JUVENILE SALMON DIETS AND INVERTEBRATE PREY RESOURCES:

ASSESSING RESTORATION ON CLEAR CREEK, PUYALLUP, WASHINGTON

by

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Abstract

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Angela Morningstar Dillon

This thesis research focuses on how restoration along Clear Creek has changed invertebrate communities and how juvenile salmon respond to those changes in their diets. Field data was collected for vegetation, terrestrial invertebrates, aquatic invertebrates, and juvenile Chinook and Coho stomach contents. Restoration was correlated with terrestrial invertebrate taxa diversity. Juvenile Chinook and Coho diets were diverse with 81 different invertebrate taxa in stomach contents from April to July 2019. Juvenile Chinook and Coho diets overlapped; although, Chinook and Coho partitioned Clear Creek spatially. Diversity in food resources through restoration will improve opportunities for Chinook and Coho to thrive throughout the seasons and improves prey availability in sites where Chinook and Coho were collected.

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Chapter One: Introduction

The landscape of the Puget Sound has changed dramatically in the last 200 years. The Donation Land Claim of 1850 permitted white men to claim land in the Oregon Territory, now considered the Pacific Northwest, (Washington State Archives, 2020), and a rush for land and settlement followed that forever changed the natural environment. Forests have been cut down, rivers have been leveed and channelized, homes have been built, and farming changed land use. Currently, there are more than 4 million people living in the Puget Sound with another 1.8 million expected by 2050 (PSRC, 2018). Resource extraction and population growth have consequences for all life, from people and wildlife, plants and fish, insects, and even single celled organisms. The habitat that remains is limited and requires us to share and manage forests and rivers and the organisms within them.

Historic Conditions

The Puyallup Basin changed dramatically when non-Indian settlers flooded the area. The upper watershed was heavily logged for timber production. Logging activities intensified erosion, lead to instable slopes, and increased sediment loads into the Puyallup River (Brown et al., 2017). Flood control management for residential and agricultural development changed the natural landscape. Wetlands were drained, tide flats were filled, and waterways were dredged and channelized (Kerwin, 1999). In the early 1900s more than 90 miles of levees were built on the Puyallup River and its tributaries (Pierce County, 2020). Channelization has resulted in a simplified stream environment that does not provide habitat functions essential to various salmon life history requirements.

Prior to Western Expansion, the Indian tribes of Washington State occupied the land. Before land ownership and boundaries of private property, tribes traveled at will and distinguished themselves according to their environment. The Puyallup Tribe is situated along the southern portion of Puget Sound, near the Puyallup River and around Commencement Bay in Tacoma. The Puyallup Tribe lived in harmony with the land and continues to preserve the natural resources that surround them.

Current Conditions

Washington State is divided into 62 Water Resource Inventory Areas (WRIA). WRIAs are defined by the major river in the area and all the streams that drain into it. The administrative boundaries that define each WRIA help tribal, state, and other local agencies monitor and manage resources for people, fish, plants, and wildlife. WRIA 10, also called the Puyallup-White watershed, has been substantially altered since the mid-1800s. In particular, the lower Puyallup River is characterized by extensive urban growth, heavy industry, a large marine port, a massive revetment and levee system, as well as a robust agricultural industry. WRIA 10 hosts Washington State's third largest city, Tacoma.

The Puyallup Tribe Reservation is within one of the most industrialized areas of Washington State with portions of the cities of Puyallup, Tacoma, Fife, Federal Way, Milton, and Edgewood within its boundaries. The Puyallup Tribe of Indians have lived off the waters of the Puyallup River since time immemorial. The Puyallup People hunted, fished, and traveled from the shores of the Puget Sound to Mount Rainier in what is called the Usual and Accustomed Areas. The river remains the lifeblood of the tribe with members depending on the fishery for cultural and subsistence purposes. The Puyallup

Reservation is in Western Washington, approximately 30 minutes south of Seattle adjacent to Commencement Bay on Puget Sound. The Puyallup Tribe is a federally recognized tribe with over 5,000 tribal members, most of who live on or near the reservation.

Study Area

The Puyallup River originates from glaciers on Mount Rainier and flows to Commencement Bay. The Puyallup River exhibits characteristics of glacial streams including high turbidity, low temperatures, and frequently shifting braided channels (Berger and Conrad, 2019). The lower reach of the Puyallup River is relatively flat floodplain with a salt-wedge estuary at the mouth. The Puyallup-White watershed supports all species of Pacific Salmon (Table 1) including Puget Sound Chinook, which is listed as a threatened species under the Endangered Species Act (ESA).

Clear Creek is a tributary on the lower Puyallup that supports off-channel refuge, rearing, foraging, and growth for juvenile salmon and spawning for adult salmon (Figure 1). Historically Clear Creek provided substantial habitat to support various salmon species and life histories but has been reduced to a fraction of its former capacity. Limiting factors on Clear Creek include low stream flows, reduced spawning habitat, noxious weeds, flooding and channel erosion, storm water runoff that negatively impacts water quality, and poor or absent riparian cover. Even with these issues, the potential of the Clear Creek basin offers one of the few remaining spaces to restore critical habitat for all Puyallup River salmon as well as steelhead trout as they leave the river to make their ocean migration. Clear Creek is considered a tidal freshwater wetland which are highly productive ecosystems. This type of habitat is a conduit for nutrients and energy that cross boundaries between different types of ecosystems (SPSSEG, 2018). Tides in Clear Creek change the water level by several feet in the lower reaches, the groundwater and surface water interactions create water temperature gradients, and salinity intrusion from tidal waters make this a unique and variable system that has the potential to be highly productive.

Table 1. Common and scientific names of Pacific salmon (genus Oncorhynchus).

Common Name	**Scientific Name**
Chinook	*O. tshawytscha*
Coho	*O. kisutch*
Pink	*O. gorbuscha*
Chum	*O. keta*
Sockeye	*O. nerka*

Figure 1. Map of WRIA 10 and Clear Creek in Puyallup, Washington.

Pacific Salmon Ecology

Pacific salmon are a keystone species. Anadromy and semelparity, life history characteristics that Pacific salmon evolved to spend most of their lives in the ocean and migrate to freshwater to spawn once then die (Quinn, 2005), are unique adaptations that cross ecosystem boundaries to support a wide food web. Vertebrate predators such as bears and birds will pull salmon from the stream and their carcasses deposit nitrogen and carbon isotopes that enrich soils and provide essential nutrients to terrestrial plants (Bilby et al., 1996). Timing of reproduction and distribution of vertebrate predators is tied to salmon migration seasons. Bald eagle abundance in Washington State is correlated with the movement of Chum salmon in the Skagit River. When high flows moved salmon carcasses downstream from riverbanks, eagle abundance declined (Hung et al., 1992). Eggs and carcasses in freshwater support invertebrate communities by stimulating food production for invertebrates and as direct consumption. Decomposing sockeye in a small tributary to Lake Tahoe, California was associated with high bacterial and fungal activity that supports phytoplankton and periphyton blooms (Richey et al., 1975) a food source for certain groups of invertebrates. Invertebrate taxa richness and diversity in a southeast Alaska stream increased with salmon carcass presence, suggesting carcass decomposition was related to insect colonization (Piorkowski, 1995). Salmon carcasses provide nutrients from marine ecosystems to freshwater and terrestrial ecosystems and support primary production, and invertebrate and vertebrate food webs in many streams that would not otherwise receive these resources.

Endangered Species

In Washington State in the 1990s, 15 populations of salmon were ESA-listed. Salmon, steelhead, and bull trout were threatened or endangered in nearly 75 percent of Washington State. Pacific salmon are challenged by habitat loss, disease, predation, and invasive species. Warming oceans, changing stream conditions, and shifting food webs are intensifying the threat. Estimates of Chinook abundance in Puget Sound are 1 to 4 percent of what they were before the 20th century (Gayeski et al., 2011). In 2010, just over 485,000 Chinook salmon in the Puget Sound were reported to the Pacific Salmon Commission, a reduction of 60 percent since tracking began in 1984 (EPA, 2019). These dramatic declines spurred salmon recovery efforts as part of the federal requirements to protect endangered species and their critical habitat. The iconic salmon has been a part of the history, culture, and economy in Washington State and salmon recovery is not limited to ESA-listed species. Protection of both listed and unlisted salmon stocks is a high priority for many individuals and agencies in the state.

The factors affecting the decline of Chinook in the Puyallup-White watershed also impact other salmonids. Puget Sound steelhead exhibit similar life history characteristics to Chinook such as anadromy, and requirements such as the need for cool, clean water for spawning and rearing, and are ESA listed. Rapid development, especially in the cities of Puyallup, Orting, and Sumner contribute to poor water quality conditions (DOE, 2011). Impacts from urbanization include aggregation of fine sediments in low energy reaches, channel incision from high storm water flows, elevated temperatures, low dissolved oxygen primarily due to high sediment oxygen demand, fragmentation and reduction of riparian canopy, loss of large woody debris to provide cover for juvenile salmon

(Eitzmann and Paukert, 2010), and population shifts of invertebrates to pollution-tolerant species (Booth et al., 2004).

Protecting and restoring critical habitat for ESA-listed salmon and all salmonids should be prioritized in light of extensive population growth and development on the reservation and within the Puyallup-White watershed. Critical habitat are areas designated by the Secretary of Commerce for the survival and recovery of listed species, however many preliminary assessments of critical habitats adopt a “ridge to ridge” approach for critical habitat that includes any mainstem river and its tributaries where salmon spawning, rearing, and migrating activities occur (Haynes et al., 1992). The lower brackish reaches of the river are paramount for juvenile salmon. Juvenile salmon osmoregulate in these lower reaches, making the transition between fresh and saltwater environments. This transition zone is critical for salmon protection and recovery. Much of the Puyallup River has been heavily altered and complete restoration is not possible. Focus is needed on locations that offer critical habitat features on properties with little or no development. Many sites involve multiple ownership and would require partnerships with several agencies.

Habitat Restoration

In 2006, the Puyallup Tribe purchased a 10-acre parcel that is nestled between Clear Creek and River Road. The buildings were removed, and the land was replanted with native trees and shrubs. At approximately river mile 1 of Clear Creek, the floodplain was reconnected on the north side to allow Clear Creek to flow laterally across the land and relieve flooding to the adjacent community on the south side. The parcel is dominated by woody vegetation of alders and willows.

In 2016, the Port of Tacoma finished construction of a 40-acre restoration project on upper Clear Creek. The project created a floodplain wetland and anastomosing stream channel. The project was part of a mitigation agreement with the Environmental Protection Agency with a cost of $9 million dollars.

Pierce County and its partners have identified Clear Creek as a potential restoration site that can provide relief from flooding, improve drainage for farmers in the area, and recover habitat for juvenile and adult salmon. Floodplains for the Future (FFTF), hosted by Pierce County, is motivated to acquire land in floodways with the primary goal of moving people out of harm's way. Additional work concentrates on projects that improve habitat and support agriculture. The group seeks out projects with multi-benefit solutions for fish, farm, and flood groups. FFTF is investing in an evaluation of Clear Creek to determine how to best support these groups and their goals.

Salmon Partnerships in Washington State

The Washington State Legislature introduced the Salmon Recovery Act of 1998 and created the Governor's Salmon Recovery Office which oversees eight salmon recovery regions in Washington state who collaboration with federal, tribal, state, and local partners to develop salmon recovery plans. Salmon recovery and projects are tracked and listed in Table 2. In the last 20 years, some salmon stocks are showing signs of recovery, while others such as the Puget Sound Chinook are getting worse. Puget Sound Chinook run throughout the Puyallup River and its tributaries and have been the focus of recovery efforts in the Puyallup-White watershed.

Table 2. 2018 State of the Salmon report and assessment of progress toward recovery. This is a non-statistical evaluation of ESA-listed species that includes metrics of natural origin salmon such as adult returns, productivity, life history, genetic diversity, and impacts from habitat loss, harvest, and hydropower.

Below Goal (Endangered Species Act – Listed Salmon in Washington State)			**Near Goal**
Getting Worse	**Not Making Progress**	**Showing Signs of Progress**	**Approaching Goal**
Upper Columbia River Spring Chinook	Upper Columbia River Steelhead	Mid-Columbia River Steelhead	Hood Canal Summer Chum
Puget Sound Chinook*	Lower Columbia River Chum	Lake Ozette Sockeye	Snake River Fall Chinook
	Lower Columbia River Coho	Lower Columbia River Steelhead	
	Lower Columbia River Fall Chinook	Snake River Steelhead	
	Lower Columbia River Spring Chinook	Puget Sound Steelhead*	
	Snake River Spring and Summer Chinook		
*Puget Sound Chinook and Steelhead are the two ESA-listed species that run though WRIA 10 and the Puyallup River.			

In 1999, when Puget Sound Chinook were listed, the Puyallup Tribe of Indians (PTOI) and Washington State Department of Fish and Wildlife (WDFW) created a recovery plan for fall Chinook that aimed to support natural fall Chinook production, monitor fish stocks, and evaluate habitat conditions in the watershed that affect potential production. These two entities monitor adult returns by counting salmon and redds on several streams throughout the watershed. PTOI operates one rotary screw trap on the Puyallup River and one on the White River to monitor juvenile salmon outmigration and estimate adult returns. Federally recognized Indian tribes are sovereign nations and government-to-government consultation is required for public land projects that affect tribal activities, practices, or beliefs. Because of this requirement, the Puyallup Tribe has a strong relationship with many agencies in the watershed and collaborates on a variety of issues affecting salmon and their habitat.

The South Puget Sound Salmon Enhancement Group (SPSSEG) is one of 14 regional enhancement groups that focus on salmon recovery. The group was formed in 1990 by the Washington State legislature and has high involvement with communities, citizens, and landowners. The SPSSEG was funded by FFTF to complete the initial evaluation on Clear Creek. The goals of the Clear Creek Floodplain Reconnection project are to develop an understanding of the natural processes within the floodplain. Fish life histories and strategies in the Puyallup River will be assessed in order to integrate the interests from fish, farm, and flood groups. The larger study includes groundwater monitoring, a sediment study, thermal imaging of the watershed, a salinity profile of Clear Creek, PIT installation and tracking of juvenile salmonids, fyke net and mark-recapture studies, and a prey resource study.

The focus of this thesis is juvenile salmon prey resources in Clear Creek. General juvenile salmon life histories and feeding behaviors will be discussed. Pacific Northwest stream invertebrates will be characterized with respect to food webs in a changing climate and urban setting. The connections between riparian habitat, invertebrates, and juvenile salmon will be evaluated. Research methodology will be discussed with a report of the 2019 data collection results. Finally, a conclusion will be provided reviewing the research and determining next steps.

Chapter Two: Literature Review

This literature review will investigate the role of riparian habitat on invertebrate communities and how changes in the distribution and abundance of invertebrates can have cascading effects that impact juvenile salmon growth and survival.

Riparian Habitat

Washington is the Evergreen State. Frequent rainy weather that supports the state's rich, green landscape contributed to Washington's nickname. Currently, Washington has 22 million acres of forest land, which is approximately half of the state's total land area (Campbell et al., 2010). Conifer forests of Sitka spruce, western hemlock, western red cedar, Douglas fir, and pine covered western Washington (Campbell et al., 2010). In the mid-1800s, logging reduced many of Washington's old growth forests with special pursuit of Douglas fir and red cedars for buildings and construction (Price and Anderson, 2002). Agriculture was another land use change that began around the same time. Agriculture is productive in fertile valleys near rivers, which provide irrigation for crops and livestock. Farming for subsistence was common until 1865 when Charles Wood imported hop roots from England (Chesley, 2008). The Puyallup Valley produced more hops per acre than any other hop growing area around the world (Chesley, 2008). Although recent land use has focused on developing urban and suburban areas, farming is still a part of life in the area. The remaining farms in the Puyallup Valley produce berries, vegetables, and flowers.

Deforestation, urbanization, and agriculture changed the landscape around the Puyallup River and its tributaries. The Puyallup River basin used to support upland conifer, forested wetland, riparian, and emergent wetland plant communities. Upland areas in the Mount Rainier National Park are protected and practices like clear cutting is no longer standard, however lower reaches that run through residential and agricultural areas remain degraded. From 2013 to 2015, 350 acres of new roads, buildings, and warehouses were constructed in the Puyallup Watershed (Pierce, 2015). Impervious surfaces in the greater Puget Sound increased from 2.6 percent in 2006 to 7 percent in 2011 (NWIFC, 2016). As impervious surfaces increase, stream temperatures and sediment transport are likely to increase. Water bodies in the Puyallup River basin do not meet many state and tribal water quality standards for biological oxygen demand, ammonia, fecal coliform bacteria, pH, sediment, and temperature (Mathieu and James, 2011). Pollution from industrial and commercial activities, residential development, and agriculture negatively impacts water quality and harms aquatic species. There were 4,083 acres of farmed land in Pierce County in 2013 (Pierce, 2015). Legacy practices of removing tree cover, building dikes, and carving out ditches for farming continues. Of the 5,900 acres of estuary habitat in Commencement Bay, only 3 percent has not been dredged, filled, or otherwise developed (NWIFC, 2016). Development is expected to continue as population in the Puget Sound grows. From 2012 to 2017, the region grew by 324,000 people with another 750,000 expected by 2026 (PSRC, 2018). Development and population growth in Pierce County, the Puyallup Watershed, and the Puget Sound will continue to impact water quality which has consequences for all.

