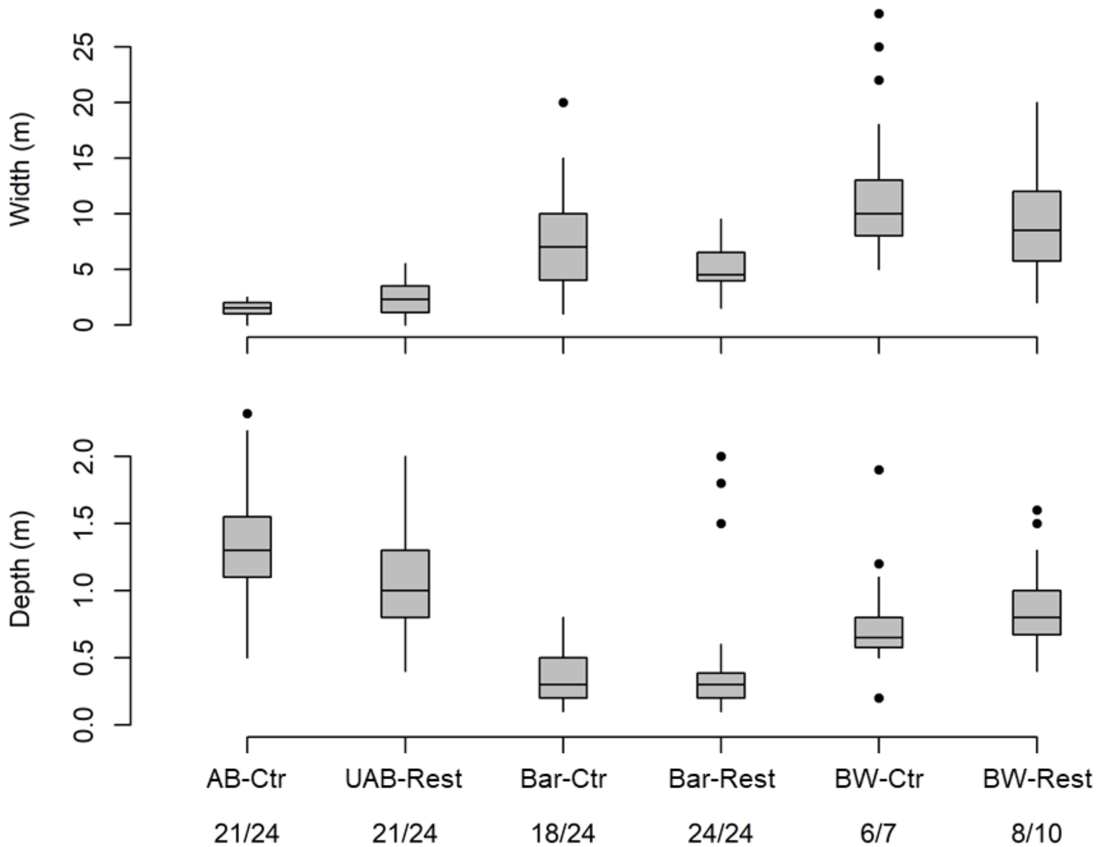

Figure D-3: Edge habitat low-velocity widths and water depths from 2018-2019 surveys of the Upper Carlson project reach. Edge-reach codes include: AB (riprap armored bank), UAB (unarmored bank), BW (backwater), Ctr (control), and Rest (restoration). Boxes indicate the first quartile, median, and third 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. The numbers at the bottom of the figure are the total transects sampled within each edge type-reach grouping (width/depth).

What were juvenile salmonid observations, and are juvenile salmonids abundances among project-related edge habitats greater than abundances among riprap armored banks?

A total of 1,387 fish from 16 different species were observed in the Upper Carlson project reach between 2016 and 2019 (Table D-1). The fork length frequencies of juvenile Chinook and coho salmon as well as rainbow trout indicated that multiple life-history types were present during project monitoring. Earlier in the season (Feb–Apr) we observed a cohort of smaller sub-yearling Chinook (hatched that winter) as well as a cohort of larger yearling Chinook (hatched the prior year) (Figure D-4). These two cohorts are indicated by the bimodal peaks in fork length frequencies during Feb–Apr, with the shorter fork lengths representing sub-yearling Chinook and the longer fork lengths representing yearling

Chinook. Later in the season (May–Jul), we primarily observed sub-yearling Chinook; however, a few yearling Chinook were still observed (indicated by the few longer fork lengths). Earlier in the season (Feb–Apr) we observed two coho cohorts including sub-yearling and yearling coho. Similar to Chinook, these two coho cohorts are indicated by the bimodal peaks in fork length frequencies during Feb–Apr. Later in the sample season (May–Jul), we primarily observed sub-yearling coho; however, a few yearling coho were still observed (indicated by the few longer fork lengths). During both the early and later sample seasons we observed a broad range of rainbow trout fork lengths, indicating that multiple juvenile cohorts as well as adults were present in the project reach.

Table D-1: Species list and total counts for fish observed along the Upper Carlson project reach.

Species code	Common name	Scientific name	Fish Counts
CHK	Chinook salmon	*Oncorhynchus tshawytscha*	356
CHM	Chum salmon	*Oncorhynchus keta*	4
COH	Coho salmon	*Oncorhynchus kisutch*	128
COT	Sculpin (unknown)	*Cottus sp.*	451
CUT	Cutthroat trout	*Oncorhynchus clarki*	15
DAC	Dace (unknown)	*Rhinichthys sp.*	91
GSF	Green sunfish	*Lepomis cyanellus*	50
LMB	Largemouth Bass	*Micropterus salmoides*	1
LSS	Large scale sucker	*Catostomus macrocheilus*	56
MIN	Minnow (unknown)	*Cyprinidae*	2
MWF	Mountain whitefish	*Prosopium williamsoni*	36
NPM	Northern pikeminnow	*Ptychocheilus oregonensis*	11
PMM	Peamouth minnow	*Mylocheilus caurinus*	1
PSS	Pumpkinseed sunfish	*Lepomis gibbosus*	1
RBT	Rainbow trout	*Oncorhynchus mykiss*	176
STH	Steelhead trout	*Oncorhynchus mykiss*	4
TRT	Trout (unknown)		2
TSB	Three-spined stickleback	*Gasterosteus aculeatus*	2

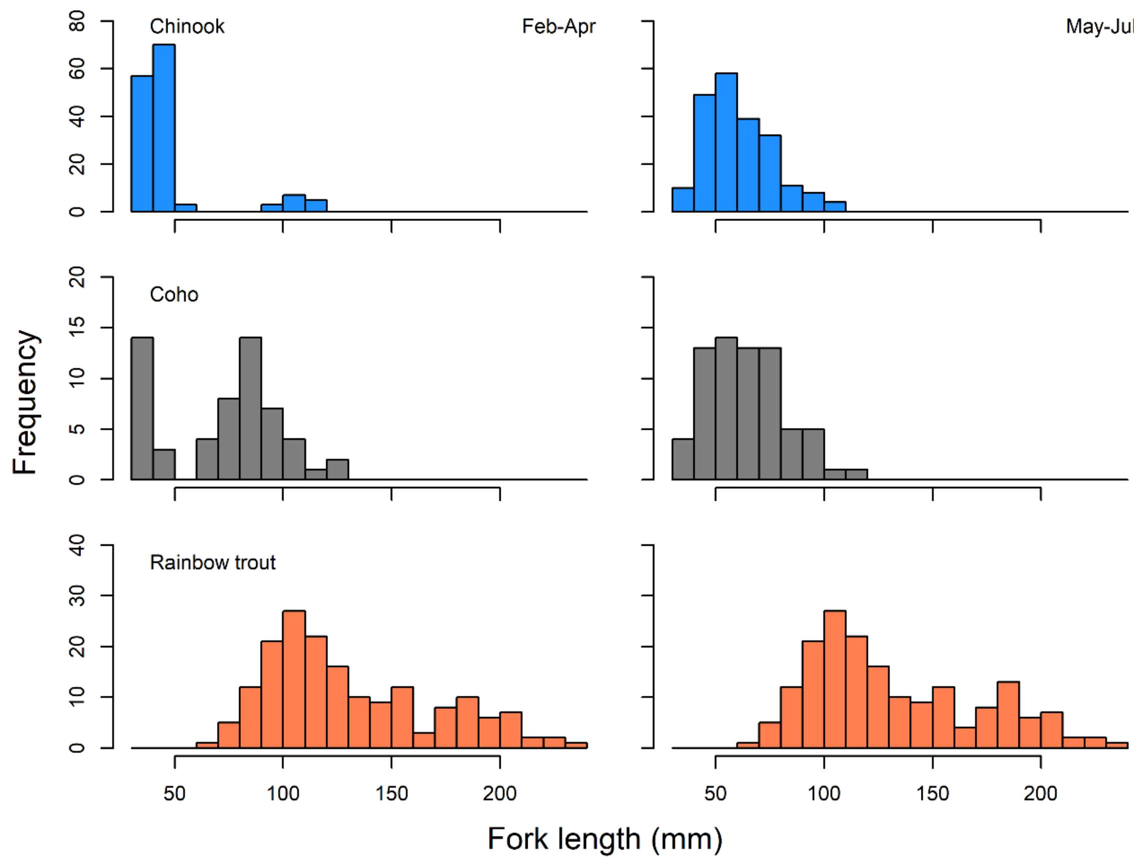

Figure D-4: Fork length frequencies of juvenile Chinook salmon, coho salmon, and rainbow trout/steelhead (*O. mykiss*) sampled during 2016-2019 from the Upper Carlson project reach.

Observations from 2016–2019 indicated that juvenile Chinook salmon were most abundant along bars and in backwaters and were less abundant along armored and unarmored banks (Figure D-5). Juvenile coho salmon generally had higher abundances in backwaters than along bars and banks. While the median abundances of Chinook and coho salmon were similar between armored control banks (AB-Ctr) and the Upper Carlson unarmored restoration bank (UAB-Rest), due to large numbers of zero-catches, both Chinook and coho salmon were observed more frequently along the unarmored restoration bank. Chinook salmon were observed in 45% of surveyed transects along the restoration bank but only in 10% of surveyed transects along riprap armored control banks. Similarly, coho salmon were observed in 41% of surveyed transects along the restoration bank but only in 27% of surveyed transects along riprap armored control banks. Rainbow trout abundance was relatively similar across edge habitat types, except for riprap armored banks and restoration backwaters where rainbow trout were less abundant. Rainbow trout were observed in 61% of surveyed transects along the restoration bank but in only 32% of transects along riprap armored control banks.