Riparian habitat is the area that connects aquatic and terrestrial habitats. The riparian zone links land and water and consists of not only vegetation near the stream, but also extends vertically to include soils, groundwater, and tree canopy (Clinton et al., 2010). Riparian areas provide habitat for wildlife, often have many woody tree species, and are near streams. These features make riparian areas desirable for human development, however development can reduce biodiversity of wildlife and aquatic organisms and harm water quality (NRC, 2002). Protection and replanting of native trees and shrubs helped to diversify the plant communities in developed areas, but invasive plant species are widespread. Invasive plants often crop up when land clearing for development occurs. Much of the Clear Creek basin was cleared for agriculture initially, followed by residential, and commercial development. Invasive plants displace native plant communities and prevent recruitment of native plants. Brazilian elodea, reed canarygrass, and Himalayan blackberry have been identified in Clear Creek. Pierce County categorizes elodea as a Class B noxious weed that can be widespread, and control is enforced by the Pierce County Noxious Weed Control Board (Pierce County, 2019). Blackberry and reed canarygrass are class C noxious weeds that are widespread and abundant, and landowners are encouraged to control these weeds independently (Pierce County, 2019). Actions to control invasive plants and restore riparian habitat with native plants has become more common, but there is still a need to enhance riparian areas and restore buffers surrounding streams.

Wetlands are protected as part of the Clean Water Act (CWA), but riparian areas are not. The federal government established the CWA to regulate pollution and maintain water quality standards. While states have authority to manage Section 319 of the CWA, which covers nonpoint source pollution (Summary of the CWA, 2018), the burden is on municipalities to enforce and implement development standards to protect critical areas. Washington RCW 36.70A.030(5) describes critical areas as wetlands, aquifer recharge areas, fish and wildlife habitat conservation areas, frequently flooded areas, or geologically hazardous areas (Washington State Department of Commerce, 2018). Wetlands provide many functions to filter water and recharge water quantity. Riparian areas perform many of the same functions as wetlands but do not receive the same protection. Riparian areas have been acknowledged recently and the protection and restoration of these areas is improving. However, each jurisdiction differs regarding how much riparian buffer is enough. The width of a riparian buffer is measured in feet. Many cities will not allow development within 50 feet of a stream or prevent cutting down a riparian buffer of 50 feet, regardless of the stream type. A fish bearing stream is provided higher protection and development can be restricted up to 200 feet, however many jurisdictions fail to maximize protection for riparian areas and buffers have been reduced to minimum standards with the lowest protections.

Riparian habitat is unique because of the variety of vegetation structure and composition. Riparian vegetation in the Pacific Northwest generally includes herbaceous groundcover, deciduous understory, and a mix of deciduous and coniferous overstory on the floodplain (Swanson et al., 1982). Land cover surrounding Clear Creek is a combination of conifer and deciduous trees and shrubs such as cottonwood, red alder, and vine maple, as well as several groundcover species, and invasive plants that include reed canary grass and Himalayan blackberry. The variety of plant species and canopy heights is unique to riparian areas as compared to upland areas that are mostly conifer forests.

Riparian vegetation provides various functions to aquatic ecosystems. Overstory and canopy provide shade to help control stream temperature (Clinton et al., 2010). In channel vegetation routes water and shapes pools and riffles, provides cover for fish, and can be food or substrate for invertebrates (Swanson et al., 1982). Roots on streambanks stabilize soils and increase bank stability (Swanson et al., 1982). Vegetation in the floodplain reduces sediment mobilization and organic debris (Swanson et al., 1982), and filters contaminants prior to entry into streams (Sabo et al., 2005). Diversity in vegetation structures and composition can support a variety of aquatic organisms.

Disturbance in riparian zones is a unique feature that creates opportunities for emerging plant and invertebrate communities. Riparian zones experience periods of floods and drought. Although the cycle of wet and dry periods can be a normal part of the natural flow regime these periods are considered disturbances that change plant and invertebrate species composition (Poff et al., 1997). Invertebrates such as beetles (Carabidae) will drift to escape flooding (Paetzold et al., 2005), while millipedes will move vertically into the tree canopy (Battirola et al., 2009). Plants in the riparian zone can be adapted to fully aquatic, fully terrestrial, or a combination of environments. Red Alder in the family Betulaceae fixes nitrogen at higher rates than other deciduous or conifer trees (Swanson et al., 1982). This pioneer species thrives with high soil moisture and in disturbed sites such as the riparian zone (Newton et al., 1968). Disturbances allow colonization of specialists that either do not exist elsewhere, experience higher productivity in riparian zones, or experience higher turnover because of flooding or drought (Sabo et al., 2005). Clear Creek experiences bank overflow during rain events. In the lower reaches, closer to the mainstem confluence, the tides can change the water level by several feet. In the restored areas of Clear Creek, the connection to the floodplain allows the stream to move laterally. These features create a predictable disturbance regime that is beneficial to plant and invertebrate species that are the first to recolonize disturbed areas. Disturbance can prohibit colonization of plants and invertebrates as well.

Disturbances that create incised banks and intensify erosion can disconnect streams from the floodplain (NRC, 2002). Reaches with these traits are good candidates for restoration.

Riparian areas provide ecosystem services including shade which protects stream water from insolation, filtration of surface and ground waters, and can improve water quantity. The changing density and height of canopy in riparian areas provides a gradient of light and temperatures. Densely vegetated riparian areas make air temperatures less variable and often cooler in summers and warmer in winters compared with upland habitat (Ramey and Richardson, 2017). Vegetation protects streams from direct solar radiation that can raise stream temperatures. Streams in western Maine with no buffers showed an increase in mean weekly maximum temperatures up to 4.4 ºC compared to a stream without a harvested buffer (Wilkerson et al., 2006). The temperature change a stream will experience depends on hydrology, morphology, and geographic regional climate, which can be unique for each watershed, however it is well documented that riparian buffers can protect streams from insolation and the resulting increase in water temperature (Moore et al., 2005; Janisch et al, 2012; Wilkerson et al., 2006). These studies also relay the ability of riparian buffers to filer contaminants before reaching waterbodies. Pollutants such as nitrogen and phosphorus that originate from fertilizer, animal waste, pesticides, or herbicides bind to soil (Hawes and Smith, 2005). Riparian buffers can absorb 50-100 percent of sediment and the nutrients and pollutants attached to it and will filter surface water runoff to reduce phosphorus loading by 80 percent (Hawes and Smith, 2005). Surface water runoff is an issue in developed areas where impervious surfaces are common. Pavement is the most common impervious surface in urban settings (Sandahl et al., 2007), however runoff occurs on all types of development, such as buildings and houses, that do not allow rainfall to infiltrate into the ground. Impervious surfaces reduce infiltration of rainfall that can prevent groundwater recharge and reduce stream flows (White and Greer, 2006). Restoration of riparian habitat generally includes placing in-stream structures such as large woody debris (LWD) or artificial beaver dams, or by allowing recruitment of LWD to occur naturally when riparian trees fall into the stream. These structures can raise the water level of the channel and subsequently raise the water table in riparian areas adjacent to the stream (Hausner et al., 2018). Streamside vegetation offers multiple benefits to the nutrient cycling process, hydrology and sediment, and habitat and food web dynamics of streams.

Riparian vegetation plays a role in the available food resources of invertebrate communities. Scrapers eat periphyton, shredders eat coarse particulate organic matter (CPOM) or aquatic plants, collectors eat fine particulate organic matter (FPOM) that floats through the water column or after it is deposited on surfaces or builds up in crevices in the sediment, and predators eat live prey (Cummins, 2016). CPOM is plant litter that has been colonized by fungi and bacteria. Once CPOM has been conditioned it is palatable to shredders. Shredders convert CPOM to small particles less than 1 millimeter in diameter and produce waste materials that are all considered FPOM (Cummins, 2016). Gougers such as beetle larvae eat large woody debris (Anderson et al., 1978). Invertebrates are generalists that take advantage of a range of available food resources. Caddisflies of the same species will exploit algae which is the primary food source in open canopies where photosynthesis occurs, and detritus in closed canopies where terrestrial plants in the riparian zone provide the most abundant food source (Cummins, 2016). Characterizing riparian conditions as well as the community of invertebrates in a stream can help identify gaps in food and habitat resources for these organisms and speaks to general stream conditions.

Riparian areas provide several functions that help to improve water quality and quantity. These functions aid in the preservation of endangered species by providing habitat and improving water quality. This has not only ecological value but also supports legal standards such as the Clean Water Act and Endangered Species Act. Riparian zones perform a disproportionate number of services and functions per unit area (NRC, 2002). Management of these areas should be a priority in order to restore habitat for fish and wildlife, improve water quality, reduce the negative impacts from high flows, and protect wetlands.

Salmon

Washington State is home to several species of Pacific salmon and trout including Chinook (O. *tshawytscha*), Coho (O. *kisutch*), pink (O. *gorbuscha*), chum (O. *keta*), sockeye (O. *nerka*), steelhead and their freshwater counterparts rainbow (O. *mykiss*), cutthroat (O. *clarki*) and bull trout (S. *confluentus*) (Quinn, 2005). The life history varies for each of these species and each type requires a different management approach (Quinn, 2005). Salmon are an important part of the ecology in the Pacific Northwest bringing marine nutrients to freshwater streams (Petticrew and Rex, 2011). In addition to being ecologically important, salmon are a valuable commercial fishery in the United States landing $461 million in 2015 according to the U.S. Department of Commerce statistical reports (2017). Tribes in Washington have used treaty-fishing rights to ensure continued harvest for tribal fishers and access to salmon for cultural purposes (Pevar, 2012). Wild salmon populations have been declining for decades from overharvest, hydroelectric dams, hatchery production and habitat degradation (Ruckelshaus, 2002). First will a review of general salmon life histories with a focus on salmon in WRIA 10. Next will be an evaluation of salmon growth and survival considering prey requirements, stream conditions, and stream temperatures.

Salmon Background and Life History

Puget Sound salmon depend on a variety of habitats in each stage of development. Adult salmon spawn in freshwater where eggs incubate and alevin and then fry grow and develop. As smolts, salmon rely on brackish water in estuaries to trigger physiological changes which allow them to spend their adult lives in the ocean. Each stage has different requirements and challenges. Eggs and alevin nest in gravel and are vulnerable to floods that scour out the small streams where they reside. Fry and smolts need space and abundant food to boost growth and provide protection from predators as they forage. Each salmon species has unique physical traits and strategies to partition their habitat spatially and temporally. Interspecies interactions with trout, pink, chum, and sockeye such as competition are a factor and an important part of local culture and policy, this review will focus on Chinook and Coho.

When salmon emerge after the embryo stage, they are called alevin. Alevin have a yolk sac attached ventrally that provides a food source in the first few months of development. Alevin are small and fragile, have only instinctual behaviors with regards to predator avoidance, and will stay close to the redd where they hatched. After the yolk sac is absorbed, the fish is called fry. Large tributaries in the Puyallup Watershed where Chinook spawn such as the Carbon River and South Prairie Creek can extend 10 to 20 miles in length. Fish passage on Clear Creek is approximately 3.5 miles upstream from the confluence at the Puyallup River. Juvenile salmon fry begin to explore their natal streams and imprinting takes place. Fry must balance their activity between foraging for prey and avoiding predators. Juvenile salmon are vulnerable to predation from birds and piscivorous fish. Parr marks, brown to black bars that vertically line the sides of salmon, provide camouflage while in streams.

Salmon are anadromous. As they begin their first migration out of the freshwater streams where they were born, to the estuary, and finally to saltwater in the ocean, salmon change morphology and physiology. As they are going through these changes, they are called smolt. Smolts regulate the salt in their bodies with the salt in the water through osmoregulation. Changes to osmoregulation allow salmon to move from freshwater to saltwater. The final stage of this generally occurs in the brackish waters of estuaries where freshwater streams and the ocean meet. When smoltification occurs, juvenile salmon lose their parr marks. Smolts are “chrome” or silver in color which provides them better camouflage in the open ocean. Smolts are generally bigger in both fork length and weight compared to fry. In 2018, sub-yearling Chinook on the Puyallup River averaged 42 millimeters in January and 64 millimeters by June. Yearling Chinook averaged 65 millimeters in January and 76 millimeters by June (Berger and Conrad, 2019). For Coho fry, growth is important in the spring and summer. Large size by the end of summer improves survival overwinter and to smolt (Quinn and Peterson, 1996). However, warm summer temperatures can reduce stream flow or dry them completely. Limited space, high stream temperatures and lack of food can impede growth. Weight loss is possible under these conditions. Fall rains make off-channel habitat such as wetlands, sloughs, and ephemeral streams available again. Coho use these areas to rear until they smolt. Coho emigrate to saltwater as yearlings, having spent up to 16 months in freshwater streams (Quinn, 2005).

Juvenile Chinook salmon are ocean-type (sub-yearlings) or stream-type (yearlings). Ocean-type Chinook emerge in the winter, grow for a few months in medium to large rivers and make their way downstream. Stream-type Chinook are found in mid elevation streams and remain there throughout the year. In a given watershed, Chinook tend to spawn and rear in lower reaches, Coho at intermediate distances upstream, and trout at headwater elevations. The stream and ocean type classification is good for generalizing Chinook behavior, however it fails to capture complex life history traits such as age at smoltification, run timing, and transitions between habitats that affect physiology, growth and survival (Bourret et al., 2016). Salmon phenotypes and life histories can vary between watersheds. Life history variation is a factor when assessing population abundance and productivity; crucial information which informs management decisions. More studies are needed to determine the specific life history strategies of salmon in WRIA10.

Salmon Diets and Food Webs

The quantity and quality of prey resources are important factors in juvenile salmon foraging performance. Terrestrial insects and aquatic insects at the adult stage are more energy rich than immature aquatic insects (Beauchamp, 2009). Fish that eat high quality prey require lower quantities to achieve a given growth rate than if they were to eat lower energy prey (Beauchamp, 2009). Human disturbances can affect foraging performance of juvenile salmon by limiting the quality and quantity of prey (Naiman et al., 2012). When prey resources are less abundant, juvenile salmon must tradeoff between conserving energy or foraging and avoiding predators. Beauchamp's bioenergetics model (2009) examines salmon body mass, feeding rates, and energetic quality of prey across different thermal regimes. The simulations show that when food is maximized, there are larger temperature ranges that support growth, but optimal temperature for growth decline when food is limited (Beauchamp, 2009).

Terrestrial invertebrates are an essential component in juvenile salmon diets. In a study comparing terrestrial and aquatic invertebrates in juvenile salmon diets, the former accounted for half of the biomass in stomach contents (Wipfli, 1997). In addition, terrestrial invertebrates were found in stomach contents consistently from May to October while aquatic invertebrate biomass dropped off in July (Wipfli, 1997), when summer stream flows drop and temperatures peak. Many salmon species need access to prey items throughout the year. It is especially important for juvenile Coho and stream-type Chinook because they spend more time rearing in freshwater compared to other salmon. Understanding the quantity and quality of prey items in salmon habitats can inform restoration actions to improve foraging capacity to benefit salmon growth and survival.

Streams Conditions and Juvenile Salmon Behavior

Salmon growth during immature life stages is linked to survival. When juvenile salmon experience starvation in early spring, growth hormones in the liver reduce protein synthesis rates leading to protein deficiencies that endure even when feeding resumes (Beamish and Mahnken, 2001). Juvenile Coho sampled in the Puget Sound displayed low levels of this growth hormone; in this cohort, the adults that returned indicated a change in size during their first fall at sea (Beamish and Mahnken, 2001). This study also tested laboratory feeding experiments on Coho that correlate low hormone levels and stunted growth; conversely, as hormones increased, size and weight of juvenile fish increased in August and September (Beamish and Mahnken, 2001). This suggests that juvenile salmon in general and Coho especially are vulnerable their first winter at sea if starvation occurs in early spring. For salmon with normal growth hormone levels, the late summer growth could be attributed to the combination of higher water temperatures and sufficient food supplies. Providing opportunities for juvenile salmon to feed consistently throughout the year could contribute to year class strength if individuals in a cohort can avoid starvation early in development and maintain growth rates as they migrate to saltwater.

Juvenile salmon growth from alevin to smolt is influenced by the density of fish in an area, food availability, and stream temperatures. A cohort of juvenile Atlantic salmon studied under heterogeneous conditions showed high variability in growth rate (Gibson, 2002). Changing stream environments require juvenile salmon to adapt their foraging strategies. The decisions fish make such as speed in engaging prey and aggressiveness when defending territory may work under certain conditions, but is not employed in every situation (Dill, 1983). This learned behavior can influence not only growth, but also fitness and survival. Larger size has advantages in competition for food or space, as well as surviving flooding due to winter storms (Ebersole et.al, 2006).

Territoriality, schooling, and competition can affect juvenile salmon feeding behavior. As fry in the spring, juvenile salmon school along the stream bank where flows are slower and predators found in deeper waters are absent (Quinn, 2005). Juvenile salmon will group together to establish and defend a territory. Freshwater rearing space is limited and there is competition for food and space. Juvenile Coho select for pools with large woody debris (Quinn and Peterson, 1996). These areas provide refuge from fast moving water and cover from predators.

Territory size is related to food availability. Experimental observations of juvenile Coho determined that territories were smaller when benthic food supply was larger (Dill, 1983). The risks that salmon take when foraging is dependent on food availability, hunger, predation, and competition. Juvenile Coho responded more aggressively to intruders when food availability was low (Dill et al., 1981), while other fishes broaden their diet as the availability of preferred prey declines (Werner and Hall, 1974). Larger food supplies may reduce trade off risks that occur when prey is sparse. Foraging plasticity can result in higher fitness compared to other juvenile salmon in their cohort if they consistently make decisions that improve feeding efficiency.

Salmon and Temperature

Water temperatures, metabolism, and prey availability are compounding factors that affect salmon growth and survival. Rising stream temperatures are a growing concern as the climate warms. In the Puget Sound, climate change is expected to reduce snowpack leading to lower stream flows in the summer and fall (IPCC, 2014). A longer warm season, low stream flows, and higher air temperatures may create conditions above the thermal tolerance for salmon, resulting in stressful conditions or mortality.

Stream temperatures can influence salmon growth and survival. Stream temperature fluctuates on diel and seasonal cycles. It is influenced by groundwater, shade coverage, and incoming flows. Salmon have evolved around these fluctuating temperatures. However, human activities and climate change have altered the natural variability of river systems. High stream temperatures in the summer are associated with stress that can compromise fitness of juvenile Coho salmon and reduce overwinter survival (Ebersole et al., 2006). In a study of sockeye salmon between 5-12 months in age, 15 ºC is an optimum temperature for maximizing growth, if energy intake is sufficient (Brett et al., 1969). When food availability decreases and energy intake fails to meet metabolic demands, stream temperatures that were previously considered optimum can reduce growth (McCullough, 1999).

Warmer streams can induce stress and raise metabolic rates. Salmon are ectotherms. Their body temperature is a function of their environment. Normal body functions require energy. Breathing and pumping blood and oxygen use energy even when resting. Resting metabolism for ectotherms is measured as standard metabolic rate (SMR); for endotherms it is called basal metabolic rate. Other activities such as walking or eating require additional energy. Ectotherms will have a higher SMR as temperatures rise. In a study on sockeye salmon, a ten-degree increase in water temperatures from 5 ºC to 15 ºC doubled its active metabolism rate (Johnston and Dunn, 1987), the energy used when moving and foraging. Ectotherms are particularly vulnerable to changes in their environment since their physiology is a function of their surroundings. The cost of activities to function as well as activity such as swimming and foraging require higher energy inputs to meet higher demands when stream temperatures are higher.

Invertebrates

When examining the connections between juvenile salmon and their prey, it is important to consider the spatial and temporal variation in stream prey availability and how the relationship is affected by factors such as water temperature. First, this review will evaluate aquatic insects and their functions in stream habitats. Next will be an examination of the movement of aquatic insects in space and time with special consideration to how changing temperatures affect insect behavior.

Invertebrate Background and Life History

Invertebrates are organisms without a backbone and represent approximately 95% of the species on earth (Resh and Rosenberg, 1984). Invertebrates, insects, and bugs will be used interchangeable to describe this group. Insects can be categorized into two big groups: aquatic and terrestrial. Aquatic insects are derived from terrestrial ancestors; both are found in the taxonomic class Insecta (Hershey et al., 2010). Evidence of their evolution is supported by features such as the trachea for respiration, a reliance on atmospheric oxygen, and an impermeable cuticle (Merritt and Cummins, 1996) that are advantageous on land but not water. Some insect orders have species such as mayflies, stoneflies, dragonflies, and caddisflies that are aquatic throughout certain life stages, while other orders like beetles, bugs, butterflies, mosquitos, have both aquatic and terrestrial species (Resh and Rosenberg, 1984).

Terrestrial invertebrates considered include not only the taxonomic class Insecta, but also the class Arachnida (spiders, mites, ticks, scorpions), the phylum Mollusca (slugs, snails), and the phylum Annelida (earthworms, leeches). This thesis will focus on terrestrial invertebrates in the riparian zone.

Aquatic insects live in or near water. When assessing individuals or groups, the evaluation of microhabitats may provide a more focused assessment. Aquatic microhabitats are small environments such as the surface of the water, the water column, or the benthos. Surface insects are adapted to living on the layer between air and water such as water striders or beetles that live both in and out of the water (Merritt and Cummins, 1996). The water column is where fish are commonly found. Nutrients that insects use as food and pollutants circulate in the water column (Merritt and Cummins, 1996). Insects will use water flow to drift from one area to another in search of food, to evade predation or competition, or when environmental conditions are unsatisfactory (Hart, 1981). Stream drift is the downstream movement of aquatic invertebrates and can influence population ecology aspects of distribution, abundance, and density. The bottom of a stream, or benthos, provides habitat for some insects such as mayflies that have flattened bodies with strong claws to cling to rocks, or the larval form of mayflies and caddisflies that have gill adaptations or midge larvae that burrow in substrate (Hershey et al., 2010).

Insects have morphological adaptations that allow them to exploit various microhabitats and food sources. Feeding adaptations can be categorized into tropic functional groups. These groups are scrapers, shredders, predators, piercers, and filter feeders (Table 3). Scrapers eat algae or periphyton, algae and the associated bacteria and detritus. Shredders break apart decomposing leaves into small pieces to eat them. Predators, also called engulfers, eat prey whole or in chunks. Piercers use a proboscis to suck fluids from aquatic plants or other insects. Filter feeders have setae, mouth brushes, fans, or silk secretions to collect fine particulate organic matter that is suspended in the water (Wallace, 1980)

Table 3. General classification for aquatic insects tropic feeding groups.
Merritt, R. W., and Cummins, K. W. (Eds.). (1996). An introduction to the aquatic insects of North America. Kendall Hunt.

Functional Group	**Food**	**Feeding mechanism**	**Consumer Status**	**Dominant Orders (scientific name)**	**Dominant Orders (common name)**
Filter feeders	Fine particulate organic matter: decomposing plants, wood	Filter or suspension feeders; gathers or deposit feeders	Primary consumers	Collembola, Ephemeroptera, Hemiptera, Trichoptera, Coleoptera, Diptera	Springtails, mayflies, true bugs, caddisflies, beetles, flies, and mosquitoes.
Scrapers	Periphyton: algae and associated material	Grazing scrapers	Primary consumers	Ephemeroptera, Hemiptera. Trichoptera, Lepidoptera, Coleoptera, Diptera	Mayflies, true bugs, caddisflies, moths and butterflies, beetles, flies, and mosquitoes
Shredders	Course particulate organic matter: aquatic plants- living or decomposing, wood	Chew course particulate organic matter	Primary consumers	Plecoptera, Ephemeroptera, Trichoptera, Lepidoptera, Coleoptera, Diptera	Stoneflies, mayflies, caddisflies, moths and butterflies, beetles, flies, and mosquitoes
Piercers	Living vascular hydrophyte cell and tissue fluids, algal cell fluids, animal fluids	Pierce tissues or cells and suck fluids	Secondary consumers	Trichoptera, Lepidoptera,	Caddisflies, moths, and butterflies
Predators (Engulfers)	Living animal tissue	Attack prey and ingest whole animals or parts	Secondary consumers	Plecoptera, Odonata, Ephemeroptera, Megaloptera, Neuroptera, Trichoptera, Lepidoptera, Coleoptera, Hymenoptera, Diptera	Stoneflies, dragonflies and damselflies, alderflies fishflies and dobsonflies, lacewings, caddisflies, moths and butterflies, beetles, bees wasps and ants, flies and mosquitoes

Invertebrates Diets and Food Webs

Aquatic insects are abundant and diverse. There are over 76,000 species of freshwater insects (Balian et al., 2007). In aquatic food webs, they serve as food items for salmon and other vertebrate and invertebrate organisms and are predators themselves. Food sources within ecological communities begins with primary producers such as plants or algae that form the base of food webs. Energy moves up as the trophic ladder as consumers or herbivores eat plants or algae. In stream ecology, the base of the food web or the primary production is supplied largely by allochthonous input and to a lesser extent alga (Brett et al., 2017).

The energy flow in a community or the trophic interactions in food webs can be described by either bottom up or top down processes. Bottom up food webs focus on producers and resources. When abiotic resources are compromised, primary productivity declines and trophic linkages are broken. Top down food webs move energy through trophic cascades (Paine, 1980). The top down model suggests that energy is regulated by topological connections that focus on predator-prey interactions (Paine, 1980). Both models offer good frameworks, but food webs are complex and can involve a combination of these processes with many factors of different strengths coming into play. This thesis will take a bottom up approach, focusing on space and nutrients regarding juvenile salmon habitat and their invertebrate prey.

Bottom up trophic interactions in food webs are limited by food resources (Power, 1992). Leaf litter from terrestrial sources has been identified as a more important food resource in forested systems compared to other sources of primary production (Brett et al., 2017). For aquatic systems, bottom up processes are controlled by drought, sunlight, and nutrients (Shurin, 2006). Runoff and detritus can move downstream and build up in streams that lie low in the watershed which means that these inputs are rarely a limiting factor (Lindeman, 1942). However, this could change as more land is transformed from forested to urban systems.

Understanding the foraging patterns of insects can inform the distribution and abundance of insect populations. A study examining periphyton found that mayfly nymphs (*Baetis tricaudatus*) foraged on uniformly covered concrete blocks over the course of a study while those on concrete blocks with lower food levels were observed to drift in search of more suitable food patches (Kohler, 1985). Stream experiments of caddisfly larvae (*Dicosmoecus gilvipes*) indicate a correlation between time and food where individuals spend more time in patches with ungrazed periphyton compared to patches that had been recently grazed (Hart, 1981). Entry into the water column as drift can be classified as active or passive. Active drift occurs when individuals release themselves from substrate in search of food, in the presence of predators, or to avoid water temperatures above or below thermal tolerances. Passive drift occurs when entry into the water column results from unsuitable environmental conditions such as flows that move substrate or dislodge insects (Kohler, 1985). Evidence of how insects employ these behaviors needs additional study, however food abundance is a contributing factor to the movement of aquatic invertebrates.

Phenology changes and smaller body sizes may have effects on food web dynamics. A change in the timing of emergence and reproduction of invertebrates can cause a mismatch in aquatic ecosystems where invertebrates arrive at times when their food availability is low or at times when they are unavailable as prey to upper trophic levels. Smaller adult body sizes of stoneflies or mayflies as preferred prey items to salmon may not be as metabolically beneficial as larger organisms or replacement prey (Hamilton et al., 2010). An important concept in aquatic ecology is that the fitness of predators is heavily dependent on available prey (Cushing, 1974). Temporal and spatial synchrony of predators and prey is linked to environmental conditions (Winder and Schindler, 2004) and mismatching has consequences throughout the food web, especially if keystone species such as Pacific salmon are involved.

Streams Conditions and Invertebrate Distribution

The physical habitat characteristics of small streams such as velocity and depth create high spatial variation that influences invertebrate drift. Stream habitat types can include pools, riffles, and glides, as well as a diversity of depths, velocities, and substrates. Stream flow can mobilize detritus and fine particles so it is available for shredders and filter feeders, however declining velocities reduce suspended particles and downstream food transport and these groups will likely drift in search of more resource rich environments (Naman et al., 2016). Pools or microhabitats that mimic lentic conditions are associated with aquatic plants and filamentous algae that piercers and scrapers use as food sources (Merritt and Cummins, 1996). Clingers, such as mayflies (*Ephemeroptera*) and caddisflies (*Trichoptera*) have long curved claws and ventral gills that act as a sucker to attach to surfaces in riffles (Merritt and Cummins, 1996). Burrowers, like some midges (*Chironomidae*), live in substrate or tunnel into plant stems in pools and in fine sediment (Merritt and Cummins, 1996). Skaters or swimmers, and some true bugs (*Hemiptera*), use riffles and glides to move between patches (Merritt and Cummins, 1996). The food these insects rely on is usually concentrated in patches and the distribution of certain species may depend on their physical adaptations to maintain locations (Merritt and Cummins, 1996).

Stream Health and Invertebrates

Invertebrate communities can be an indicator of stream health. The benthic index of biotic integrity (B-IBI) is one way to evaluate the biological health of streams based on their invertebrate community assemblages. The Benthic Index of Biotic Integrity (B-IBI) originated as a way to assess water conditions to meet Clean Water Act requirements (Karr, 1998) and has been adopted by various agencies in the Puget Sound to monitor the health of freshwater streams (Fore et al., 2013). Invertebrates are collected in various streams in the Puget Sound and the communities are analyzed using 10 metrics of taxa richness and diversity (PSSB, 2019). When overall taxa diversity is low and dominated by invertebrates that are more tolerant of human disturbance, the B-IBI scores or biological condition of the stream is considered fair to poor (PSSB, 2019). When overall taxa diversity is high and the invertebrate community contains mayflies, stoneflies, and caddis flies, the B-IBI scores and biological conditions are good to excellent (PSSB, 2019).

Invertebrates are good indicators of stream health because they are sensitive to changes in habitats. Developing a B-IBI for the Puget Sound is a way to identify taxa that are tolerant and intolerant to human disturbances in the region (Fore et al., 2013). In watersheds, disturbance such as human development is highly correlated with B-IBI (Fore et al., 2013). Human disturbances are identified by land use such as population density and road crossings, as well as land cover that evaluated the percent of forested and urban areas (Fore et al., 2013). Developed watersheds with more urban areas create physical and chemical conditions affecting salinity, temperature, and dissolved oxygen that differ compared to streams in upper watersheds with fewer human structures (Fore et al., 2013).

Some invertebrate taxa are more tolerant to development and the changes in habitat associated with it. The invertebrate community assemblage and their abundance are considered when correlating invertebrates with habitat that is polluted or degraded (Gaufin and Tarzwell, 1952). The B-IBI looks at overall taxa diversity and abundance of certain types of invertebrates when scoring the biological health of a site (PSSB, 2019). Sites with "Fair to Very Poor" scores indicate low taxa diversity and high abundance of tolerant taxa (PSSB, 2019).

Invertebrates and Temperature

As the climate warms, aquatic systems will experience warmer stream temperatures, changing flow patterns, and increasing storm events (Poff et al., 2002). In WRIA 10, the system will change from snow melt to rain dominated and water quantity in rivers and streams will be reduced as glacial melt in the spring and summer declines due to shrinking glaciers and less snow accumulation (Whitely Binder et al., 2019). Mean global air temperatures changes could affect terrestrial communities while warming streams could have consequences for aquatic communities.

Metabolism, growth, emergence, and reproduction are directly related to temperature. A large scale field experiment in a small first order stream near Toronto, Canada, increased water temperatures by 3.5 °C in the winter and 2 °C in the other seasons, conditions that are predicted by global warming scenarios following a doubling of atmospheric CO_2 (Hogg et al., 1995). The amphipods in the experimental channel showed accelerated development and adults began breeding two months earlier relative to a control and adult stonefly emerged two weeks earlier and maintained a smaller body size as adults (Hogg et al., 1995). The early emergence and smaller body sizes are consistent with Sweeney and Vannote's models (1978) that correlate small size and rising temperatures. In cooler climates, some invertebrates are living below their thermal tolerance and warming may improve fitness (Deutsch et al., 2008). However, the amphipods in Hogg's (1995) experimental streams did not exhibit extended breeding in warm winter streams although they are capable of continuous breeding. Invertebrate populations may not respond as predicted when environmental conditions are altered.

Chapter Three: Methods

Site Description

Clear Creek is in the City of Puyallup, on Puyallup Tribe Reservation land in WRIA 10 (Figure 2) The Clear Creek basin is a freshwater tidal stream characterized by floodplain wetlands with Swan, Squally, and Canyon Creek tributaries flowing into it and converging at the Puyallup River 2.9 miles upstream of Commencement Bay in the Puget Sound.

Clear Creek was divided into eight sites, each under various conditions of vegetation and development influences (Table 4). An imagery map of the area was used to assess land cover and land use (Figure 3). A group of four with representatives from the South Puget Sound Salmon Enhancement Group, Port of Tacoma, and the Puyallup Tribe reviewed an aerial image of the Clear Creek basin. Using local knowledge, the group determined that both parcel ownership and vegetation could be used to delineate reaches within the study area. There are distinct changes in habitat and a reach can be delineated by the type of vegetation with it. Sites 1, 5, and 6 were restored by the Port of Tacoma as part of their mitigation requirements. This restoration along Clear Creek enhanced wetland and riparian habitat with features such as native trees and shrubs, snags, large wood, and braided creek channels. The group classified sites 1 and 6 as mature forest using the Cowardin plant classes for wetland habitat, described below. Site 2 is surrounded by commercial and residential development and was considered developed. Site 3 has commercial development on the south side and 10 acres of restored habitat to the north. The restoration in site 3 occurred within the last eight years and the property is owned by the Puyallup Tribe of Indians. This area was classified as both developed and scrub-shrub. No sampling was done in site 4. Site 5 was restored and was classified scrub-shrub. Site 7 is an unrestored area of mature forest. Clear Creek in site 7 runs along the railroad on the south side and next to a dirt access road on the north side. Although there is mature forests in the vicinity of Clear Creek in this site, the ditched channel, lack of riparian buffer, invasive vegetation, and lack of intentional native planting led to the unrestored classification. Site 8 is unrestored and categorized as emergent. Site 8 has agricultural influences from adjacent farming activity. The neighboring farm produces organic crops. No livestock were observed.