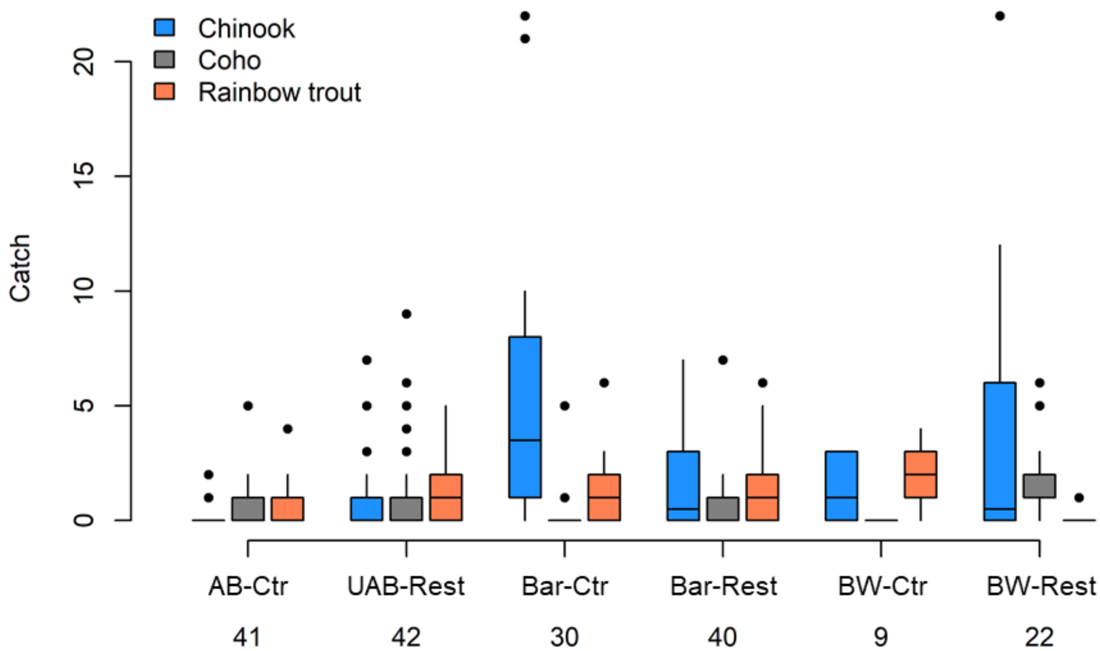

Figure D-5: Juvenile Chinook salmon, coho salmon, and rainbow trout/steelhead (O. mykiss) abundance (catch per seconds of electrofishing) among edge habitat types across the Upper Carlson project reach from 2016-2019. Edge-reach codes include: AB (riprap armored bank), UAB (unarmored bank), BW (backwater), Ctr (control), and Rest (restoration). 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. The numbers at the bottom of the figure indicate the total transects sampled within each edge type-reach grouping.

As highlighted above, the removal of the Upper Carlson revetment resulted in the formation of a gravel bar and backwater along the opposite (left) bank. These areas provide additional low-velocity habitat and the abundance of juvenile Chinook and coho along the restoration-related backwater and bar habitats (BW-Rest & Bar-Rest) were within the range of abundances observed in the control backwater and bar (BW-Ctr & Bar-Ctr). With bars and backwaters throughout the project reach displaying the highest abundances of juvenile Chinook and coho salmon, the formation of the bar and backwater across from the restoration bank as well as improved habitat conditions along the Upper Carlson restoration unarmored bank have likely improved juvenile salmon rearing conditions throughout the Upper Carlson project reach.

Observations also indicated that juvenile Chinook salmon shifted habitat use across the sample season. Juvenile Chinook appeared to use backwaters earlier in the sample season and then bars and unarmored banks later in the sample season (Figure D-6). This suggests that as juvenile salmon grow and transition through early life stages, their habitat use and distribution shifts. Additionally, these results suggest that a suite of habitat types throughout the project reach (bars, backwaters, unarmored banks, etc.) are likely important for juvenile salmon rearing.

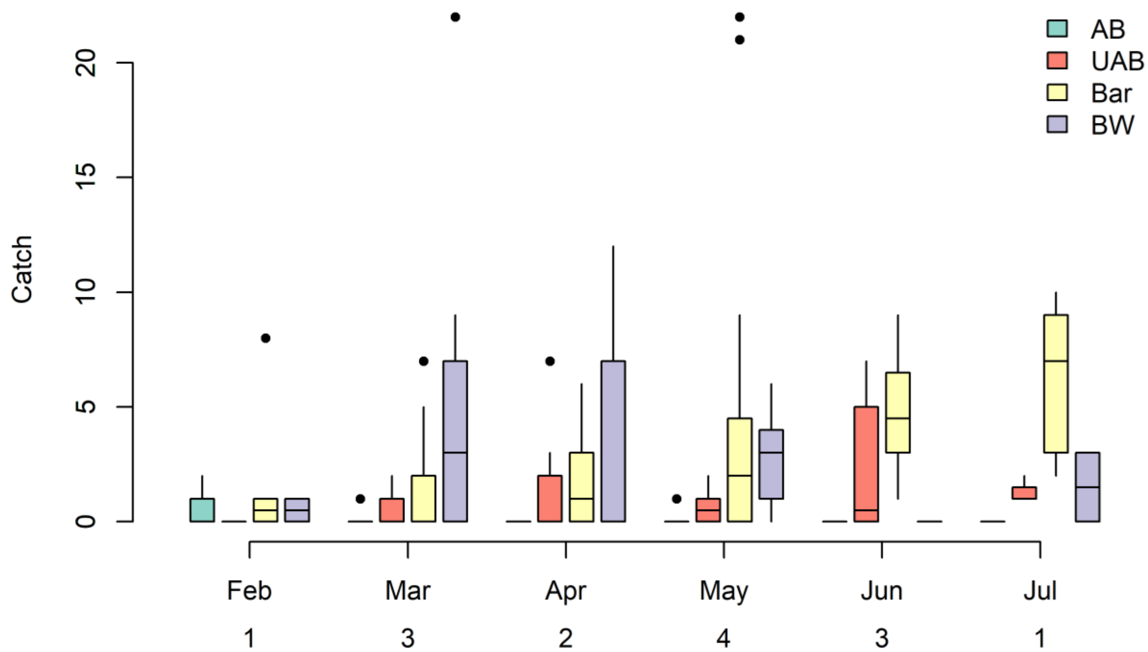

Figure D-6: Monthly juvenile Chinook salmon abundance (catch per 25m) among edge habitat types across the Upper Carlson project reach from 2016-2019. Edge-reach codes include: AB (riprap armored bank), UAB (unarmored bank), and BW (backwater). Boxes indicate the first quartile, median, and third quartile. 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. The numbers at the bottom of the figure indicate total sampling events within each month.

How did juvenile salmon and trout respond to the project?

Juvenile salmonid use of the Upper Carlson project site has likely increased over pre-project conditions. The Upper Carlson floodplain restoration project increased both the total amount of edge habitat and the types of edge habitat that support the highest abundances of juvenile salmon within the project reach. One key unknown is whether there are more fish at the project site now than before, and whether they are surviving at a higher rate. Though we surveyed fish use extensively, we cannot, and did not expect to be able to answer either of those questions. Instead, our findings allow us to confirm that a) critical habitat for juvenile salmonids has increased throughout the project area, and b) juvenile salmonids using those habitats are at relatively higher abundances compared to riprap-armored banks. In combination, these observations suggest that the project has provided valuable benefit to juvenile salmon.

Based on our observations, the project has likely benefited juvenile salmonids by improving bank conditions (Upper Carlson revetment removal) as well as by creating adjacent low-velocity edge habitat (project-related bars and backwaters). Pre-project, the Upper Carlson project bank was completely armored with riprap rock and minimal large wood was present throughout the project reach.

During post-project monitoring periods (2016–2019), the Upper Carlson treatment bank was characteristic of erodible natural floodplain alluvium with a greater abundance of large wood present and engaged with the channel. Post-project conditions have improved riverine processes (e.g., channel migration, wood recruitment, reach-scale sediment deposition, etc.), which resultingly support habitat quality and quantity in the project area. These habitat improvements are reflected in the abundance and distribution of juvenile salmon. For example, both juvenile Chinook and coho salmon were observed more frequently along the Upper Carlson project bank, compared to riprap armored control banks. Additionally, juvenile Chinook and coho salmon were also observed in relatively high abundances among treatment-related bar and backwater habitats. The improvement to bank conditions and creation of adjacent habitat areas helps to provide a suite of habitat types throughout the Upper Carlson project reach. The suite of habitat areas are likely to support various fish species as well as juvenile salmon as they grow and transition through early life stages.

Caution is needed when interpreting the overall effectiveness of the Upper Carlson restoration project. No comparable pre-project monitoring data exist to contrast with current conditions. Robust evaluation of restoration project performance requires data from both treatment and control reaches and from both before and after project implementation. Furthermore, current interpretation of the cataraft electrofishing data assumes that sampling efficiency is the same across edge habitat types, while in reality sampling efficiency likely varies among different edge habitat types. We recommend that future evaluations of restoration projects collect both pre- and post-implementation data in both treatment and control reaches. Examination of differences in sampling efficiency of the electrofishing cataraft among different edge habitat types and sampling conditions is also necessary to validate this sampling approach.

Appendix E: Tolt Pipeline Protection and Deer Creek Restoration

Data and information from King County (2015a) and King County (2019).

Where is the project and when was it completed?

The Tolt Pipeline protection and Deer Creek restoration project area (hereafter referred to as Tolt Pipeline project) is located on the Snoqualmie River around RM 13 downstream of the NE 124th Street Bridge crossing (Figure E-1). The project was completed in 2018.

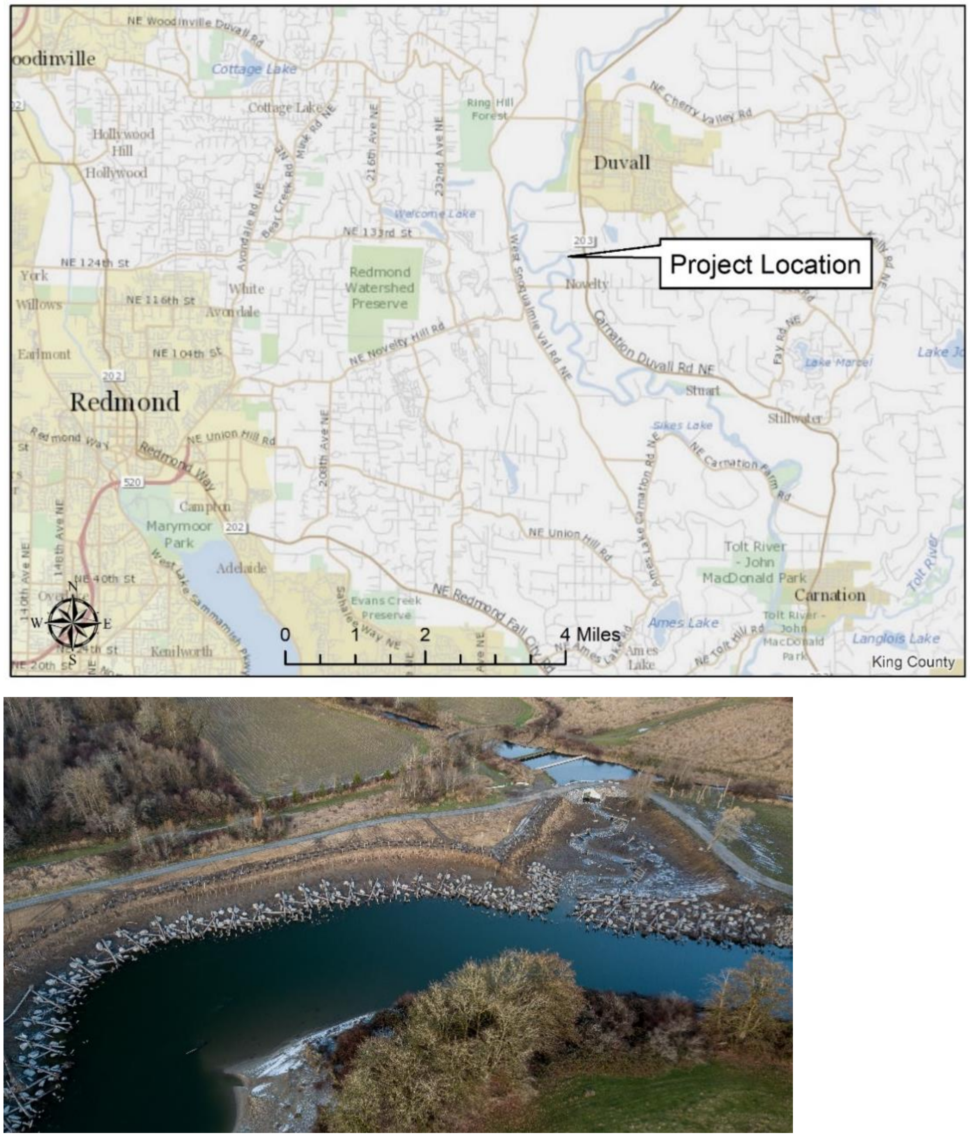

Figure E-1: Top panel showing the vicinity of the Tolt Pipeline protection and Deer Creek Restoration project. Bottom panel is an oblique aerial photo of the project.