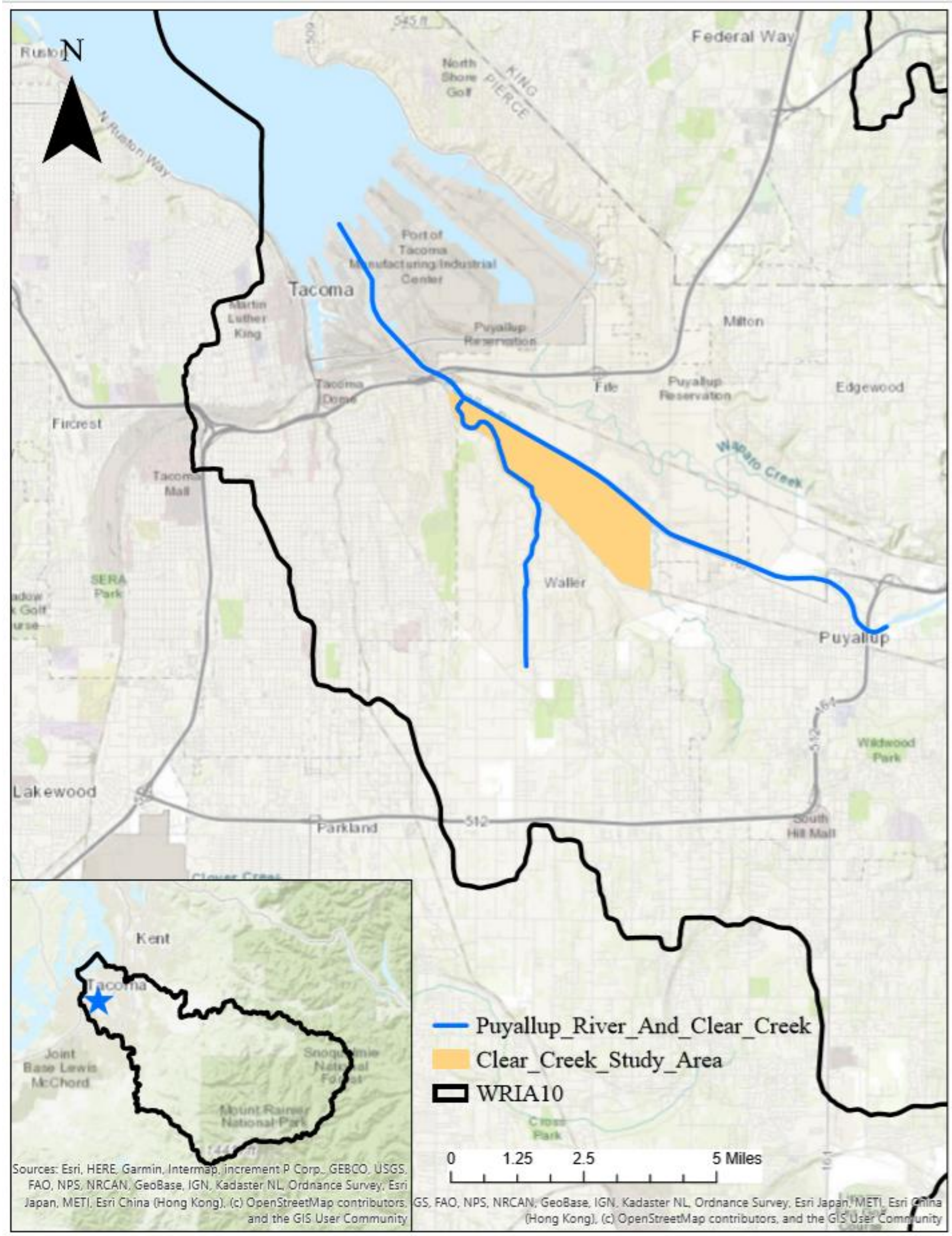

Figure 2. Map of Clear Creek, the Puyallup River, WRIA 10 and the Clear Creek study area.

Table 4. Description of the habitat units along Clear Creek and the surrounding influences of vegetation and development.

Site Number	Site Name	Parcel ownership	Surrounding Influences	Year Restored	Years Since Restoration
1	LCC	Port of Tacoma	Restored	1998	20
2	Pierce	Pierce County	Unrestored	N/A	0
3	Tribe	Puyallup Tribe of Indians	Partially Restored	2012	8
5	UCC	N/A	Restored	2016	3
6	Degobah	Port of Tacoma	Restored	2016	3
7	Squally	Port of Tacoma	Unrestored	N/A	0
8	Diamond	Pierce County/ Port of Tacoma	Unrestored	N/A	0

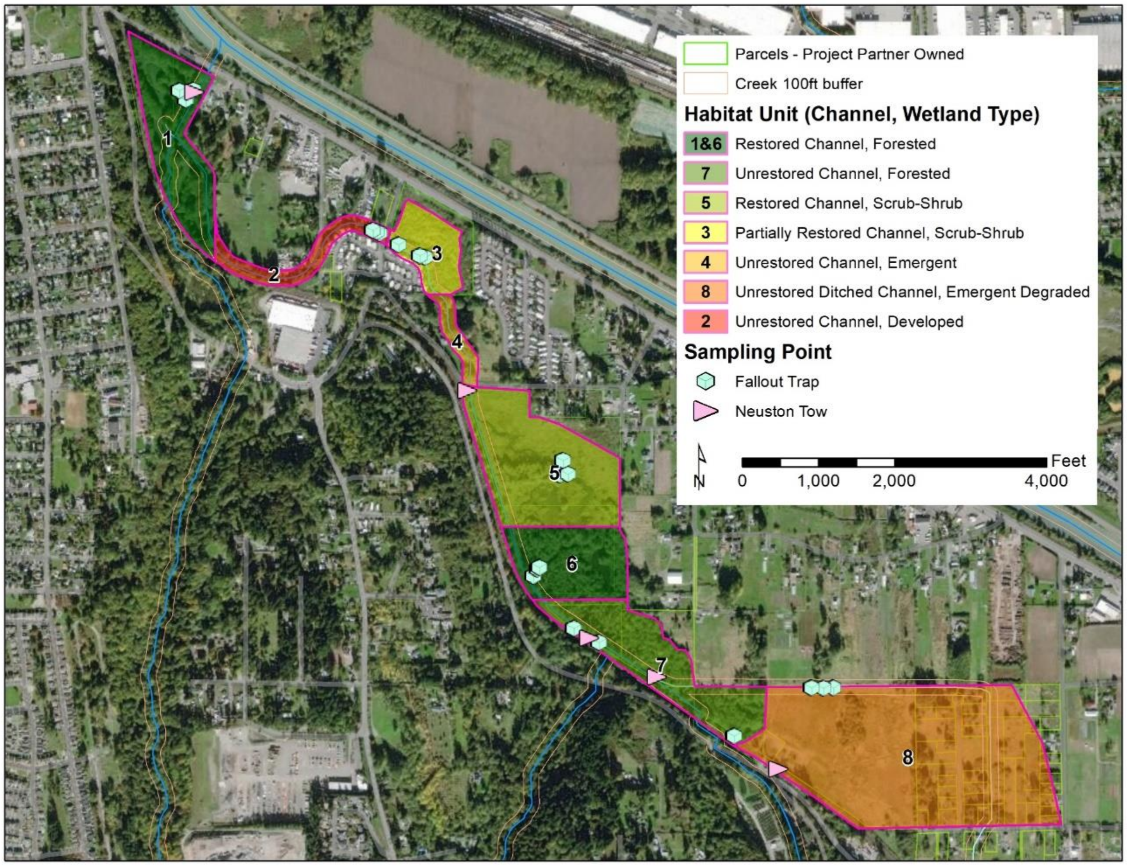

Figure 3. Sites and sampling locations along Clear Creek in Puyallup, Washington.

The Wetland Rating System for Western Washington is the approved method for classifying wetlands by the Washington State Department of Ecology (Hruby, 2014) in which plant communities are classified using the Cowardin classification. Cowardin plant classes are distinguished by the canopy layers that cover 30% or more of the wetland area (Cowardin et al., 1979). The Wetland Rating System for Western Washington uses four of the major Cowardin plant classes as described in Table 5. These Cowardin plant classes were the basis for determining distinct habitat units along Clear Creek. Specific woody and herbaceous species were identified during field sampling.

Table 5. "Cowardin plant classes used by the Washington State Department of Ecology in the Wetland Rating System for Western Washington."
Descriptions taken from Hruby, 2014. Hruby, T. (2014). Washington State Wetland Rating System for Western Washington: 2014 Update. (Publication #14-06-029). Olympia, WA: Washington Department of Ecology.

Cowardin Plant Class	**Description**
Forested	An area (polygon) in the wetland unit where the canopy of woody plants over 20 feet (6 m) tall (such as cottonwood, aspen, cedar, etc.) covers at least 30% of the ground. Trees need to be at least partially rooted in the wetland in order to be counted toward the estimates of cover (unless the unit is a mosaic of small wetlands as described in Section 4.3 and the trees are on hummocks between the wetlands). Some small wetlands may have a canopy over the unit, but the trees are not rooted within the wetland. In this case the wetland does not have a Forested class.
Scrub-shrub	An area (polygon) in the wetland unit where woody plants less than 20 feet (6 m) tall are the top layer of plants. To count, the shrub plants must provide at least % cover and be the uppermost layer. Examples of common shrubs in western Washington wetlands include the native roses, young alder, young cottonwoods, hardhack (*Spirea douglasii*), willows, and red-osier dogwood.
Emergent	An area (polygon) in the wetland unit covered by erect, rooted herbaceous plants excluding mosses and lichens, and where total cover of shrubs and trees is less than 30%. These plants have stalks that will support the plant vertically in the absence of surface water during the growing season. These plants are present for most of the growing season in most years. To count, the emergent plants must provide at least 30% cover of the ground and be the uppermost layer. Cattails and bulrushes are good examples of plants in the Emergent class. (Herbaceous plants are defined as seed-producing species that do not develop persistent woody tissue such as stems and branches. Many herbaceous species die back at the end of the growing season).
Aquatic Bed class	An area (polygon) in the wetland unit where rooted aquatic plants, such as lily pads, pondweed, etc., cover more than 30% of the surface of the standing water. These plants grow principally on or below the surface of the water for most of the growing season in most years. This is in contrast to the emergent plants described above that have stems and leaves that extend above the water most of the time. Aquatic bed plants are found only in areas where there is seasonal or permanent ponding or inundation. *Lemma* spp. (duckweed) is not considered an aquatic bed species because it is not rooted. Aquatic bed plants do not always reach the surface and care must be taken to look into the water.

Field Sampling

Fallout traps and neuston tows were used to describe the community of terrestrial and aquatic invertebrates in Clear Creek. Stomach contents of juvenile salmon were used to assess the prey items they consumed. Clear Creek was surveyed for vegetation in order to link primary production to terrestrial prey resources and inform how structure and function affects these resources. Table 6 describes the types of data collected, method of collection and the research questions each data hopes to address.

Table 6. Methods for data collection on Clear Creek.

Questions Addressed	Evidence	Methods used	Collection Dates
What are the terrestrial invertebrates in each habitat type?	Terrestrial Invertebrates	Fallout Traps: 3 replicates in sites 1, 2, 3, 5, 6, 7, 8	April 24, 2019 June 12, 2019 June 26, 2019
What are the aquatic invertebrates in each habitat type?	Aquatic Invertebrates	Neuston tows in sites 1, 5, 6, 7, 8	June 12, 2019 June 26, 2019
What is the vegetation community in each habitat type?	Habitat Type	Aerial images to delineate sites and a vegetation survey of species and percent cover	June 12, 2019
What are the diet preferences of juvenile salmon in Clear Creek?	Stomach Contents	Gastric lavage on juvenile salmon caught by beach seine in four sites of Clear Creek	April 24, 2019 May 22, 2019 June 13, 2019 June 27, 2019 July 16, 2019

Terrestrial fallout traps were placed in sites 1, 2, 3, 5, 6, 7, and 8. Clear, plastic traps were 22 inches in length by 16 inches width. The traps were set on the bank within 100 feet of the ordinary high-water mark to collect terrestrial invertebrates. In the sites where the water level changes and stream flow would reach the trap location, PVC pipes were installed to allow the trap to rise and fall with the tide. Three replicates were placed in each reach with a solution of sieved creek water and natural dishwashing soap to break water tension so that invertebrates were trapped within the bin. The location was marked using ESRI Collector (ESRI Inc., Redlands, CA, U.S.A.) to ensure that the traps were set in the same place for two sampling events. Fallout traps were left in place for 48 hours. A 0.50 mm mesh sieve was used to strain the invertebrates from the fallout traps. The samples were preserved in a 70% isopropyl alcohol solution. Each sample had a data sheet to record time, date, location, and replicate number for identification in the laboratory.

A neuston net was submerged in the thalweg of Clear Creek in sites 1, 4, 6, 7, and 8 to collect aquatic invertebrates in the water column. The neuston net had a mesh size of 335 micrometers, is 6 feet long, and had a diameter of 2 feet at the opening. The submerged neuston net was held just under the surface for 30 minutes in each reach. After this time, the net was carried to the stream bank for processing. The cod end of the net was removed, and contents were poured into a 0.50 mm mesh sieve to strain the invertebrates into sample jars. Each sample has a data sheet to record time, date, and location. The samples were preserved in a 70% isopropyl alcohol solution. Aquatic invertebrate samples were collected on the same dates and times the fallout traps were set.

After assessing the collection methods for aquatic invertebrates, it was determined to vary the time spent submerging the neuston net in order to maintain consistent flow through the net and make contents more comparable between reaches. All neuston data collected in 2019 was sampled for 30 minutes at each site. For future data collection, a flow meter will be used concurrently with neuston tows to standardize the volume of water that passes through the net.

A vegetation survey was completed with the initial invertebrate collection. All herbaceous and woody species were identified within a 1m and 12 m radius respectively of each terrestrial fallout trap. Height and absolute percent cover were recorded. All species were abbreviated using the United States Department of Agriculture plants list (USDA, 2019).

Stomach contents were taken from salmon via gastric lavage. A 60-cc syringe with a plastic tip was inserted into salmon orally. Sieved stream water was used to flush out stomach contents from up to 10 salmon of each species and mark type. Contents were batched according to species and mark type. Each sample was labeled with location, date, time, species, mark type, and number of salmon in the batch for identification in the laboratory. Juvenile salmon were collected using a 100-foot beach seine. The seine was deployed in sites 1, 3, and 5 for two different sampling events. The locations were chosen based on access and site conditions.

Laboratory Analysis

All samples were processed at the U.S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Invertebrate Ecology Laboratory in Fremont, CA. Terrestrial invertebrates and stomach lavage content samples were enumerated and identified using stereo-dissection microscopes at a magnification range of 7-45x to the most practical taxonomic level.

Invertebrates from neuston tows were enumerated and identified using stereo-dissection microscopes at a magnification range of 7-45x to the most practical taxonomic level. When the entire tow cannot be processed, due to large amounts and time constraints, a sub-sample was processed. The sample was mixed to homogenize contents. A 10-mL sub-sample of the tow was put into a 1000 mL container. The 1000 mL container was filled with water and invertebrates were enumerated and identified. This sub-sample represents 1% of the total and values were extrapolated.

Data Analysis

Data analysis was done using R 3.6.3, Holding the Windsock. I looked for differences in invertebrate taxa richness and diversity to test the null hypothesis that invertebrate communities do not differ between habitat types. Table 7 summarizes the various statistical tests to be employed. I calculated taxa richness within each reach from the number of species in each sample. Taxa diversity was calculated using Shannon's Index or "H´". ANOVA was used to test for differences in richness and diversity between restored, unrestored, and partially restored reaches. Linear regression was used when reaches were defined as years since restoration. Principle Component Analysis was used to measure distances between sample diversity to evaluate similarity between samples.

Table 7. Statistical tests used for data analysis.

Data (independent)	Data (dependent)	Data Type	Test
Vegetation (percent cover)	Terrestrial Invertebrate abundance and diversity	Continuous	Linear Regression
Reaches (years since restoration)	Terrestrial and aquatic invertebrate abundance and diversity	Continuous	Linear Regression
Reaches (developed vs restored)	Terrestrial and aquatic invertebrate abundance and diversity	Categorical	ANOVA

The key variables in this study were the habitat types and abundance and diversity of invertebrates collected. The independent (explanatory) variable was habitat type: Forested (restored), Forested (unrestored), Developed, Scrub shrub, Emergent. The dependent (response) variable was the count and type of terrestrial invertebrates within each habitat.

Chapter Four: Results

A vegetation survey was performed and all trees, shrubs, and plants surrounding terrestrial fallout traps were recorded. Three vegetation surveys were performed per site. The three surveys were combined to describe vegetation within a site. The native and invasive vegetation supported general categorization of sites as restored, unrestored, and partially restored. Fallout traps describe the terrestrial invertebrate community. Neuston tows describe the aquatic invertebrate community. Stomach contents from juvenile Chinook and Coho from Clear Creek in Water Resource Inventory Area (WRIA) 10 were collected from April to July 2019. WRIAs are defined by the major river in an area. WRIA 10 is also called the Puyallup-White watershed and includes all the tributaries that drain into these two rivers. Results are organized into four sections 1) restoration and vegetation survey, 2) fallout traps, 3) neuston tows, and 4) gastric lavage 5) linear regression 6) Principle Component Analysis.

Restoration

Each site is categorized as either restored, partially restored, or unrestored (Table 8). A restored site is defined as a site that had native vegetation installed on both sides of the stream. Partially restored sites had native vegetation installed but receives influences from paved surfaces and built structures within 200 feet of the stream. Unrestored sites have not experienced any native vegetation replanting.

There are a total of seven sites (Table 8). Site 1 is Lower Clear Creek the furthest downstream site in this study, at the confluence of the Puyallup River. The parcel is owned by the Port of Tacoma and was replanted with native vegetation in 1998. Site one is considered restored. Site 2 is called Pierce. It is owned by Pierce County. No native planting has occurred on this site. Site 2 is unrestored. Site 3 is called Tribe. The Puyallup Tribe owns the parcel on the north side of Clear Creek. The property was purchased in 2012. All structures on the property were removed and the parcel was planted with native vegetation. The south side of Clear Creek on site 3 is a commercial property with multiple homes within 200 feet of the stream with little to no riparian buffer. Site 3 is affected by influences from both restored and developed habitats. Site 3 is partially restored. Due to time and funding limitations, and similarities in habitat to other sites, no sampling occurred on site 4. Sites 5 and 6 are owned by the Port of Tacoma. These sites were replanted in 2016 with native vegetation. A robust riparian buffer, connection to the floodplain, and limited human disturbance qualify these sites as restored. Site 7 is forested with little development except for the railroad. This site has not experienced intentional native planting; therefore, it is categorized as unrestored. Site 8 is called Diamond. There used to be multiple single-family homes at this location. Pierce County purchased these homes to protect residents from a high risk of flooding. The houses on site 8 were removed and reed canarygrass emerged. This site is covered by invasive vegetation and is categorized as unrestored.

Table 8. Sites on Clear Creek and their restoration status.
The order is from downstream (site 1) to upstream (site 8). Site 4 was not sampled.

Site Number	Site Name	Category	Date Restored	Years Since Restoration
1	LCC	Restored	1998	20
2	Pierce	Unrestored	N/A	0
3	Tribe	Partially Restored	2012	8
5	UCC	Restored	2016	3
6	Degobah	Restored	2016	3
7	Squally	Unrestored	N/A	0
8	Diamond	Unrestored	N/A	0

Vegetation Survey

On June 12, 2019, all herbaceous vegetation within a 1m radius of each fallout trap and all woody vegetation within a 12m radius were recorded. Absolute percent cover was estimated. Because cover is estimated at multiple layers of canopy, the absolute percent cover often exceeds 100 percent. Each canopy layer was evaluated in the field using Cowardin plant classes: forested classes of woody vegetation over 20 feet tall, scrub-shrub woody vegetation less than 20 feet tall, and emergent herbaceous plants. Aquatic Bed classes were omitted from the survey because the information collected only describes vegetation surrounding terrestrial fallout traps.

Invasive species were calculated as a percentage of absolute cover for each trap. Three traps in each site were averaged to get one percentage that describes invasive species as part of absolute cover. Percent invasive species is reported in relation to absolute percent cover for each fallout trap (Table 9). Invasive species along Clear Creek include reed canarygrass and English Ivy, two Class C noxious weeds. All sites are categorized by level of restoration. The three sites with the highest average invasive vegetation are categorized as unrestored. Sites 2, 7, and 8 are unrestored. The highest percentage of invasive vegetation relative to other species was in site 8. All traps in site 8 were 100% surrounded by reed canarygrass. The next highest percentage of invasive species was in site 2. Site 2 averaged 62.72 percent invasive species compared to native species. The third highest percentage of invasive species was in site 7. Site 7 averaged 53.60 percent invasive species compared to native species.

Site 1, site 5, and site 6 are categorized as restored. Site 3 is partially restored. There were 46 different species of trees, shrubs, and ground cover across seven sites. There were 42 different vegetation species on three restored sites (Table 10). There were 10 different vegetation species on one partially restored site. The unrestored site had 11 different species of vegetation. Shannon diversity values were applied using percent cover for each species in each site (Figure 4). Shannon Index values are traditionally calculated using individual counts. For this vegetation analysis, percent cover was used to calculate Shannon Index values. Calculating Shannon Index in this way could bias the results because percent cover relates to tree size. A large tree will produce a large percent cover. A higher percent cover could result in a higher diversity value. When Shannon Index is normally calculated with individual counts, the size of the individuals does not skew the results. However, the calculation provides a general assessment of diversity and is consistent with the analysis for fallout traps, neuston tows, and lavage samples, making the comparison across categories similar. The three restored sites had the highest species diversity. The three unrestored sites had the lowest species diversity. Site 8 was 100 percent reed canarygrass. There is no diversity in vegetation at this site.

In addition to assessing the diversity of vegetation which are mainly native plants, an analysis of invasive species and their relationship to restoration is informative. Linear regression was calculated for years since a site was restored and the percent of invasive vegetation on each site (Figure 5). A R^2 value of 0.3 was calculated for this model. There is a downward trend that shows high percentages of invasive vegetation in sites with no restoration and low percentages of invasive vegetation in sites with some restoration. Invasive vegetation is under 4 percent in the sites restored in 2016 and remains under 9 percent in the site restored 20 years ago. The partially restored site is lowest in invasive vegetation; however, the vegetation survey was only conducted in fallout traps on the north side of Clear Creek that was restored eight years ago.

Table 9. Percent invasive vegetation for each site from highest to lowest.

Site	Percent Invasive
8	100%
2	62.72%
7	53.60%
1	8.52%
6	3.81%
5	3.45%
3	2.38%

Table 10. Vegetation on Clear Creek grouped by site condition.

Restored		Partially Restored	Unrestored
American skunkcabbage	Ovate spikerush	Indian plum	Davis mountain mock vervain
American speedwell	Prickly currant	jewelweed	Arctic raspberry
Arabian schismus	Redosier dogwood	Pacific willow	Black cottonwood
Arctic raspberry	Reed canarygrass	Red alder	jewelweed
Bay forget-me-not	Robert geranium	Redosier dogwood	Marsh horsetail
Beaked hazelnut	Salmonberry	Reed canarygrass	Oregon ash
Black cottonwood	Sitka spruce	Salmonberry	Pacific willow
Blue wildrye	Sitka willow	Sitka willow	Red alder
Cascara buckthorn	Slough sedge	Twinberry honeysuckle	Red elderberry
Cluster rose	Spreading gooseberry		Reed canarygrass
Common ladyfern	stickywilly		stickywilly
Common rush	Stinging nettle		Stinging nettle
Dune willow	Toad rush		
English ivy	Tufted hairgrass		
European bur-reed	Twinberry honeysuckle		
Field forsetail	Two-headed water starwort		
Geyer willow	Vine maple		
jewelweed	Western swordfern		
Marsh horsetail	White willow		
Mosquito plant	Youth on age		

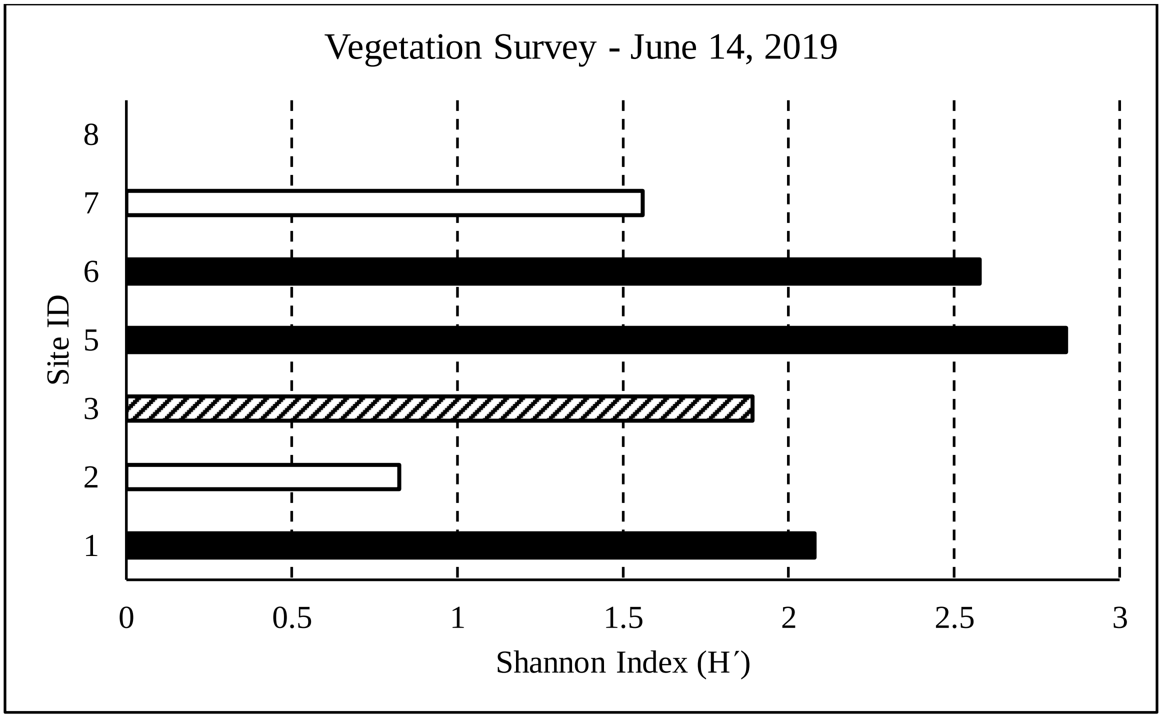

Figure 4. Average species diversity of vegetation per site from upstream to downstream. Solid fill indicates restored sites, hatched fill indicates partially restored sites, no fill indicates unrestored sites.

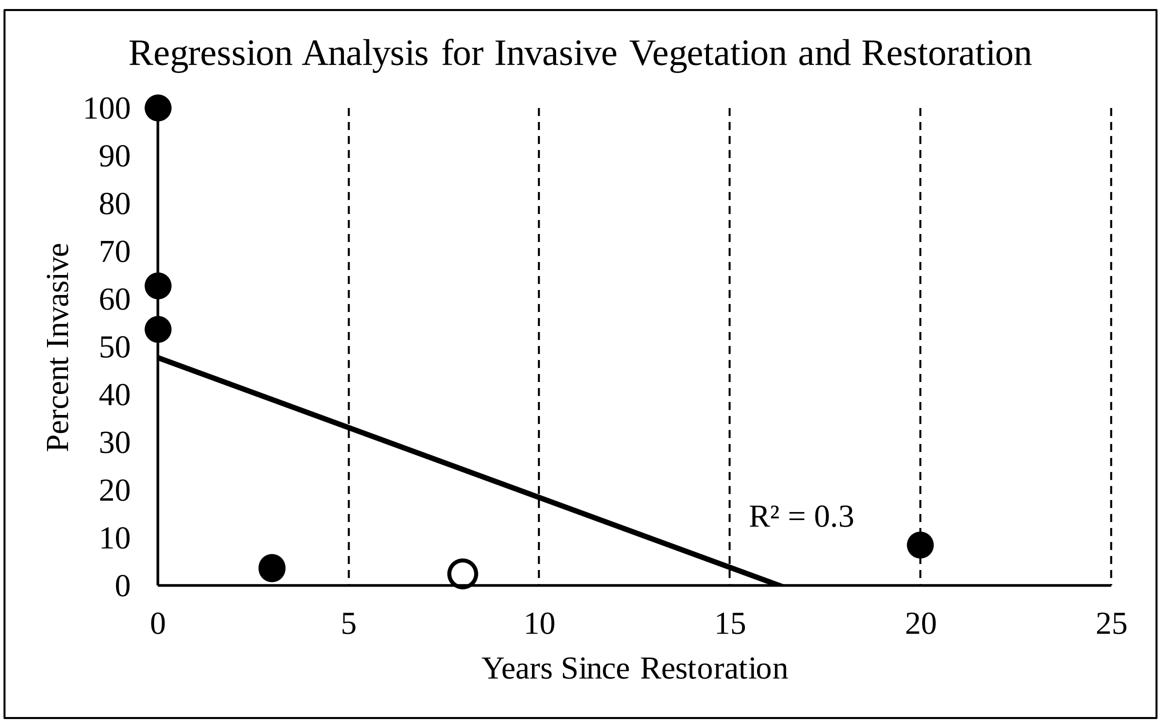

Figure 5. Linear Regression for percent invasive vegetation for each site and years since restoration.
Hollow data point shows the site with partial restoration.

Terrestrial Fallout Traps

Fallout traps were set 48 hours a time for one sampling event in April 2019 and two sampling events in June 2019. The first sampling event was April 24 to April 26, 2019. This event was a test for fallout traps and the only site sampled was site 3, the Tribe's property. Three traps were set in site 3 in the month of April on site 3. The next two sampling events were June 12 to June 14, and June 26 to June 28, 2019. Fallout traps were set in all seven sites along Clear Creek. Three fallout traps were placed in each site.

The commonly found invertebrate taxa found in all fallout traps were the classes Gastropoda, Insecta, and Arachnida, the sub class Collembola, and the orders Isopoda, Hemiptera, Diptera, Coleoptera, Hymenoptera, and Thysanoptera (Table 11). The average number of invertebrates in each trap was similar across all sites except for site 8, the Diamond property which had a higher number of invertebrates (Figure 6). Invertebrates at the Diamond property were mostly Diptera (n = 383) and Hymenoptera (n = 194). The percentage of each taxa is shown in Figure 7. Diptera were most common in all traps. Hymenoptera were present at the site 2, 6, 7, and 8. Arachnida, and Hemiptera were present at all sites.

Average taxa diversity was calculated using Shannon Index (H´). Each site had 3 replicate terrestrial fallout traps for two sampling events in June 2019. A total of n = 6 traps were averaged for each site: 1 (Lower Clear Creek), 2 (Pierce), 5 (Upper Clear Creek), 6 (Degobah), 7 (Squally), and 8 (Diamond). Site 3 was sampled three times for a total of n = 9 replicate terrestrial fallout traps. Site 3 was sampled once in April 2019, and twice in June 2019 concurrently with the other sites. A Shannon Index value was calculated for each trap, then averaged for all traps within a site. Sites 1, 5, and 6 were combined into one category to describe taxa richness and diversity of restored sites. Sites 2, 7, and 8 were combined into one category of unrestored sites. Site 3 was categorized as partially restored.

The sites were grouped to compare taxa richness and taxa diversity between categories and to increase sample size to n = 18 for restored, n = 18 for unrestored, and n = 9 for partially restored. The null hypothesis is that the means will not vary significantly between groups. The alternative hypothesis is that at least one mean is different. An Analysis of Variance (ANOVA) was used to compare the means of taxa richness between three categories (Table 12). A Shapiro-Wilk test was employed to test for normality. All p-values were less than 0.05 and the data was considered normally distributed. Taxa richness does not vary significantly between restored, unrestored, and partially restored sites ($F_{2,12} = 0.438$, $p = 0.655$). An Analysis of Variance (ANOVA) was used to compare the means of taxa diversity between three categories (Table 13). The mean diversity of fallout taxa in restored sites is significantly different than unrestored sites (Tukey's HSD, $p = 0.034$) (Table 14). There is no significant difference in taxa diversity between restored and partially restored sites. There is no significant difference in taxa diversity between unrestored and partially restored sites. The mean taxa diversity and evenness for April 2019 are shown Figure 8. Site 3 was the only site sampled in April. Mean taxa diversity and evenness for June are shown in Figure 9 and Figure 10. All sites were sampled in June. Standard deviation was calculated from the average of all 18 fallout traps in restored and unrestored sites and 9 fallout traps in the partially restored sites. Error bars represent standard deviation. Average taxa diversity and evenness is reported in Figure 11. Taxa diversity is lowest in the unrestored sites and highest in restored sites.

Evenness is the proportion of taxa present on a site. The more equal the taxa are in proportion to each other, the higher the evenness. A site with low evenness indicates that a few species take over the site. Evenness scores range from 0.50 in unrestored sites to 0.70 in restored sites.

Table 11. Commonly found taxa in terrestrial fallout traps.