What was the purpose?

- Reconstruct approximately 1,200 linear feet of the Winkelman revetment, protecting the City of Seattle's Tolt Pipeline. This project provides regional benefits by protecting the Tolt Pipeline, which carries approximately 30% of the City of Seattle's water supply source.
- Provide improved aquatic edge habitat complexity and areas of slow water refuge through integration of large wood jacks and jams into the bioengineered revetment. Reconnect and improve lower Deer Creek.

What actions were taken?

- Reconstruction of about 1,200 feet of revetment with the new revetment including riprap at the deepest parts of a scour hole as well as about 700 ballasted wood jacks and 60 engineered log jams throughout revetment (wood jacks and log jams were included to create edge habitats for fish).
- Reconnected Deer Creek to the Snoqualmie River by replacing a crushed culvert with a set-back regulated flap-gate and boxed culvert.
- Restored lower Deer Creek through creation of a floodplain alcove, channel meandering, and large wood arrays.
- Re-vegetation of banks and upland areas.

What were the goal(s) specific to aquatic habitats and juvenile salmonids?

Goal: Improved aquatic edge habitat complexity, areas of slow water refuge, and juvenile salmon rearing habitat.

Performance Measure/Indicator:
- Edge habitat characteristics
- Juvenile salmonid presence and relative abundance (compared to riprap armored banks)

Goal: Reconnect and improve lower Deer Creek

Performance Measure/Indicator:
- Juvenile salmonid presence

What were aquatic habitat and juvenile salmonid observations?

What are the edge habitat characteristics across the project reach?

Measurements across project transects surveyed from 2016–2019 (refer to Figure E-2) indicated that bars had considerably shallower depths compared to unarmored banks and armored banks (Figure E-3). Additionally, control-reach bars generally had wider low-velocity edge habitat areas compared to unarmored and armored banks. Bars are depositional areas with relatively low gradients, which typically support larger low-velocity areas compared to banks. Along the Tolt Pipeline project reach, armored and unarmored banks appeared to have similar width and depth characteristics with relatively smaller low-velocity areas. Low-velocity edge widths were negatively related to river flow (Figure E-4). As flows increased, the shear line between low-velocity edge areas and mid-channel areas often shifted towards the channel's edge. Additionally, as flows increased and bar areas became inundated, the low-velocity areas shifted from the lower-gradient toe of bars towards the higher-gradient extent along the channel's edge. When comparing pre- and post-project edge habitat conditions, it appears that the project may have increased low-velocity width and depth along the bioengineered revetment treatment bank (AB-Trt) (Figure E-5). These observations suggest that the bank treatment may have increased low-velocity edge habitat area adjacent to the project. However, flows during year 1 of post-project monitoring (average = 1945 cfs) were considerably lower than flows observed during pre-project monitoring (average = 3898 cfs). The lower flows observed during post-project monitoring resulted in generally wider low-velocity edge widths across all edge habitat types (compared to pre-project widths), suggesting that the increases in low-velocity edge width at the treatment bank may in-part be due to low flow conditions in addition to the project treatment. Additional years of post-project monitoring, across a range of flows, will help in fully evaluating how the bank treatment has influenced low-velocity habitat areas along the project reach.

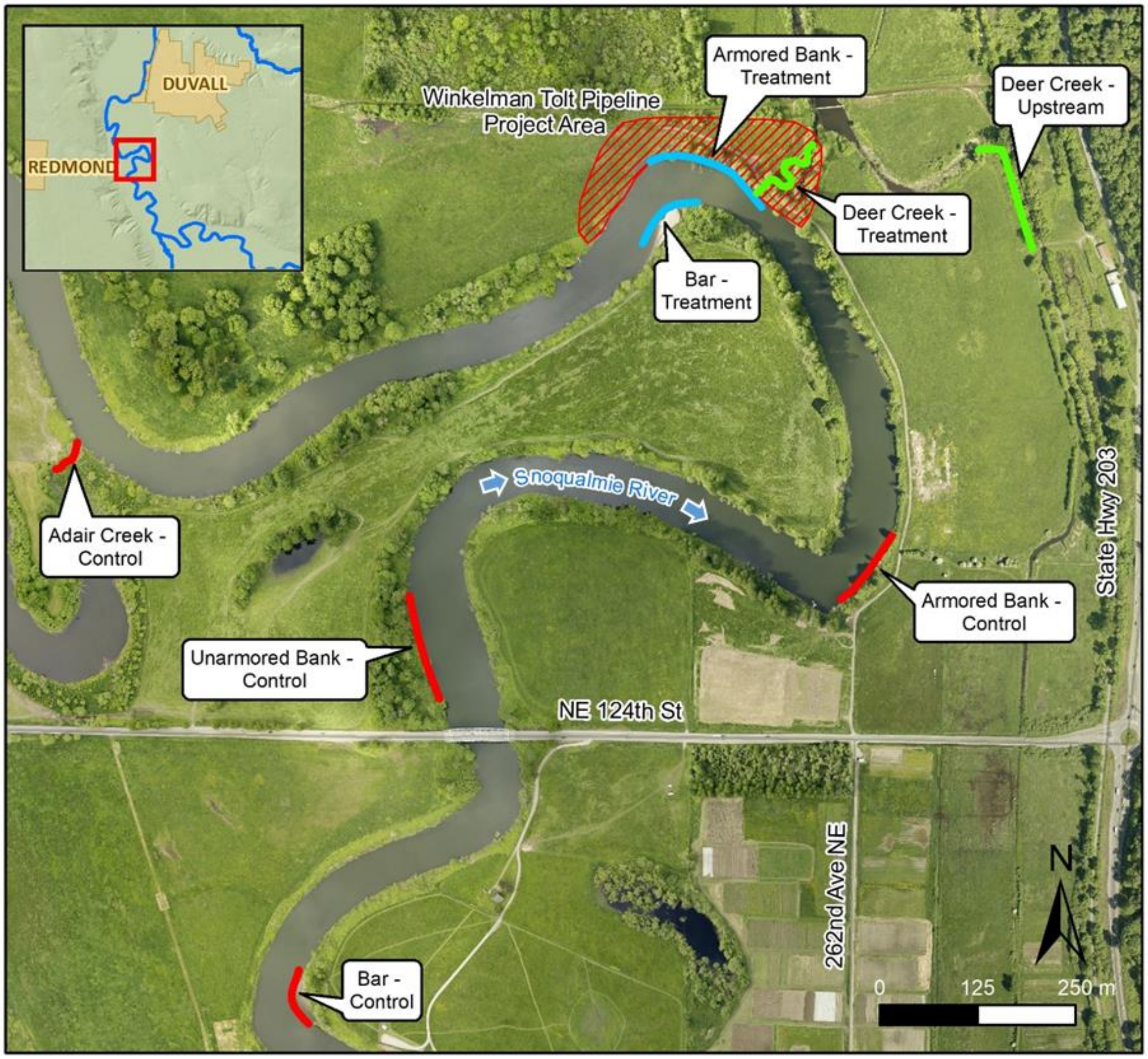

Figure E-2: Winkelman Tolt Pipeline survey transect areas located on the Snoqualmie River. Aerial photo from 2017.

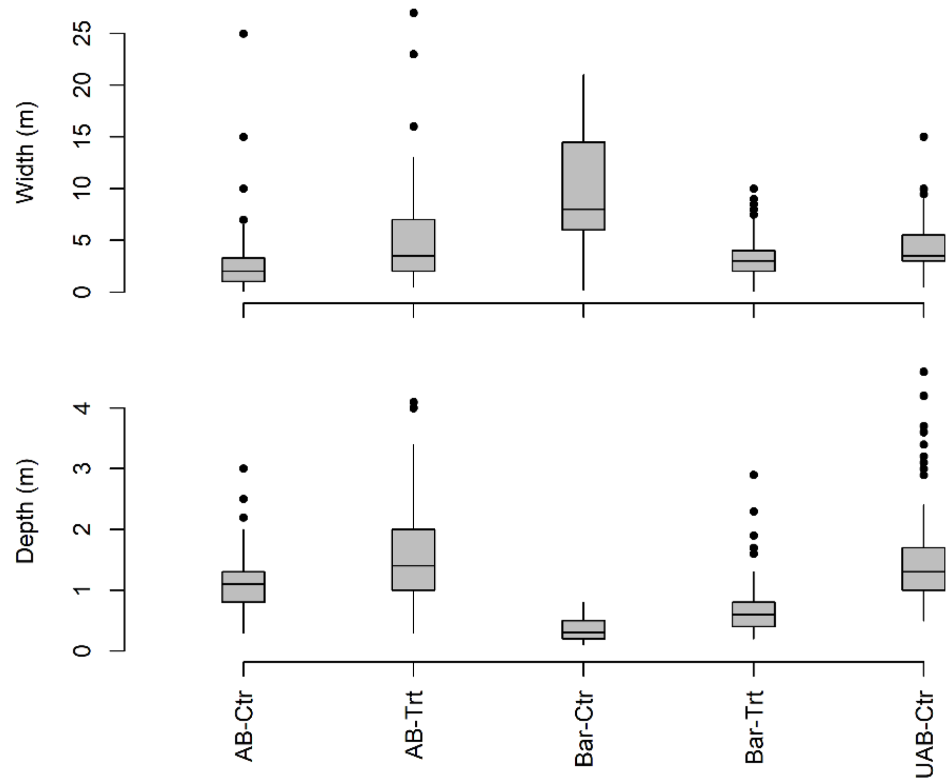

Figure E-3: Edge habitat widths and depths from surveys conducted during 2016-2019 for the Winkelman Tolt Pipeline project reach. Habitat codes include AB (riprap armored bank), UAB (unarmored bank), Ctr (control), and Trt (treatment - bioengineered revetment or indirectly influenced habitat). Boxes 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.

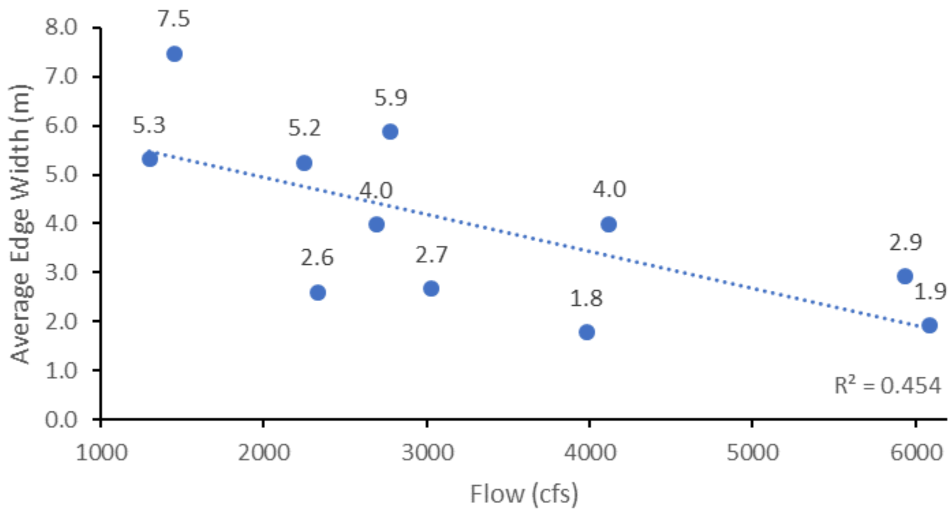

Figure E-4: Average edge habitat low-velocity width (all edge types combined) as a function of sample event flows. Flows downloaded from USGS 12149000 in Carnation, WA.

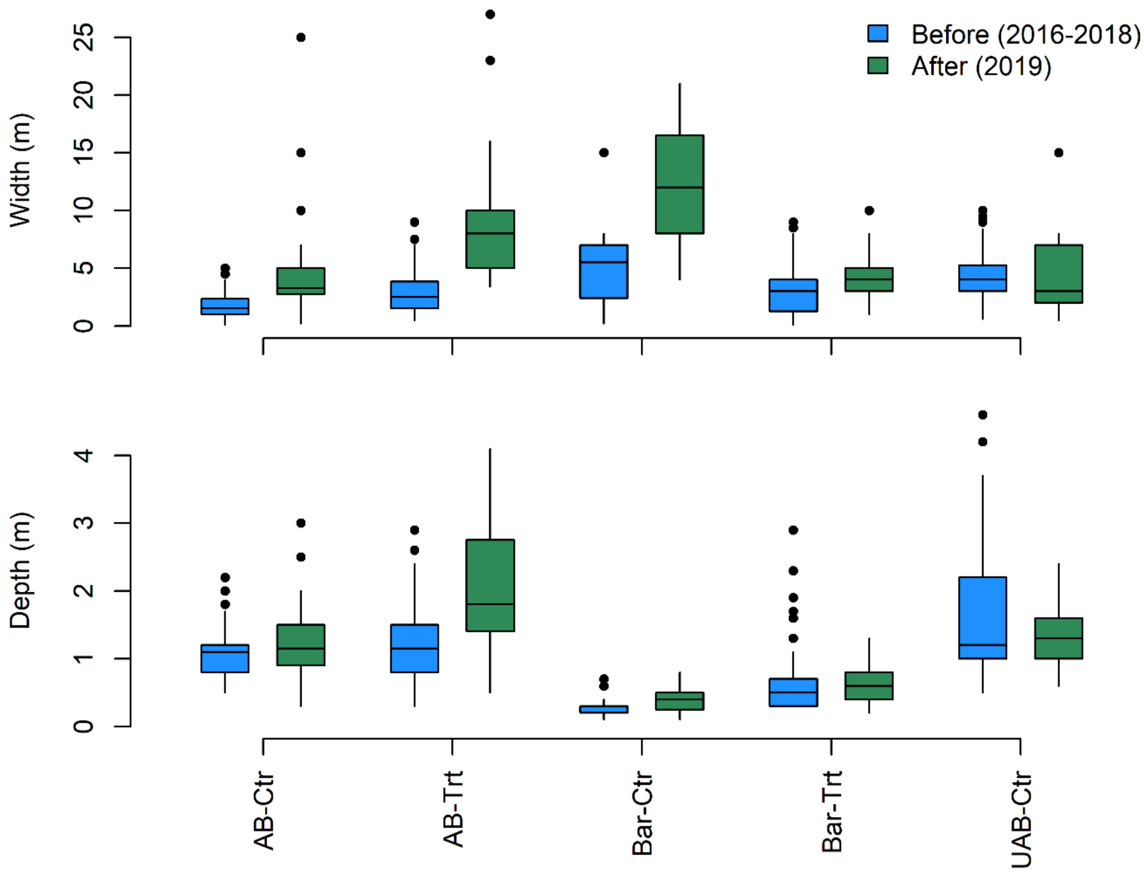

Figure E-5: Pre- and post-project edge habitat widths and depths from surveys conducted during 2016-2019 for the Winkelman Tolt Pipeline project reach. Habitat codes include AB (riprap armored bank), UAB (unarmored bank), Ctr (control), and Trt (treatment - bioengineered revetment or indirectly influenced habita). 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.

What were juvenile salmonid observations?

From 2016-2019, monitoring efforts throughout the Tolt Pipeline project reach observed a total of 1,943 fish among 22 different species (Table E-1). Specific to juvenile salmon, 402 Chinook, 16 chum, and 210 coho were sampled.

Table E-1: Species list and total counts for fish observed along the Tolt Pipeline project reach (including mainstem and tributary areas).

Species code	Common name	Scientific name	Overall Fish Counts	
			Mainstem Snoqualmie River	Tributaries
BBH	Brown bullhead	*Ameiurus nebulosus*	1	1
BCP	Black crappie	*Pomoxis nigromaculatus*	1	2
BGS	Bluegill sunfish	*Lepomis macrochirus*	2	
CHK	Chinook salmon	*Oncorhynchus tshawytscha*	341	61
CHM	Chum salmon	*Oncorhynchus keta*	3	13
COH	Coho salmon	*Oncorhynchus kisutch*	80	130
COT	Sculpin (unknown)	*Cottus sp.*	593	8
CUT	Cutthroat trout	*Oncorhynchus clarki*	5	7
DAC	Dace (unknown)	*Rhinichthys sp.*	5	135
GSF	Green sunfish	*Lepomis cyanellus*	12	20
LAM	Lamprey (unknown)		Not counted	
LSS	Large scale sucker	*Catostomus macrocheilus*	63	25
MIN	Minnow (unknown)	*Cyprinidae*	3	8
MWF	Mountain whitefish	*Prosopium williamsoni*	17	
NPM	Northern pikeminnow	*Ptychocheilus oregonensis*	15	20
PMM	Peamouth minnow	*Mylocheilus caurinus*	142	25
PSS	Pumpkinseed sunfish	*Lepomis gibbosus*	2	57
RBT	Rainbow trout	*Oncorhynchus mykiss*	49	
RSS	Redside shiner	*Richardsonius balteatus*		1
SMB	Smallmouth bass	*Micropterus dolomieu*		1
TRT	Trout (unknown)		1	
TSB	Three-spined stickleback	*Gasterosteus aculeatus*	11	81
YLP	Yellow perch	*Perca flavescens*	2	

Among juvenile Chinook and coho salmon, the frequencies of fork lengths indicated that multiple life-history types were observed during project monitoring. Across the mainstem Snoqualmie transect reaches, earlier in the season (Feb–Apr) we observed a cohort of smaller sub-yearling Chinook (hatched that winter) as well as a cohort of larger yearling Chinook (hatched the prior year) (Figure E-6). These two cohorts are indicated by the bimodal peaks in fork length frequencies during Feb-Apr, with the peak in shorter fork lengths indicating sub-yearling Chinook and the peak in longer fork lengths indicating

yearling Chinook. Later in the season (May–Jul), we only observed sub-yearling Chinook; however, this later-season cohort was significantly more abundant than the early season cohort. Earlier in the season (Feb–Apr) we primarily observed yearling coho and later in the season (May–Jul) we observed a combination of sub-yearling and yearling coho. Similar to Chinook, the bimodal peaks in coho fork length frequencies (observed later in the sample season) indicated that two cohorts were present.

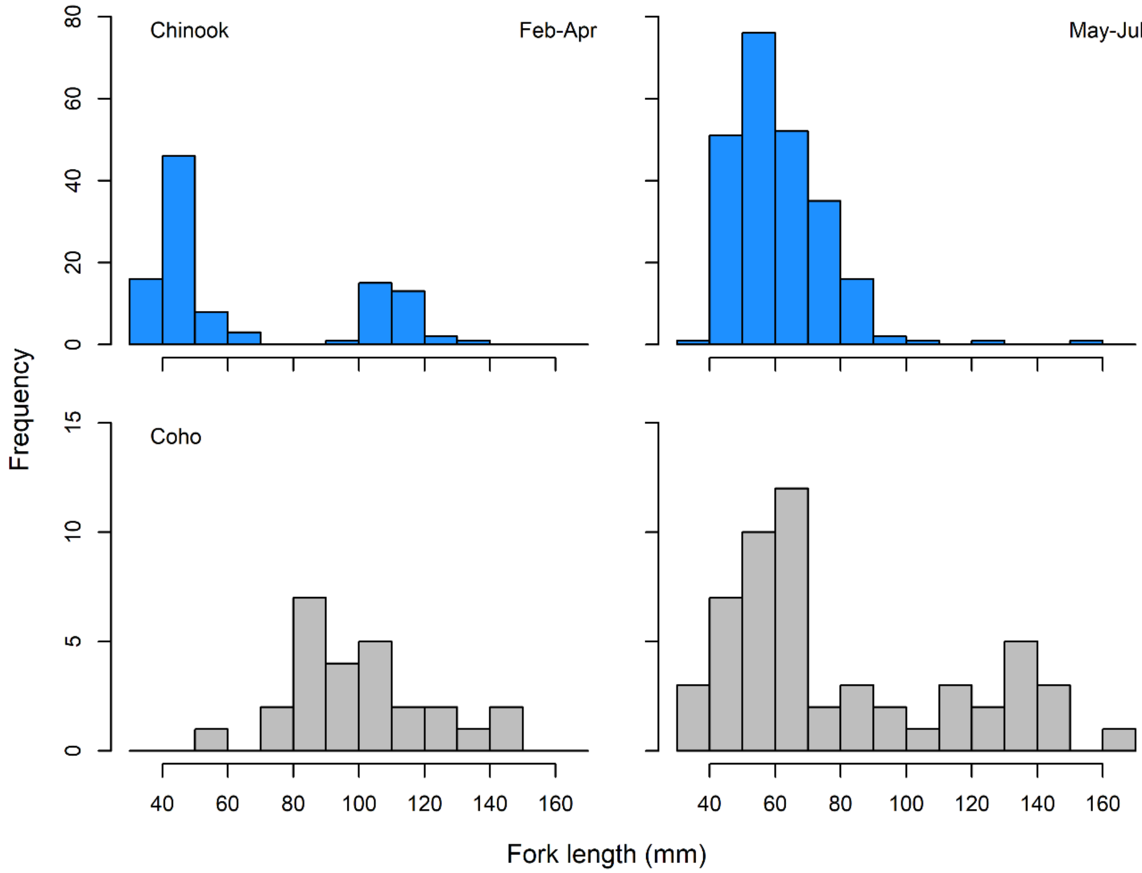

Figure E-6: Fork length frequencies of juvenile Chinook and coho salmon sampled from 2016–2019 throughout the mainstem Tolt Pipeline project reach.

Among the sampled tributaries, we only observed sub-yearling juvenile Chinook early in the sample season (Feb–Apr) and did not observe any yearling Chinook (Figure E-7). The majority of these tributary sub-yearling Chinook were found in the restored Deer Creek channel from the confluence with the Snoqualmie River upstream to the flap gate (discussed below). Earlier in the sample season (Feb–Apr) we observed both sub-yearling and yearling coho (indicated by the bimodal peaks in fork lengths) and later in the sample season (May–Jul) we only observed sub-yearling coho.