Classification	**Scientific Name**	**Common Name**
Class	Gastropoda	Slugs and Snails
Class	Other Insecta	Insects
Class	Arachnida	Spiders, scorpions, ticks, mites
Subclass	Collembola	Springtails
Order	Isopoda	Crustaceans
Order	Hemiptera	True Bugs (aphids, cicadas, hoppers)
Order	Diptera	Flies and Mosquitoes
Order	Coleoptera	Beetles
Order	Hymenoptera	Bees, Ants, and Wasps
Order	Thysanoptera	Thrips

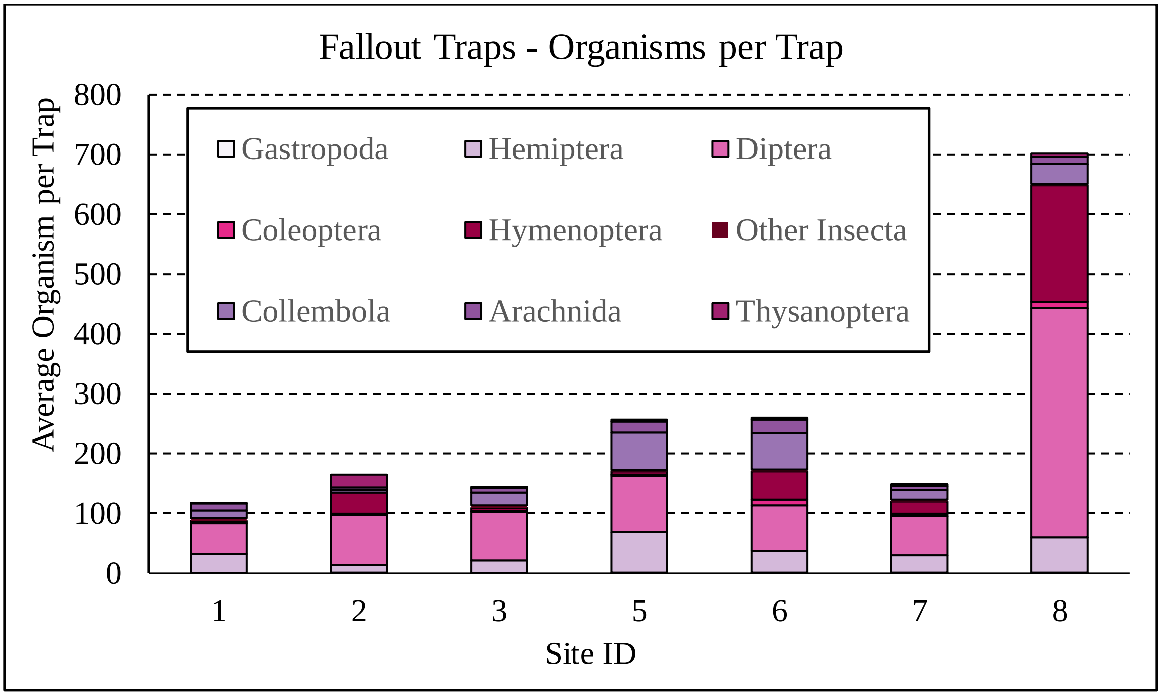

Figure 6. Average number of organisms per terrestrial fallout trap
Sites are organized from downstream (LCC) to upstream (Diamond). All sites were sampled twice in June. One site (Tribe) was sampled once in April.

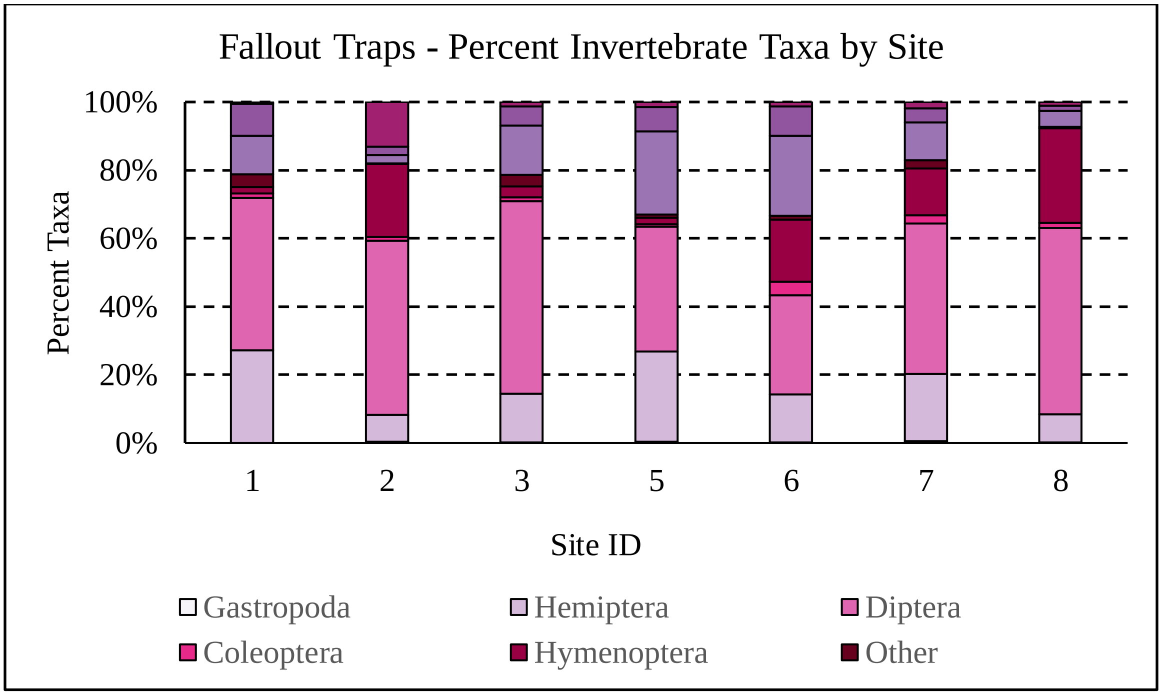

Figure 7. Percent invertebrate taxa per site for all terrestrial fallout traps. Sites are organized from downstream (LCC) to upstream (Diamond). All sites were sampled twice in June. One site was sampled once in April.

Table 12. ANOVA summary of taxa richness for fallout traps.

	df	Sum of Squares	Mean squares	F-ratio	p
Category	2	20.9	10.45	0.438	0.655
Residuals	12	286.0	23.84		

Table 13. ANOVA summary of taxa diversity for fallout traps.

	df	Sum of Squares	Mean squares	F-ratio	p
Category	2	1.157	0.5783	4.217	0.041
Residuals	12	1.646	0.1371		

Table 14. Tukey test summary of taxa diversity for fallout traps.

Category	Difference	lwr	Upr	P adj
Restored - Partially Restored	0.2046667	-0.3935831	0.8029164	0.6429190
Unrestored-Partially Restored	-0.4845000	-1.1472551	0.1782551	0.1672673
Unrestored-Restored	-0.6891667	-1.3269030	-0.0514303	0.0341613*
*statistically significant result				

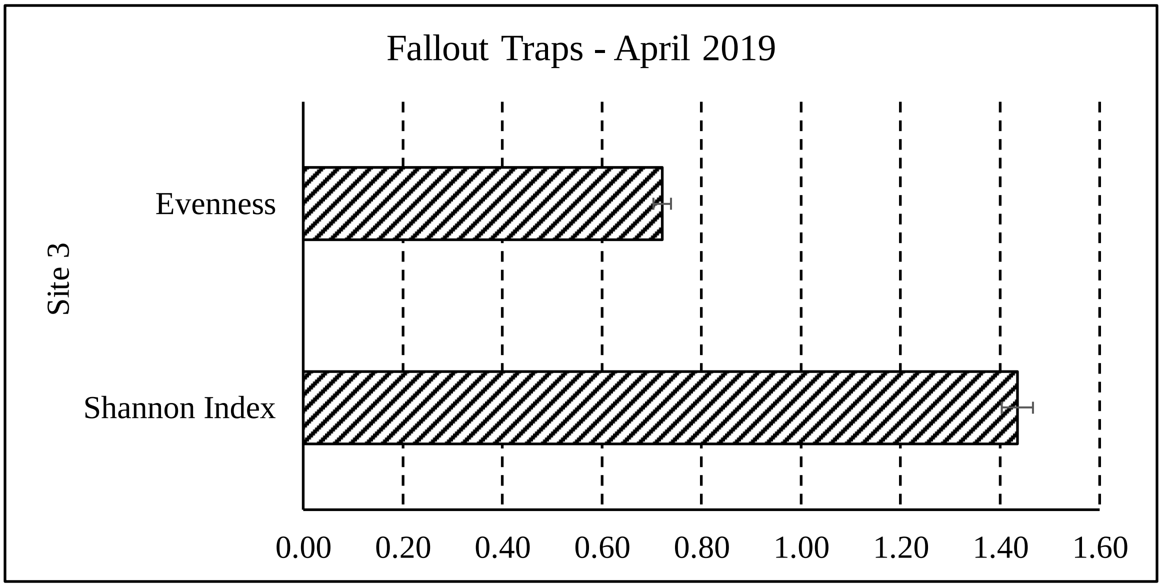

Figure 8. Diversity and evenness scores for fallout traps in the month of April 2019. Only one site (site 3, Tribe) was sampled in April. There were three fallout traps sampled in April. Hatched fill indicates partially restored sites.

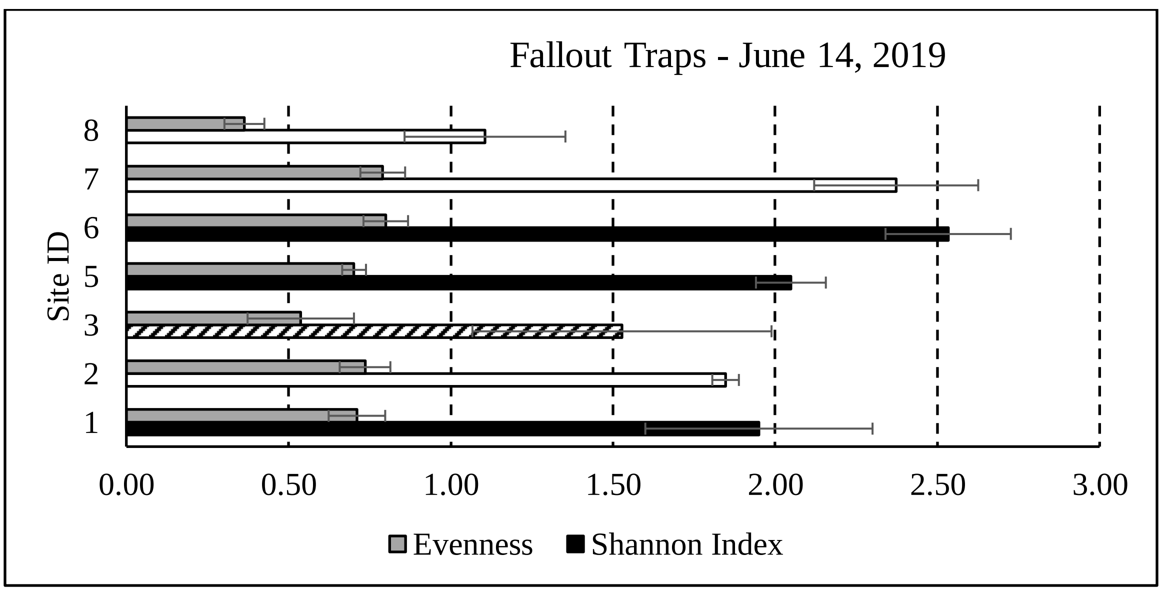

Figure 9. Diversity and evenness scores for fallout traps set on June 14, 2019.
All seven sites were sampled in June. Three fallout traps were placed in each site. For diversity scores: solid fill indicates restored sites, hatched fill indicates partially restored sites, no fill indicates unrestored sites. Evenness scores are grey for every site.

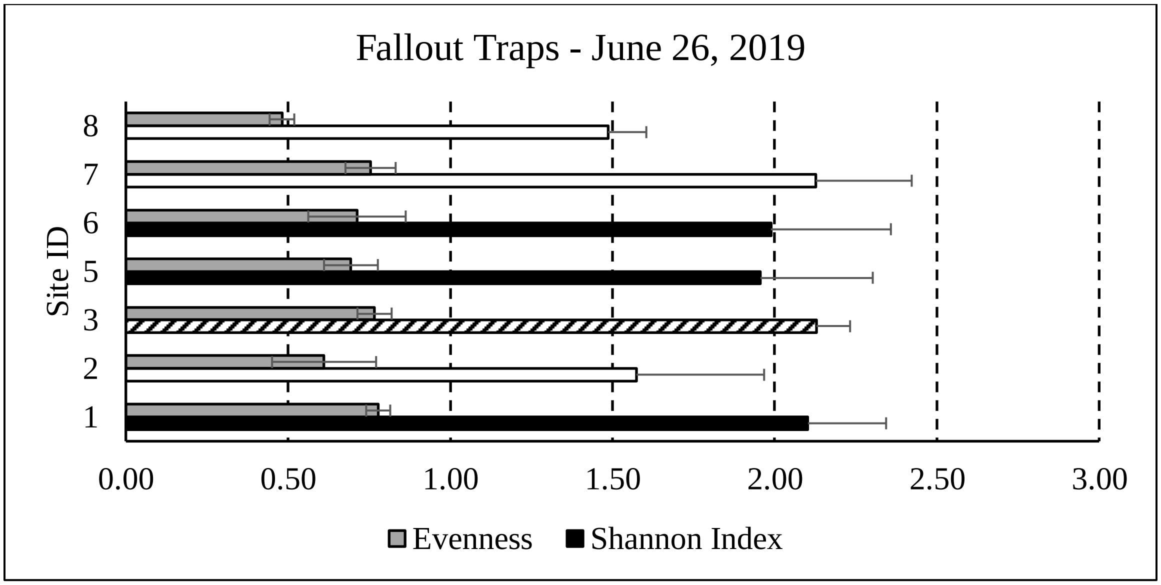

Figure 10. Diversity and evenness scores for fallout traps set on June 26, 2019.
All seven sites were sampled in June. Three fallout traps were placed in each site. For diversity scores: solid fill indicates restored sites, hatched fill indicates partially restored sites, no fill indicates unrestored sites. Evenness scores are grey for every site

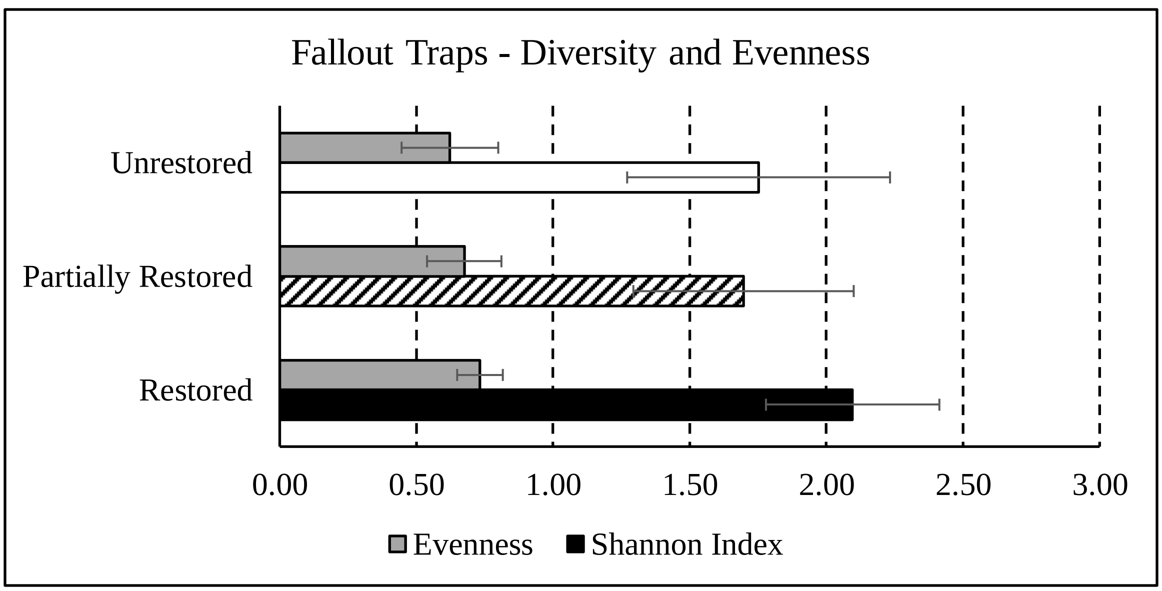

Figure 11. Mean taxa diversity and evenness of restored, unrestored, and partially restored sites for fallout samples.
Solid fill indicates restored sites, hatched fill indicates partially restored sites, no fill indicates unrestored sites. Evenness scores are grey for every site

Neuston Tows

The aquatic invertebrate community was characterized using neuston tows. A total of 10 tows were performed for five sites on two different dates in June 2019. Neuston tows were set 30 minutes at a time to collect invertebrates in the water. The neuston tows were collected on June 12 and June 26, 2019. The neuston tows were performed on the same day the terrestrial fallout traps were set so that we could capture aquatic invertebrates concurrently with terrestrial invertebrates. Neuston tows were set in five sites along Clear Creek (Figure 3). Site 8 is the most upstream site. This neuston tow was set in Canyon Creek, a tributary that flows through the Diamond property into Clear Creek. Moving downstream, the next neuston tow was set just above the confluence of Canyon Creek and Clear Creek. The next two neuston tows were set above and below the confluence of Squally Creek and Clear Creek. The neuston tow in site 5 is downstream of the restoration on sites 5 and 6. The fifth neuston tow is at the most downstream location on site 1.

All invertebrates from 12 and 26 June neuston sampling events were added and averaged (Figure 12). Diptera were the most common taxa found at all sites. Site 1 had the highest average Diptera count (n = 330, 72%). Site 8 had the lowest average Diptera (n = 144, 38%). Hemiptera were present at all sites. The highest average Hemiptera count was in site 6 (n = 111, 17%). Site 8 had the lowest average Hemiptera (n = 17, 5%). The average number of Coleoptera and Hymenoptera were low throughout each site. Coleoptera averages ranged from 6-33. Average Hymenoptera per site ranged from 1-17. Average Isopoda were negligible in all reaches except site 5. Site 5 averaged 22 isopods in two neuston tows. Gastropods averages ranged from 1-7. Other Insecta were the class of insects that could not be identified to order. Percentage of invertebrates in neuston tows at each site are shown in Figure 13.

Three of five sites are categorized as restored. Two of five sites are categorized as unrestored. The samples are independent and random. The sites were grouped to compare taxa richness and diversity between categories. The null hypothesis is that the mean of the restored sites is the same as the mean of the unrestored sites. The alternative hypothesis is that the means are not the same. A two-sample t-test was used to compare the means of restored and unrestored sites. There is no significant difference in taxa richness between the mean of the unrestored sites and the mean of the restored sites (Table 15). There is no significant difference in average taxa diversity between restored and unrestored sites. Average taxa richness and diversity were lower in restored sites (n=6) compared to unrestored sites.

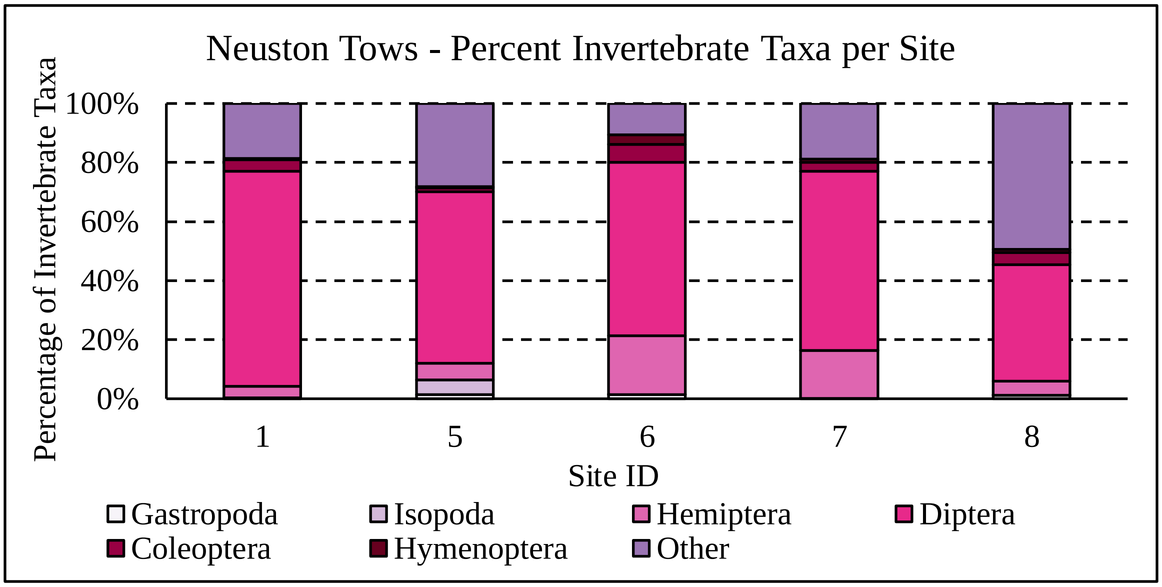

Figure 12. Average number of invertebrates per site from two neuston sampling events. Sites are organized from downstream (site 1) to upstream (site 8).

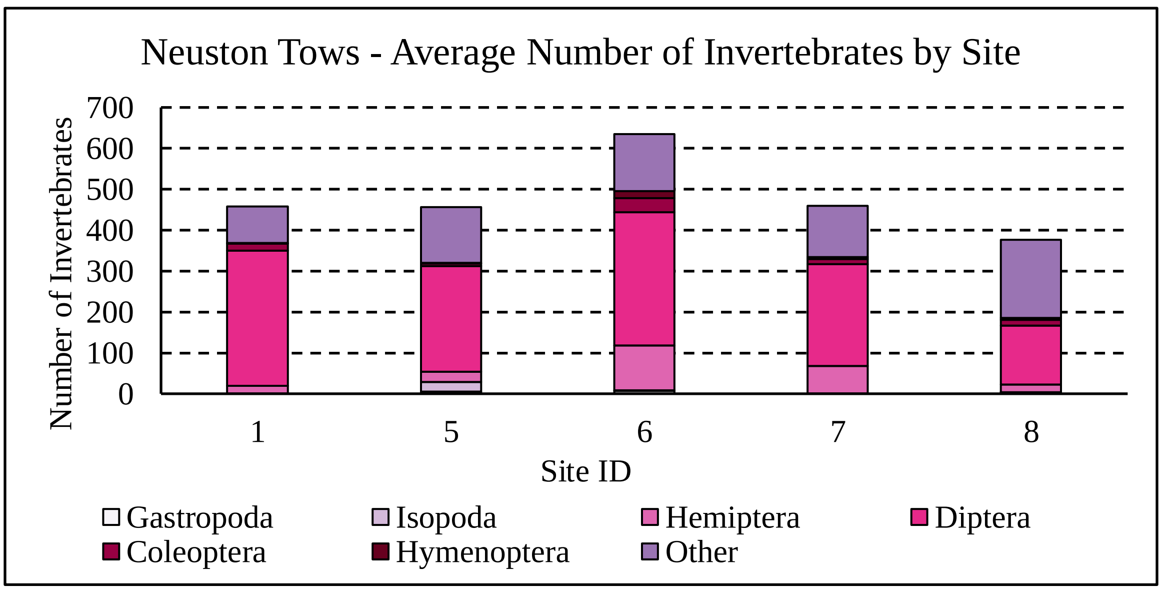

Figure 13. Percent invertebrate taxa per site for two neuston tows.
Sites are organized from downstream (LCC) to upstream (Diamond).

Table 15. T-test comparing the mean of restored and unrestored sites for taxa richness and diversity of neuston tows.

Neuston t-test: Taxa Richness	**Neuston t-test: Taxa Diversity**
Difference between means: -1.66	Difference between means: -0.37
t= -0.288	t = -2.083
df= 3	df = 3
p = 0.792	p = 0.129
Confidence Interval: 95%	Confidence Interval: 95%

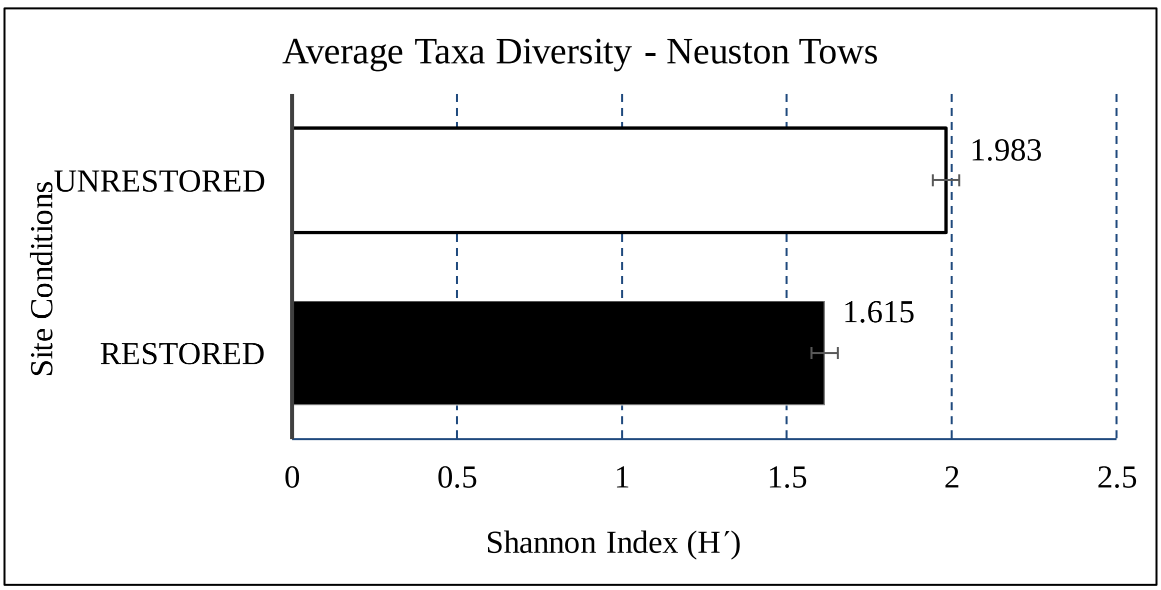

Figure 14. Average taxa diversity of four neuston tows in unrestored sites and six neuston tows in restored sites.
Solid fill indicates restored sites and no fill indicates unrestored sites.

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Gastric Lavage Stomach Content

Stomach contents were taken via gastric lavage from 92 Chinook and Coho of various mark types. These salmon were caught using a 100-foot beach seine in sites 1, 3, and 5. There were two seine locations in site 1. Fish were caught at the upstream side of the culvert on Clear Creek which is located on the Port of Tacoma's restoration site. This site is referred to as Lower Clear Creek. Fish were also caught on the downstream side of the culvert at the mouth of Clear Creek. This site is called Tidegate. There are many areas in Clear Creek where the stream is too deep or too wide to seine and areas where the habitat prevents entry. Seine sites were chosen based on ease of use and access. The first seine was completed on April 24, 2019 at the site 3. The next seine occurred on May 22, 2019 at site 3. The third seine was completed on June 12, 2019 on site 5. The fourth seining event occurred on June 13, 2019 on site 1. Both site 1 and 3 were seined on June 27, 2019. The final seine of the season was on July 16, 2019 at the Tidegate and site 3.

Throughout the season, Chinook and Coho consumed 83 different invertebrate taxa from April to June across four sites. The five most common prey items identified in stomach content samples are ranked in Table 16. Chironomidae larvae and pupae were the most abundant prey (n = 661). Chironomidae are aquatic in their larva and pupa form and terrestrial as adults. This taxon was found in the stomach contents of Chinook and Coho throughout the season. Consumption peaked in the month of June when 20 unmarked and 4 ad clip Chinook on Lower Clear Creek consumed 182 Chironomidae. The second most common prey in stomach contents were Ceratopogonidae larvae and pupae (n = 124). Ceratopogonidae are also aquatic in the larva and pupa stages. In the month of June, four unmarked Coho at the Upper Clear Creek site consumed 50

Ceratopogonidae. The next most common prey consumed by both Chinook and Coho were Aphididae adults (n = 60). Aphididae are terrestrial invertebrates. Both Chinook and Coho consumed aphids in the months of May, June, and July. Aphid peak consumption was 30 individuals by 12 Chinook at the Tidegate site. Aphid abundance in stomach contents is followed closely by Chironomidae adults (n = 59) and Hymenoptera larvae (n = 58). Both taxa are terrestrial. Hymenoptera larva were present in stomach contents in June and July only. No Hymenoptera larvae were found in stomach contents collected in April or May. The top ten prey items by percentage are shown in Figure 15. Chironomidae larvae and pupae are up to 80 percent of Chinook and Coho diets in April, May, and June, but drop off by July. Other taxa consumed are shown in Figure 16. Chinook and Coho consumed 72 other taxa from April to July 2019.

Chironomidae larvae and pupae were the most abundant prey item in stomach contents. Chironomidae comprised 42 percent of taxa in all stomach content samples. In the immature life stages, Chironomidae are aquatic. Chironomidae larvae and pupae are only 0.10 percent of taxa in fallout traps but are 42 percent of the taxa collected from neuston tows. Ceratopogonidae were the second most common prey item found in stomach content samples. Ceratopogonidae larvae and pupae were 8 percent of stomach contents. Ceratopogonidae larvae and pupae were 0.009 percent of fallout taxa and 0.55 percent of neuston taxa. The most common orders in stomach contents are Diptera, Hemiptera, and Hymenopter. Table 17 lists the percentages of these orders collected from Chinook and Coho stomach contents, in fallout traps, and neuston tows. The percentage of Dipterans collected from neuston tows is similar to the percentage of Dipterans found in Chinook stomachs. The percentage of Hemiptera in fallout traps is similar to the percentage of Hemiptera in Chinook stomachs. There were more than twice as many Hymenoptera in fallout traps compared to Hymenoptera found in stomach contents.

Taxa diversity of stomach contents is shown in Figure 17. Shannon index values are higher in sites 1 and 5, the restored sites, compared to site 3, the partially restored site. Stomach contents were combined for Chinook and Coho to describe overall taxa diversity of invertebrate prey within a site. Taxa diversity by species is not investigated here. Site 1, the downstream site, had the highest taxa diversity of stomach contents. 63 Chinook and Coho were included in site 1 calculations. Fish collected at the Tidegate and Lower Clear Creek were grouped into site 1. Site 5 had the next highest taxa diversity of stomach contents. Only four Coho were collected at site 5. Site 3 had the lowest taxa diversity of the three sites. 25 Chinook and Coho were collected at site 3. The large disparity in sample size may affect comparability of Shannon index values between sites. Ideally, the sample size would be the same between sites, however the short sampling season, lack of personnel, and limited funding prevented additional seining in sites 3 and 5.

Table 16. Commonly found prey items in stomach content samples.
These invertebrates were consumed by Chinook and Coho.

Order	**Family**	**Common Name**	**Aquatic/ Terrestrial**	**Found in Fallout Traps (Y/N)**	**Total number of individuals in fallout traps**	**Total Individuals Consumed**
Diptera	Chironomidae larvae/pupae	Non-biting midges	Aquatic	Y	11	661
Diptera	Ceratopogonidae larvae/pupae	Biting midges	Aquatic	Y	1	124
Hemiptera	Aphididae	Aphids	Terrestrial	Y	258	60
Diptera	Chironomidae adults	Non-biting midges	Terrestrial	Y	2027	59
Hymenoptera	Not identified to family	Bees, Ants, & Wasps	Terrestrial	Y	1851	58

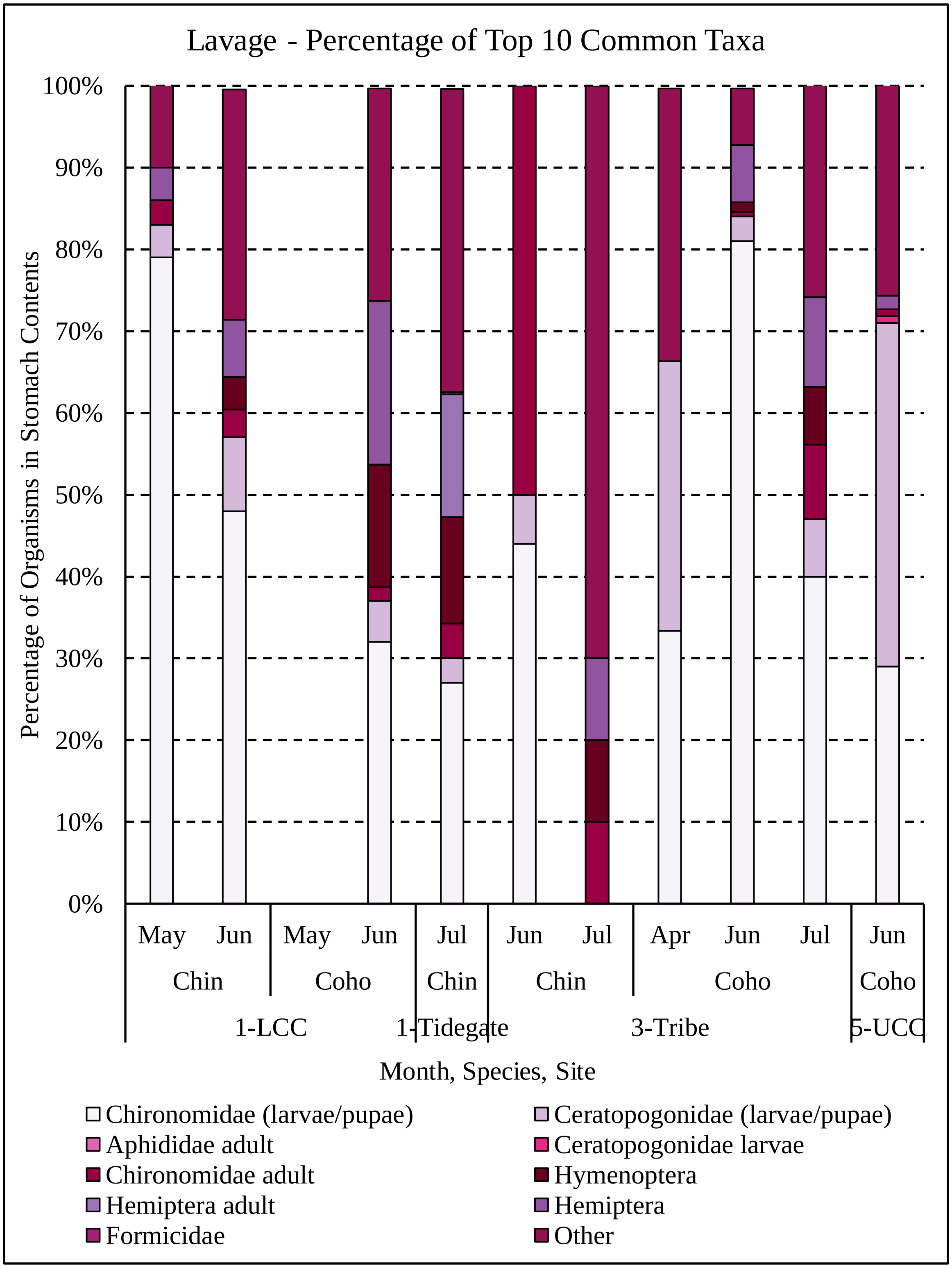

Figure 15. Percentage of invertebrate taxa in gastric lavage stomach content samples by site, by species, and by month.