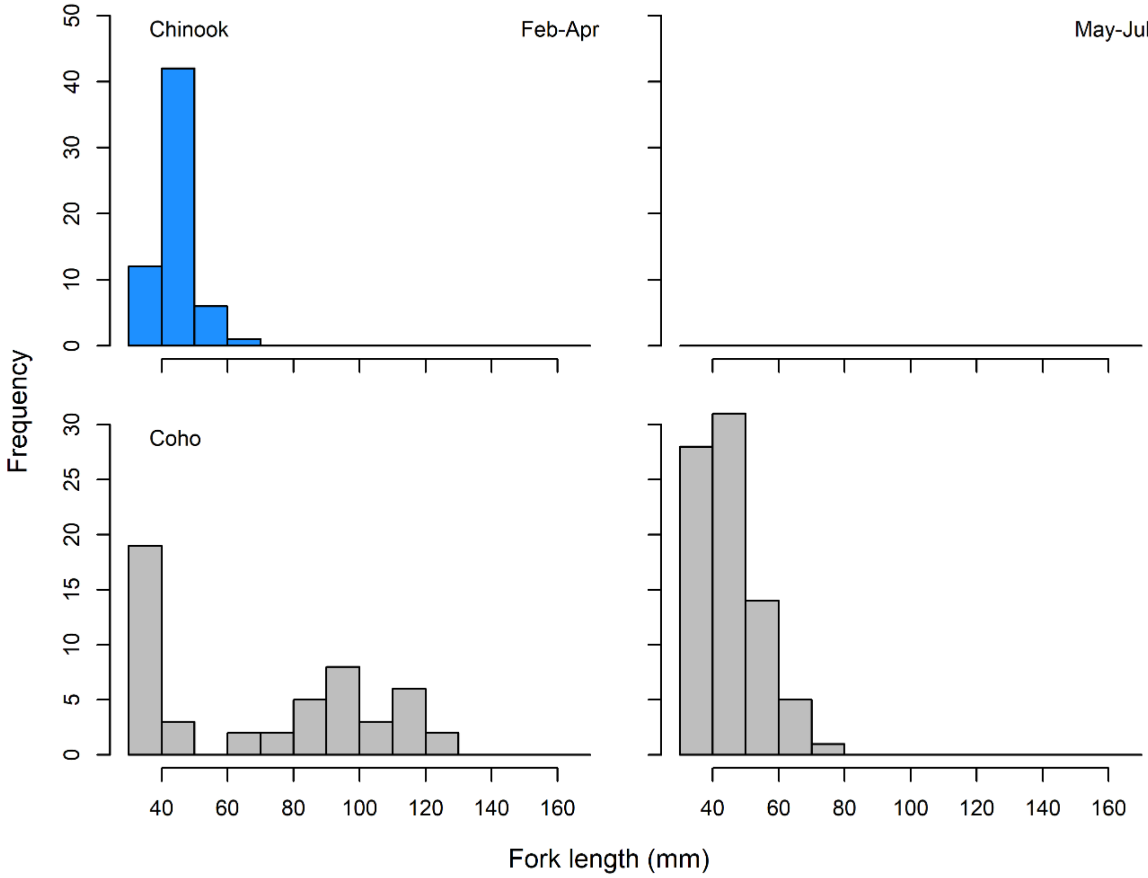

Figure E-7: Fork length frequencies of juvenile Chinook and coho salmon sampled from 2016-2019 within the Tolt Pipeline project reach tributaries.

Are juvenile salmonids using mainstem project-related edge habitats?

Pre-project observations (2016–2018) suggested that juvenile Chinook were most abundant along bars and less abundant along armored and unarmored banks (Figure E-8). Juvenile coho appeared to have relatively low abundances pre-project across most edge habitat types with most coho found on the project treatment bank (AB-Trt) as well as the control bar (Bar-Ctr). Relatively few juvenile Chinook and coho salmon were observed along the project treatment bank (AB-Trt) prior to project construction.

It is important to note that the unarmored bank that was sampled had a large amount of overhanging vegetation along the channel's edge. This limited our ability to sample right up against the channel edge and resulted in sampling occurring further away in deeper areas of the channel. The benefits of overhanging vegetation for juvenile salmon rearing and refuge has been well-documented across river systems, thus our observations of low fish abundances among unarmored banks may be due to sampling limitations.

The first year of post-project monitoring (2019) indicated that juvenile Chinook were still more abundant in bar habitats compared to armored and unarmored banks. Abundances along bars were not as high as before the project, highlighting inter-annual variation in juvenile production within the Snoqualmie River as well as the need for multiple years of post-project monitoring to fully represent habitat-specific salmon abundances. Specific to the project treatment bank (AB-Trt), juvenile coho had greater abundance along the treatment bank compared to control armored and unarmored banks. Furthermore, the abundance of juvenile coho was greater among the project treatment bank compared to all other edge habitat types. Juvenile Chinook had slightly higher abundance along the treatment bank compared to control armored and unarmored banks; however, the treatment effect for Chinook was considerably lower than that of coho.

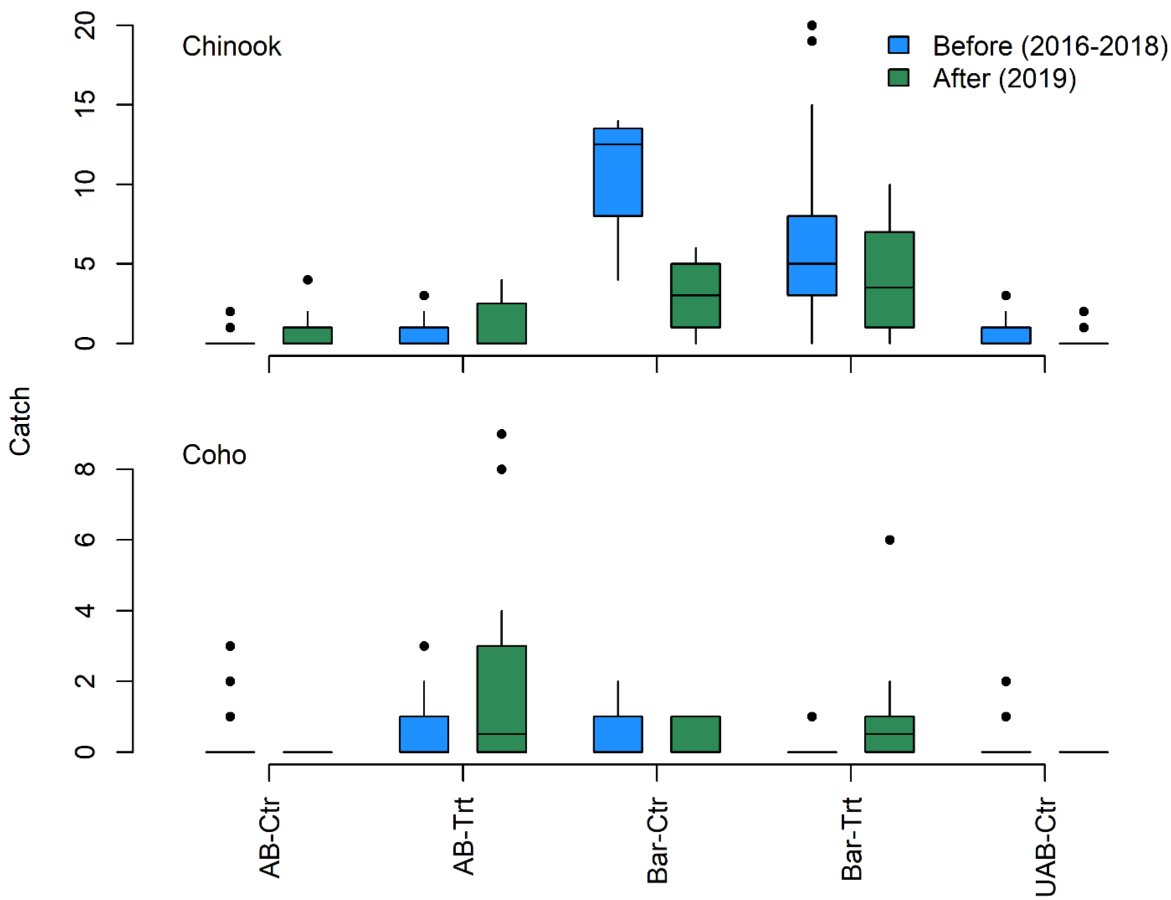

Figure E-8: Juvenile Chinook and coho abundance (catch per 25m) among edge habitat types before and after project construction across the Winkelman Tolt Pipeline project reach. Edge-reach habitat codes include: AB (riprap armored bank), UAB (unarmored bank), Ctr (control), Trt (treatment–bioengineered revetment or indirectly influenced habitat). 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.

When comparing individual transects along the project treatment bank (Figure E-9), most of the increases in juvenile Chinook and coho abundance appeared to be associated with the Deer Creek confluence (Trt-1) (Figure E-10). This transect ran along the area where Deer Creek joined the Snoqualmie River and supported the highest abundance of juvenile Chinook and coho across the treatment bank transects. These observations highlight the benefits of confluence restoration and suggest that overall improvements in edge habitat conditions along the project treatment bank are highly influenced by these confluence conditions.

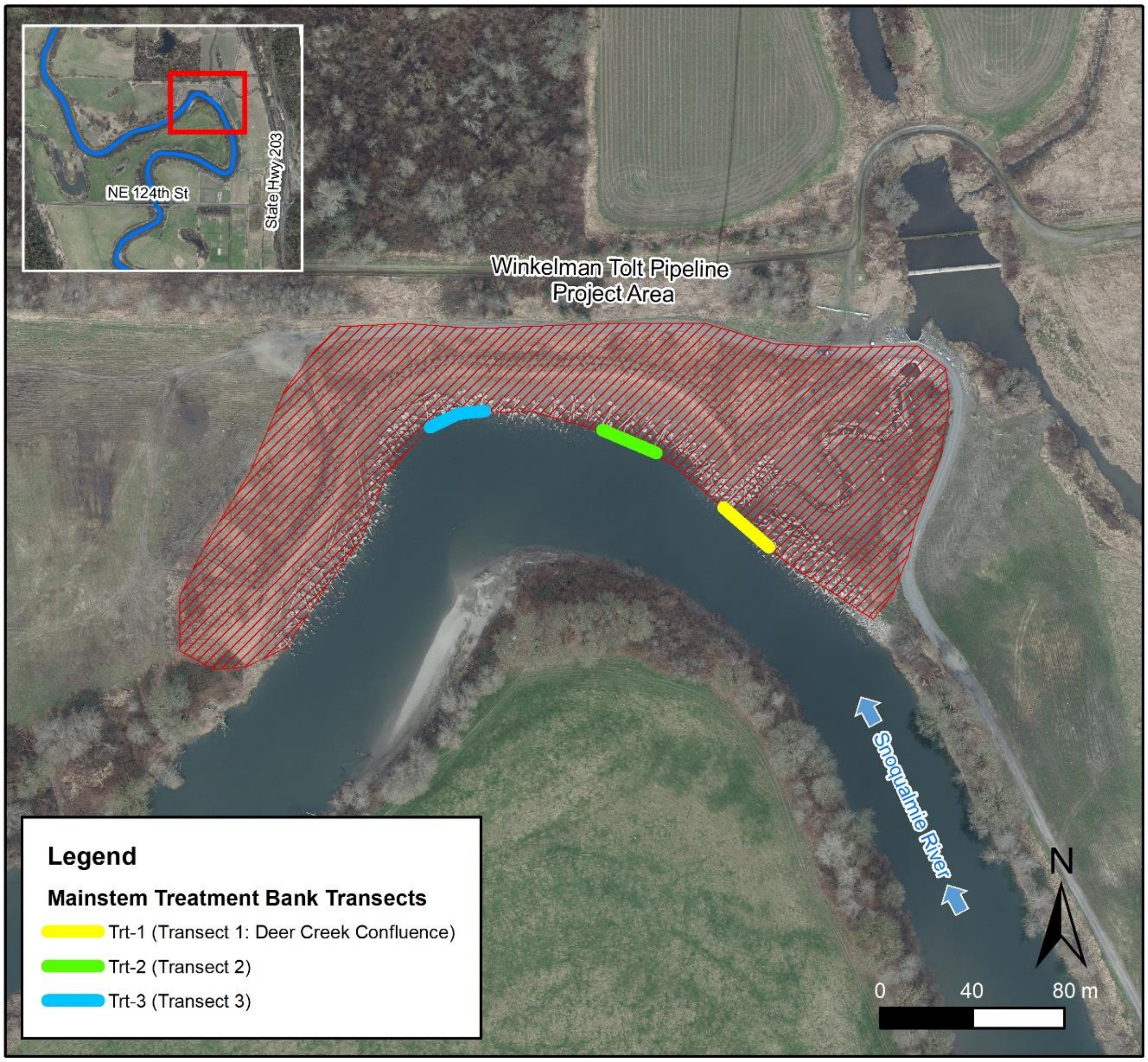

Figure E-9: Bioengineered revetment treatment bank transects (Trt) along the Tolt Pipeline project on the mainstem Snoqualmie River.

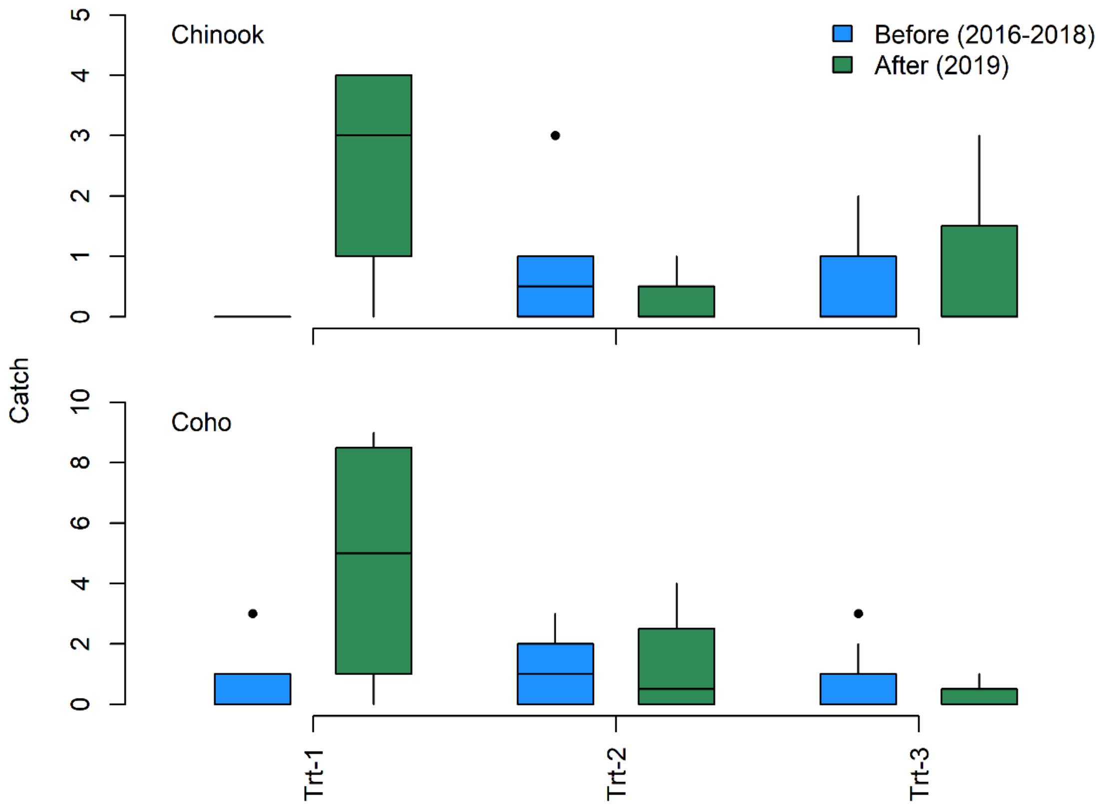

Figure E-10: Juvenile Chinook and coho abundance (catch per 25m) among bioengineered revetment treatment bank transects before and after project construction. Treatment bank transect codes include: Trt-1 (Deer Creek confluence transect), Trt-2 (treatment transect 2), Trt-3 (treatment transect 3). Boxes 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.

Are juvenile salmonid using habitats in lower Deer Creek?

Pre-project observations (2016–2018) indicated that juvenile Chinook salmon were only observed at Adair Creek (control) and at the mouth of Deer Creek (Figure E-11). The culvert upstream of the Deer Creek/Snoqualmie River confluence was crushed prior to project construction, which may have prevented juvenile Chinook access to upstream reaches of Deer Creek. Juvenile coho were found in Adair and throughout Deer Creek before project construction; however, abundances were generally low among sample transects (average of 0–1 fish per transect). Deer Creek supports adult coho spawning and during flood events becomes connected with the mainstem Snoqualmie River, which may indicate why juvenile coho were found throughout Deer Creek prior to project construction.

The first year of post-project monitoring (2019) indicated that juvenile Chinook and coho salmon abundances were relatively higher throughout Deer Creek, compared to pre-project

periods (Figure E-11). Specifically, during pre-project monitoring, a total of 6 juvenile Chinook and 26 juvenile coho salmon were observed throughout Deer Creek. During post-project monitoring, a total of 28 juvenile Chinook and 87 juvenile coho salmon were observed throughout Deer Creek. The increase in juvenile Chinook and coho presence throughout Deer Creek suggest that replacing the crushed culvert and restoring the lower Deer Creek channel increased juvenile salmon use and distribution. Post-project monitoring also observed juvenile Chinook upstream of the wetland pond (Deer - US), which were not observed along that reach during pre-project monitoring efforts. Adair Creek (control) also had relatively higher Chinook and coho abundances during post-project periods, which further highlights inter-annual variation in juvenile production and the importance of multi-year project monitoring. Collectively, these tributary observations in addition to mainstem observations suggest that improving the connectivity to Deer Creek as well as restoring habitat areas within Deer Creek has increased tributary habitat access and juvenile salmon use.

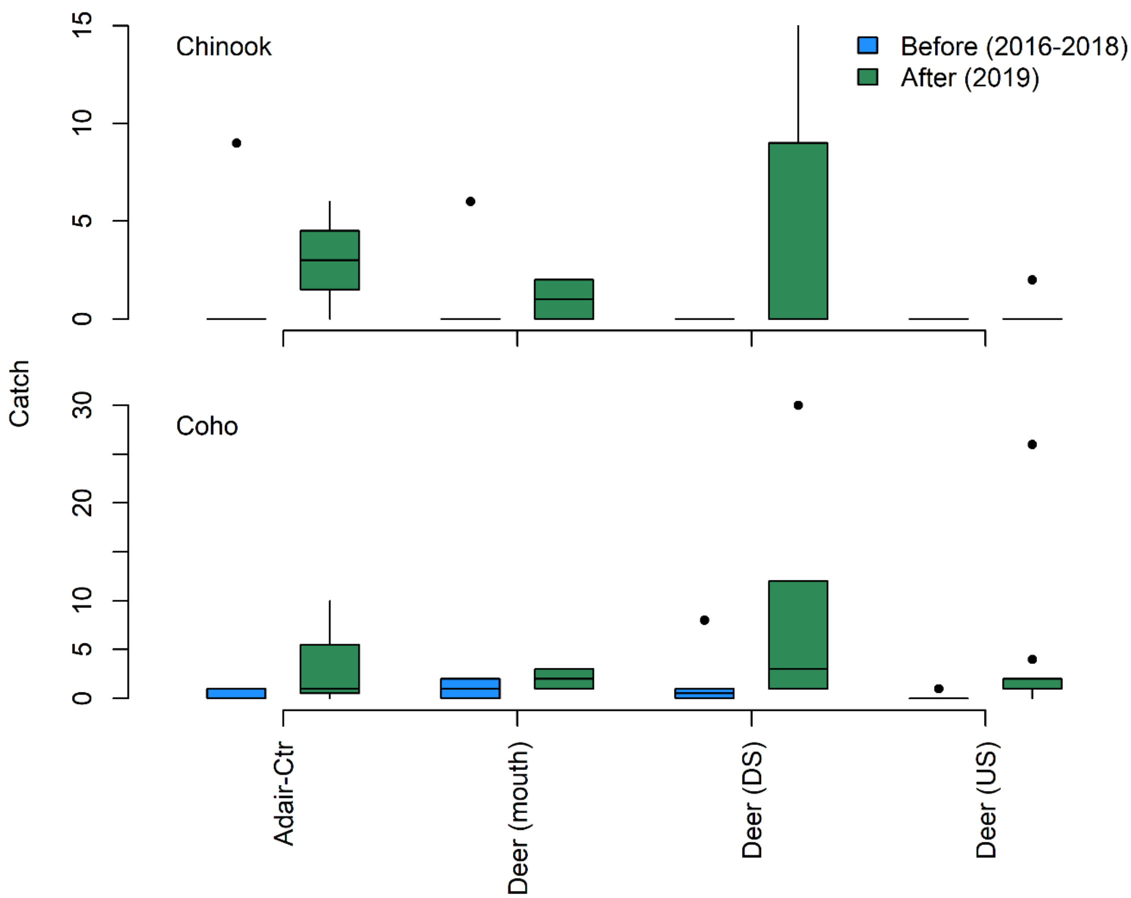

Figure E-11: Juvenile Chinook and coho abundance (catch per transect) within Adair Creek and Deer Creek before and after project construction. Tributary habitat codes include: Ctr (Control), mouth (confluence of Deer Creek with the Snoqualmie River), DS (Deer Creek downstream from the wetland pond), and US (Deer Creek upstream of the wetland pond). 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.

Observations across pre- and post-project monitoring suggests that consideration of interactions among habitat areas may be important when evaluating project benefits and habitat improvements. For example, as previously discussed, the majority of juvenile Chinook and coho observed along the post-project treatment bank were associated with the Deer Creek confluence. The improved connectivity and restoration of the adjacent tributary likely had a positive impact on the performance of the treatment bank. Additionally, the bar across the channel from the project area consistently had a high abundance of juvenile salmon and supported the majority of salmon found in the project reach. This suggests that a suite of habitat types (bars, tributary confluences, banks, etc.) throughout the project reach are likely important for juvenile salmon rearing. Understanding how a project influences adjacent habitat area, as well as reach-scale hydraulic and sediment processes, may help in evaluating project-related impacts and benefits. The long-term potential for the Winkelman Tolt Pipeline project to support juvenile salmon rearing and refuge is likely dependent on the project's ability to maintain mainstem and tributary habitat areas, the connectivity of adjacent tributaries, as well as the suite of edge habitat types along the project reach.

Appendix F: Sinnema Quaale SR-203 and Snoqualmie Trail Protection

Data and information from King County (2015b) and King County (2017c).

Where is the project and when was it completed?

The Sinnema Quaale SR-203 and Snoqualmie Trail protection project (hereafter referred to as the Sinnema Quaale project) is located on the Snoqualmie River around RM 18 (~1.5 miles upstream of Ames Creek) (Figure F-1). The project was completed in 2016.