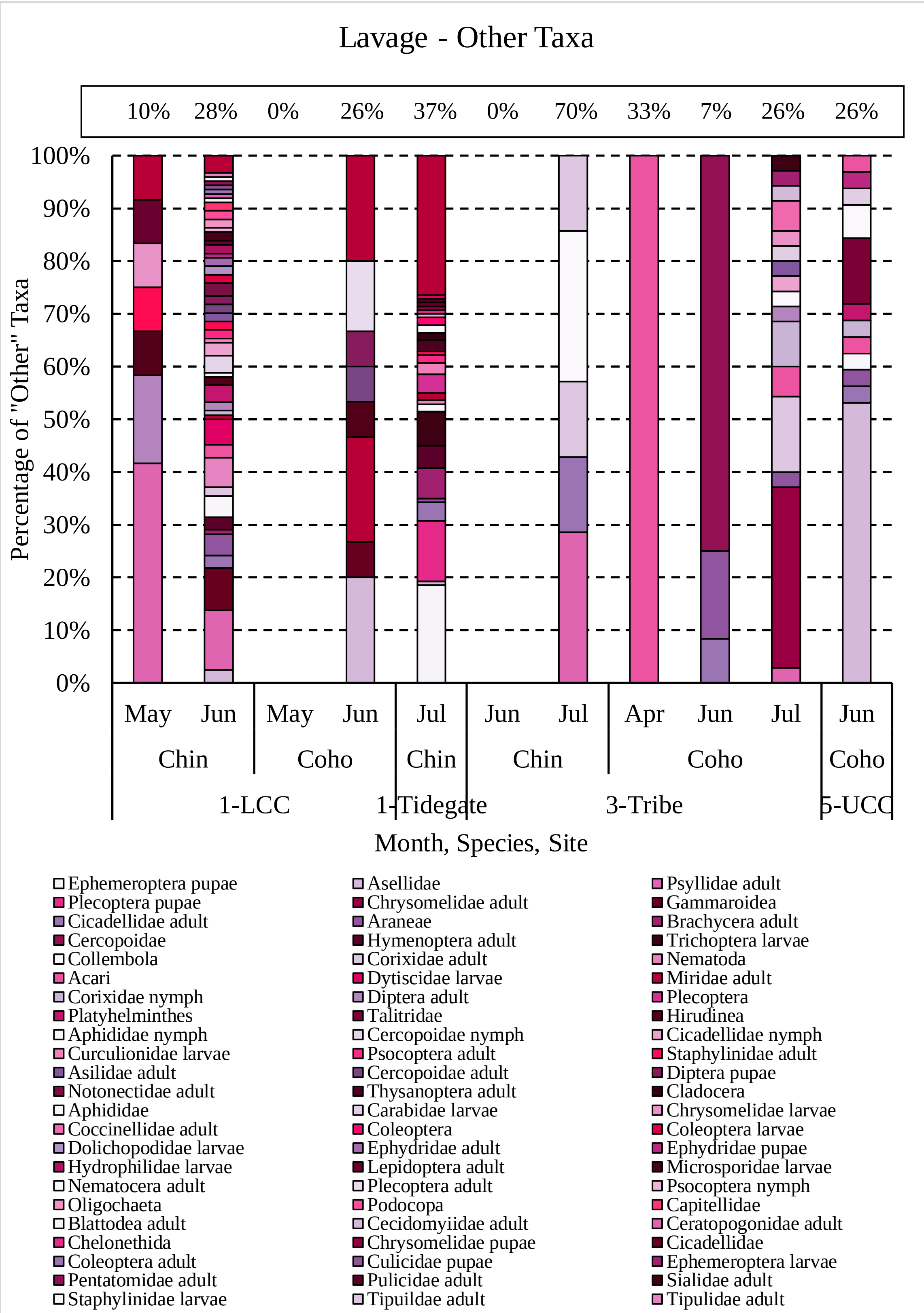

Figure 16. Percentage of 72 invertebrate taxa in gastric lavage stomach content samples by site, by species, and by month.

Table 17. Comparison of common taxa in fallout traps, neuston tows, and lavage samples

Taxa	**Percent in Fallout Trap**	**Percent in Neuston Tow**	**Percent in Chinook stomachs n = 60**	**Percent in Coho stomachs n = 32**
Dipteran	46.75	54.18	53.92	63.38
Hemiptera	14.14	10.40	15.92	17.37
Hymenoptera	19.11	2.83	8.74	4.93

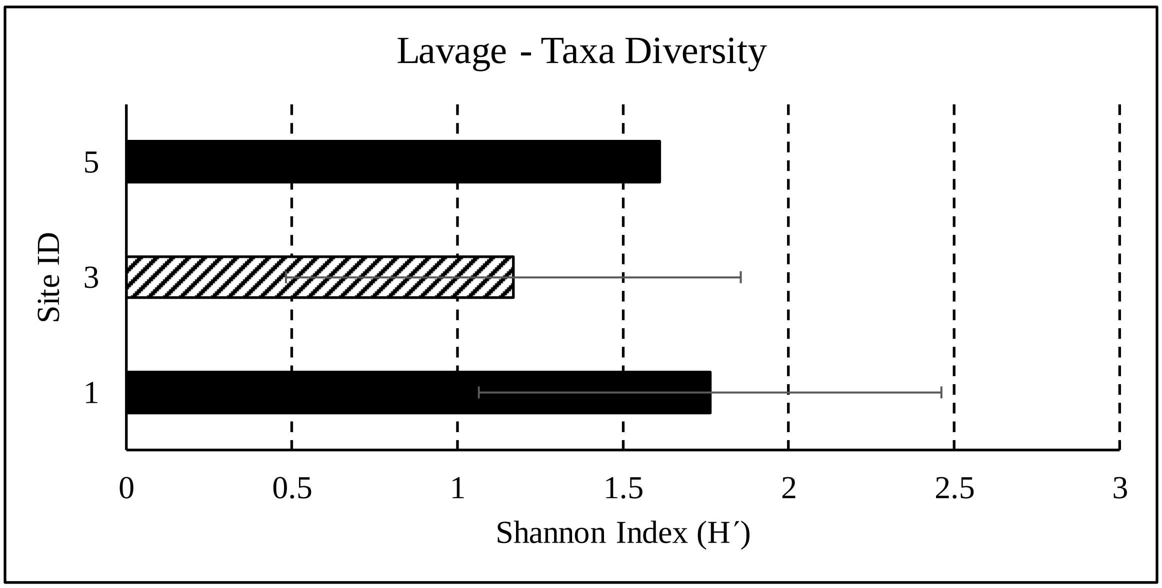

Figure 17. Average Shannon index values for lavage samples.
Chinook and Coho were collected by seine and lavage samples were taken. The average values include all seines from April 24 to July 16, 2019. One seine was completed at UCC. Three seines were completed at the Tribe's site. Three seines were completed at LCC. Solid fill indicates restored sites. Hatched fill indicates partially restored sites.

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Linear Regression

Linear regression was calculated to compare fallout, neuston, and lavage taxa diversity and years since restoration in Figure 18. Fallout diversity increases slightly with years since restoration (Figure 18a). There is a negative relationship between taxa diversity in neuston tows and years since restoration (Figure 18b.). This result is similar to Figure 14. Taxa diversity is highest in unrestored sites (7, 8) and lower in restored sites (1, 5, 6). The relationship between taxa diversity in lavage samples and years since restoration is negligible (Figure 18c). The chart shows that taxa diversity for lavage samples in the restored sites are higher than the partially restored site, but linear regression analysis does not support a relationship.

There is a strong and positive relationship between taxa diversity of fallout traps and taxa diversity of vegetation (Figure 19). As noted in earlier, percent cover was used to estimate Shannon Index values for vegetation diversity, and this could skew results. However, it was employed for ease of comparing values from one data set to another. The diversity values are highest for restored sites and lowest for unrestored sites for both fallout and vegetation taxa. There is a strong and positive relationship between fallout traps and taxa diversity of lavage samples (Figure 19b). Lavage samples were collected in two restored sites and one partially restored site and the correlating fallout values were plotted. The chart excludes 4 fallout diversity datapoints. There is a strong and positive relationship between taxa diversity of neuston tows and taxa diversity of lavage samples (Figure 19c). The neuston tows were limited to sites 1, 5, 6, 7, and 8. The lavage samples were taken in sites 1, 3, and 5. Only two data points from sites 1 and 5 were plotted.

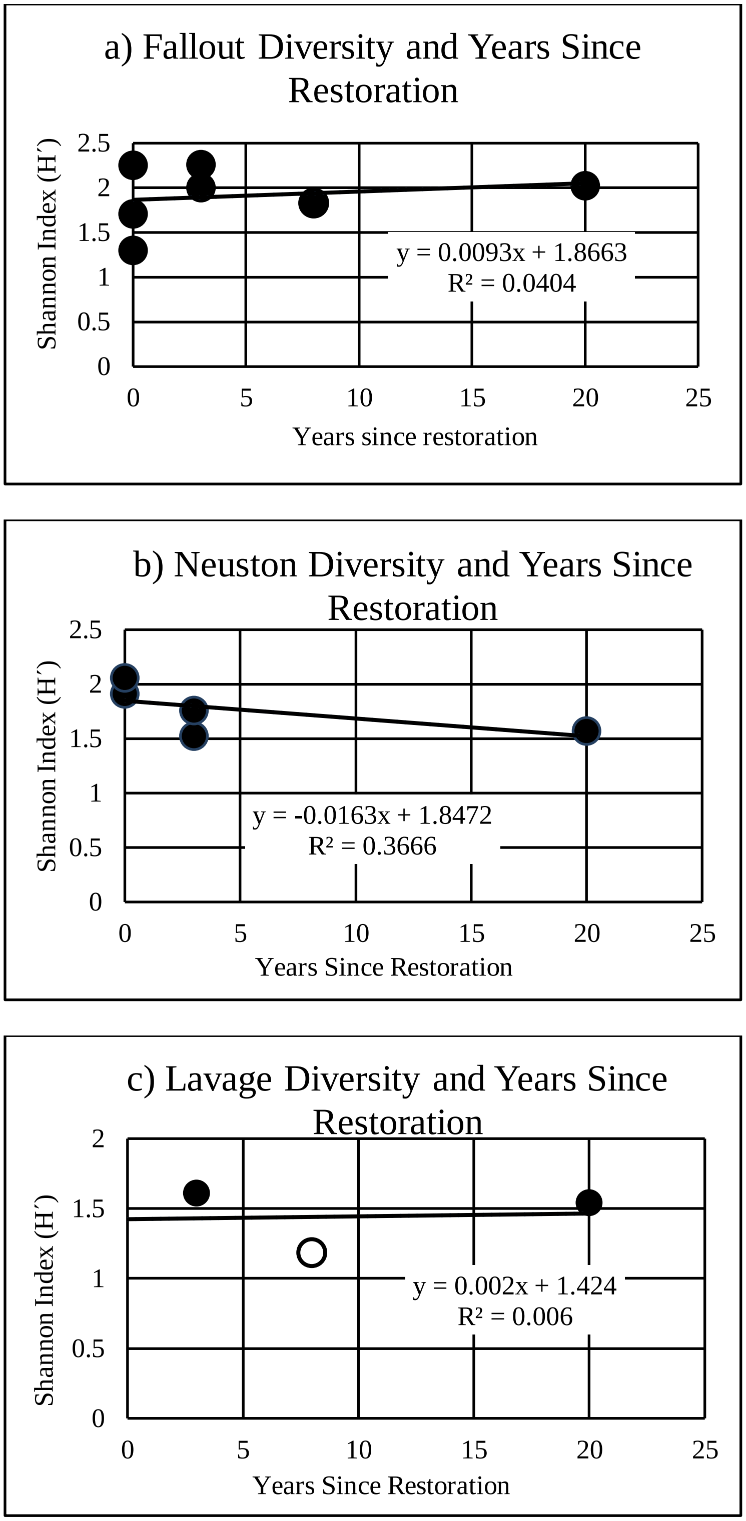

Figure 18. Linear regression comparing taxa diversity and years since restoration for (a) Fallout traps (b) Neuston tows (c) Lavage.
Hollow points indicate partially restored sites.

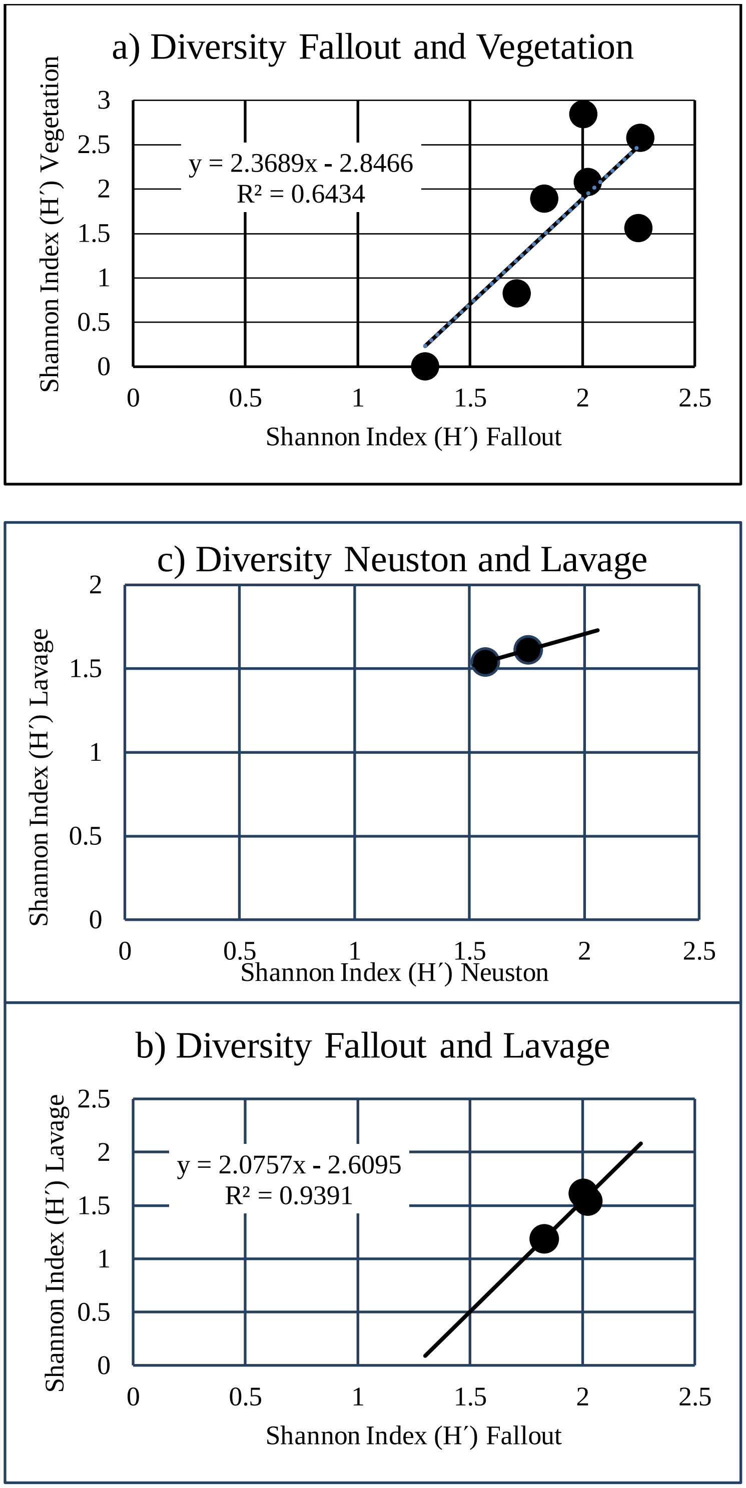

Figure 19. Linear regression comparing taxa diversity for (a) Fallout traps and Vegetation (b) Fallout and Lavage (c) Neuston and Lavage.

Principle Component Analysis

Principle Component Analysis (PCoA) is used to transform large datasets with multiple variables. PCoA describes similarity between communities by portraying the distances between samples in a two-dimensional representation. For abundance data, a Bray-Curtis metric is used. Fallout, neuston, and lavage samples are shown in Figure 20. The data clustered together are similar to each other. Fallout samples are similar except for one point. The terrestrial invertebrate community in the outlier is different compared to the invertebrate community in other fallout samples. The outlier was from site 8, which is an unrestored site with 100% reed canarygrass. The neuston samples are relatively close to each other. Site 7, unrestored, is slightly different than the other neuston samples. Two of the lavage samples from the restored sites are similar to each other. The outlier from this group is stomach contents from site 3, partially restored. The fallout, neuston, and lavage clusters are fairly distinct. The right side of the PCoA chart relates to aquatic invertebrates and the left side of the chart to terrestrial invertebrates. This analysis was performed based on the invertebrate categories that separate life stage. Differences between clusters can be attributed by larvae that are aquatic and adults that are terrestrial.