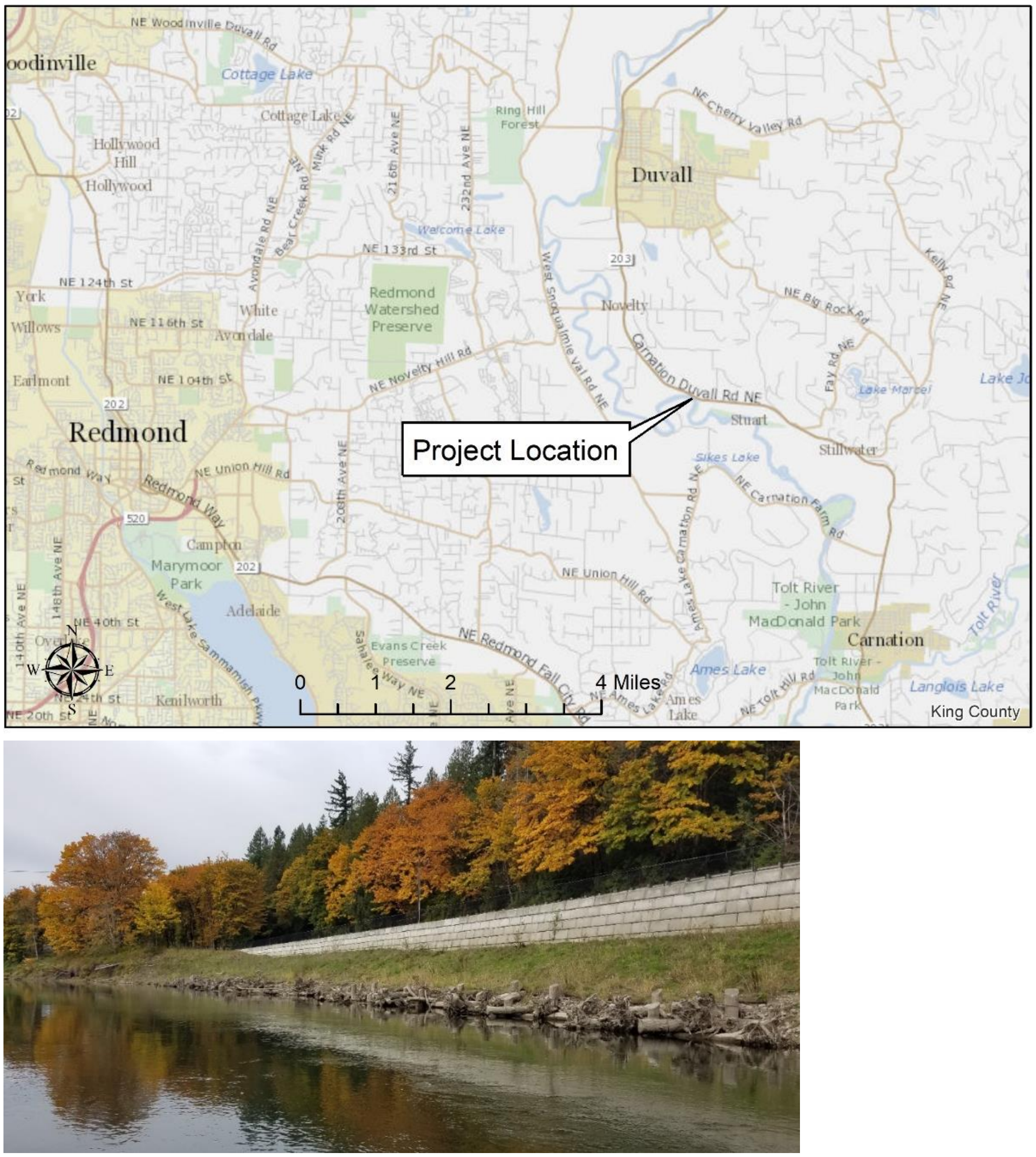

Figure F-1: **Top panel showing the vicinity of the Sinnema Quaale SR-203 and Snoqualmie Trail Protection project.**

What was the purpose?

- Reduce risks to Snoqualmie Valley Trail, State Highway 203, and fiberoptic lines from channel migration hazards.
- Avoid or minimize environmental impacts of flood hazard management
- Provide improved aquatic edge habitat complexity through integration of large wood structures into the bioengineered revetment.
- Reduce the long-term maintenance needs and costs of flood hazard management.

What actions were taken?

- Reconstructed approximately 750 feet of bank revetment (bioengineered revetment) to protect the Snoqualmie Valley Trail and State Highway 203 from ongoing bank erosion and slope instability.
- Bioengineered revetment used large wood structures to stabilize bank and increase edge habitat complexity.
- Re-vegetated banks and upland areas.

What were the goal(s) specific to mainstem aquatic habitats and juvenile salmonids?

Goal: Improved aquatic edge habitat complexity and juvenile salmon rearing habitat.

Performance Measure/Indicator:
- Edge habitat characteristics
- Juvenile salmonid presence and relative abundance (compared to riprap armored banks)

What were mainstem aquatic habitat and juvenile salmonid observations?

What are the edge habitat characteristics across the project reach?

Measurements across project transects surveyed from 2016–2019 (refer to Figure F-2) indicated that both control and treatment sand bar habitats were found to have significantly shallower depths than riprap control habitats ($P<0.001$) (Figure F-3). Mean depth at the engineered log structure edge habitats (bioengineered revetment) were comparable to the natural bank habitats (unarmored bank), which had mean depths less than riprap control habitats, but greater than sand bar habitats. Both reference and treatment sand bar habitats had significantly shallower depths than the riprap control habitats (similarly, the reference-control and treatment sand bar habitats had significantly greater Chinook CPUE than the riprap control habitats).

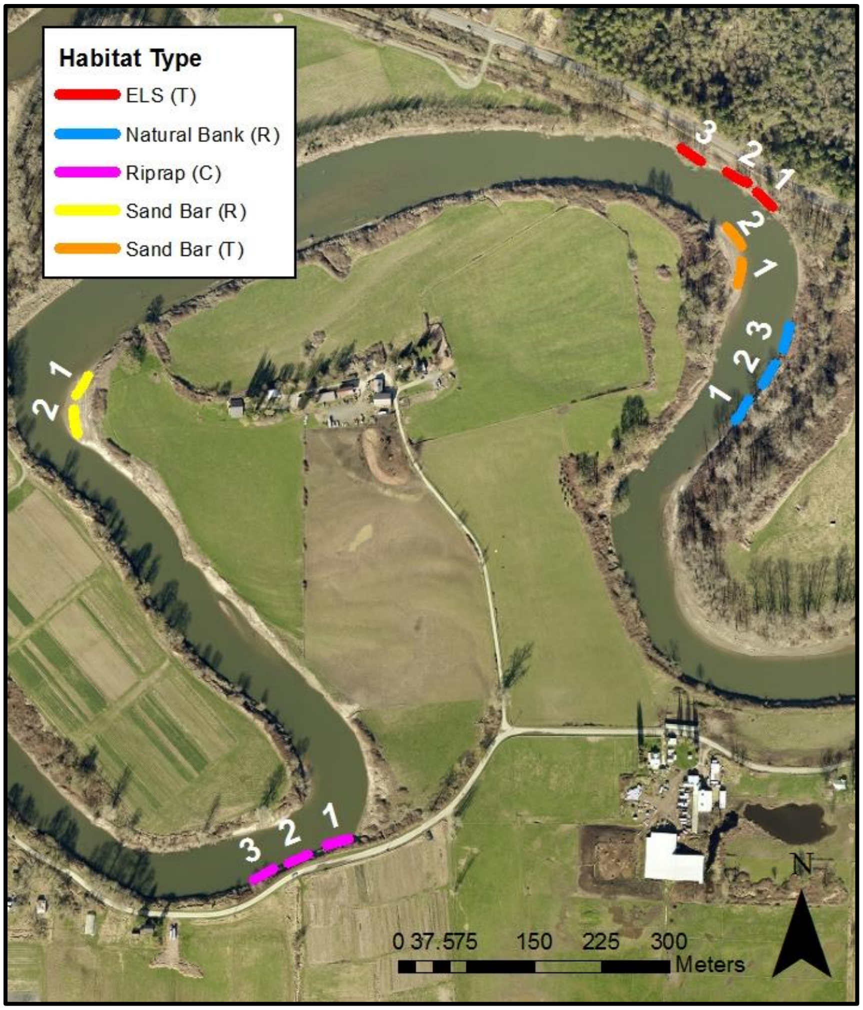

Figure F-2: Sinnema Quaale survey transect areas located on the Snoqualmie River. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat).

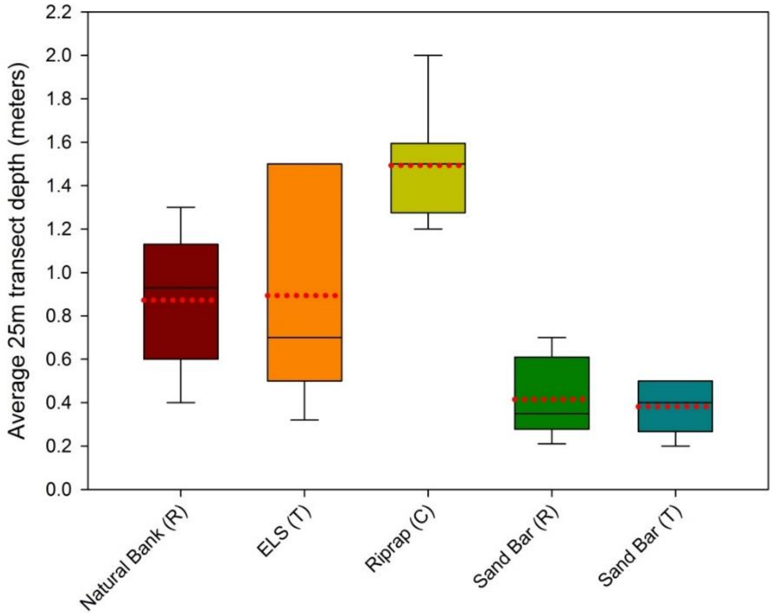

Figure F-3: Average depth (m) from a minimum of 3 points within 25m transects during all events in 2017. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

Across flows, low velocity edge habitat extent was greater among bars and engineered log structures (bioengineered revetment) (Figure F-4). Both engineered log structures (bioengineered revetment) and sand bar reference-controls were found to have significantly more edge habitat than the natural bank reference habitats (unarmored banks) (P=0.002) (Figure F-5). While not significant, the engineered log structures (bioengineered revetment) appeared to provide relatively more low velocity edge habitat compared to riprap armored control banks.

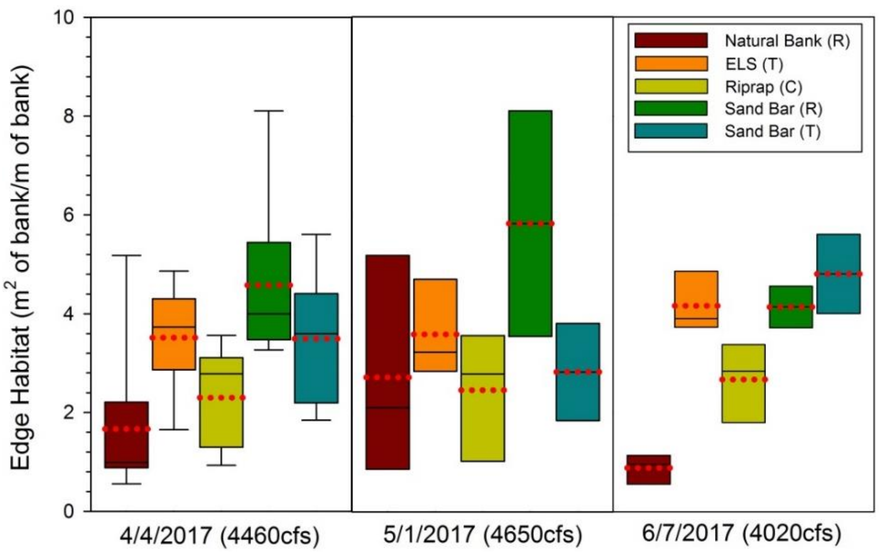

Figure F-4: Low velocity edge habitat (<0.45m/s) measured within the 25m transects during three sampling events in 2017. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

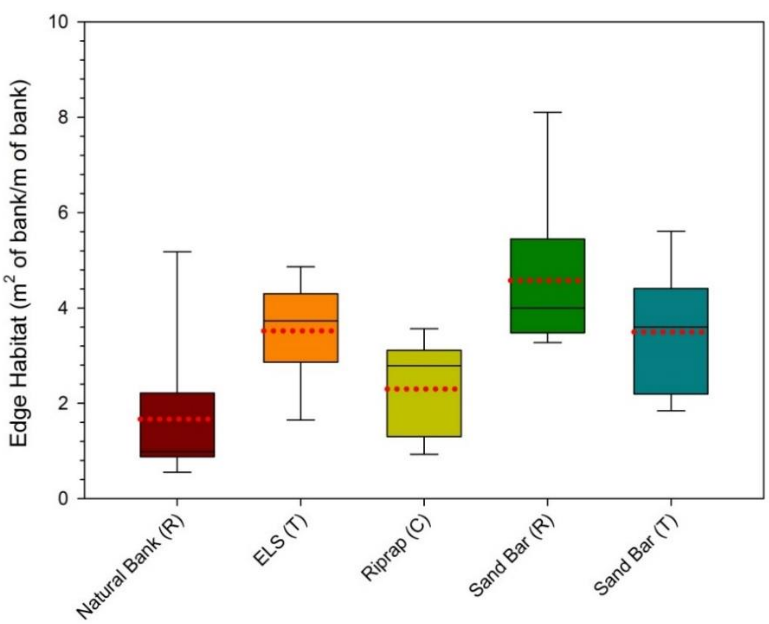

Figure F-5: Combined low velocity edge habitat (<0.45m/s) measured within the 25m transects during three sampling events in 2017. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

Are juvenile salmonids using mainstem project-related edge habitats?

Fish sampling for the SQU project consisted of both snorkeling (pre- and post-construction) and boat electrofishing (post-construction). Snorkeling was chosen for pre-construction monitoring because this was the best available method to survey this particular reach at the time of sampling. Due to higher turbidity associated with runoff in the winter and spring, snorkeling was limited to coho and trout focused surveys during late spring and summertime when the water was clear enough to accurately count and identify fish. While juvenile Chinook (both yearling and sub-yearling) may have been present, the timing of pre-construction monitoring was outside the typical Chinook rearing period (January–June), which limits our ability to assess baseline Chinook use of the project. With the availability of the electrofishing cataraft for post-construction monitoring, we were able to perform fish sampling in the springtime during the typical Chinook rearing period. While the electrofishing cataraft was the primary sampling method post-construction, one additional snorkel survey was included for comparison with the 2015 pre-project data. Only cataraft-based electrofishing is presented here.

During 2017, monitoring efforts throughout the Sinnema Quaale project reach observed a total of 401 fish among 12 different species (Table F-1). Both the reference-control and treatment sand bar habitats were found to have significantly higher Chinook CPUE than the riprap control banks ($P<0.001$) (Figure F-6). Even across flows, bars had consistently higher juvenile Chinook abundances compared to other edge habitat types (Figure F-7). The Sinnema Quaale project had relatively low use by juvenile Chinook during the time sampled compared to nearby sand bar habitats; although, average catch rates were higher than riprap control sites (representative of pre-project conditions) and similar to natural banks (unarmored banks). Juvenile coho and trout (rainbow and steelhead) did not appear to show a significant difference among edge habitat types ($P= 0.063$ & 0.208, respectively) (Figures F-8 & F-9). However, mean juvenile coho and trout abundance was considerably higher among engineered log structures (bioengineered revetment bank) compared to other edge habitat types.

Table F-1: Species list and total counts for fish observed along the Sinnema Quaale project reach (during cataraft-based electrofishing surveys). Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat).

Common name	Scientific name	Natural Bank (R)	ELS (T)	Riprap (C)	Sand Bar (R)	Sand Bar (T)
Chinook salmon	*Oncorhynchus tshawytscha*	13	15		64	57
Coho salmon	*Oncorhynchus kisutch*	2	18	1	4	2
Chum salmon	*Oncorhynchus keta*					
Rainbow/steelhead	*Oncorhynchus mykiss*	3	15	1	5	6
Cutthroat trout	*Oncorhynchus clarkii clarkii*		2		1	

Common name	Scientific name	Natural Bank (R)	ELS (T)	Riprap (C)	Sand Bar (R)	Sand Bar (T)
Sculpin	*Cottus sp.*	22	48	40	18	22
Largescale sucker	*Catastomus macrocheilus*	2	4	6	1	
Mountain whitefish	*Prosopium williamsoni*	2	3		1	1
Dace	*Rhinichthys sp.*				1	1
Green sunfish*	*Lepomis cyanellus*	5	2	4		
Pumpkinseed sunfish*	*Lepomis gibbosus*	1			1	1
Three-spined stickleback	*Gasterosteus aculeatus*	1	3	1	1	

*Indicates non-native species

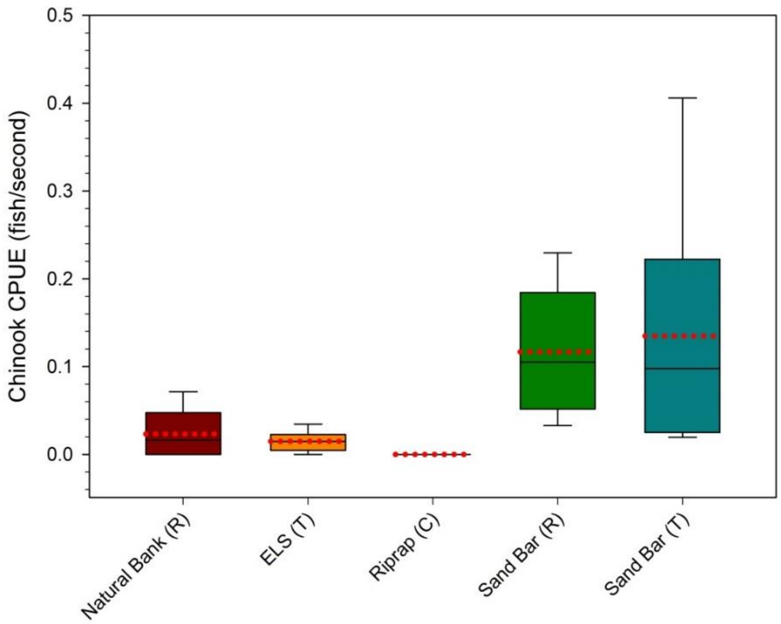

Figure F-6: 2017 juvenile Chinook salmon CPUE (catch per seconds of electrofishing) among all habitat types and sampling events. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

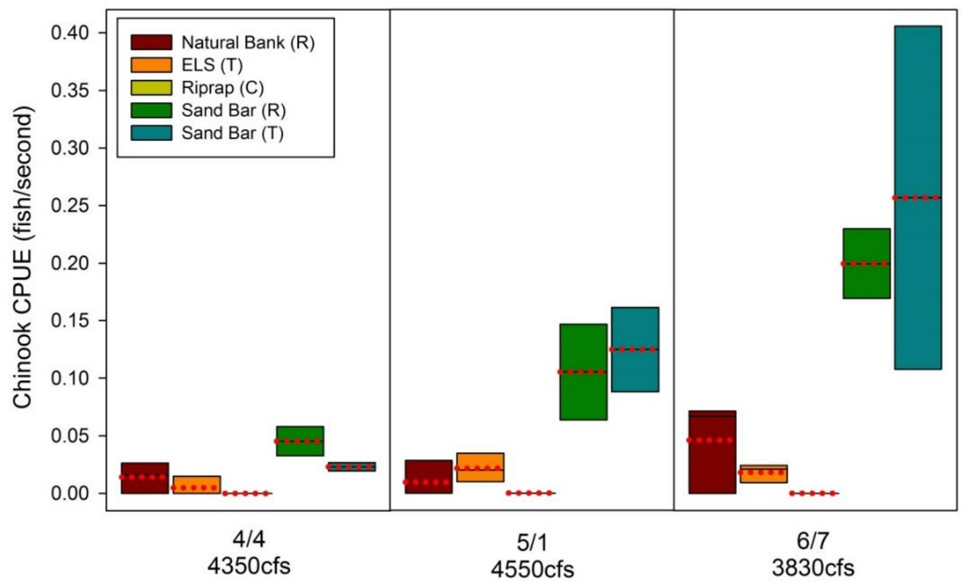

Figure F-7: 2017 juvenile Chinook salmon CPUE (catch per seconds of electrofishing) among all habitat types for each sampling event. abitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile.

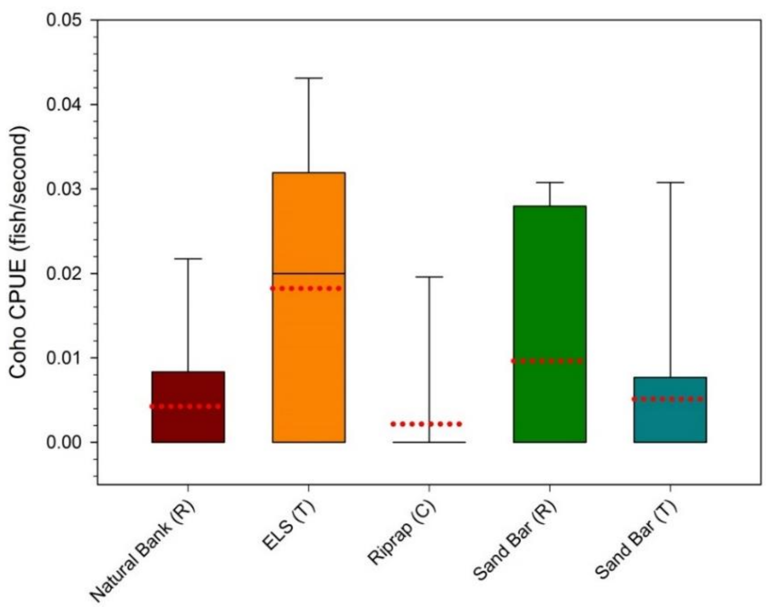

Figure F-8: 2017 juvenile coho salmon CPUE among all habitat types and sampling events. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.

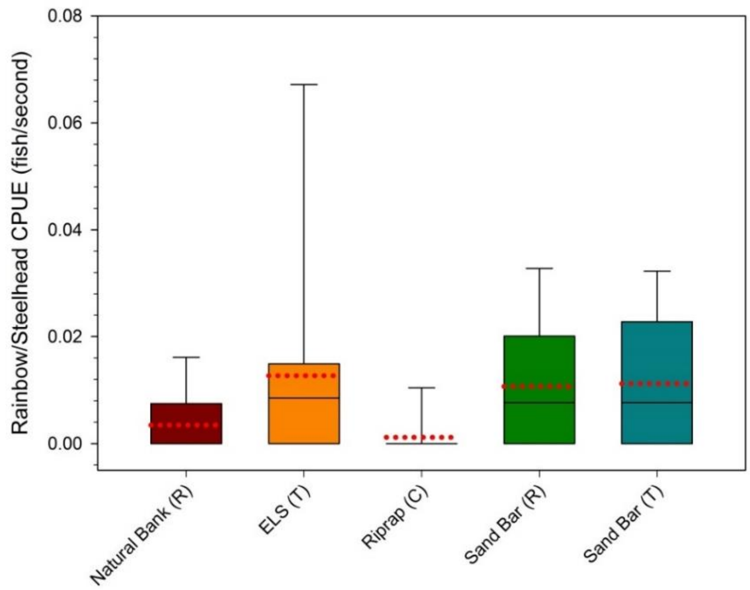

Figure F-9: 2017 juvenile rainbow trout/steelhead CPUE among all habitat types and sampling events. Habitat codes and naming include natural banks (unarmored banks), ELS (engineered log structures; i.e., bioengineered revetment), R (reference/control), T (treatment–bioengineered revetment or indirectly influenced habitat). The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, the dotted red line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles.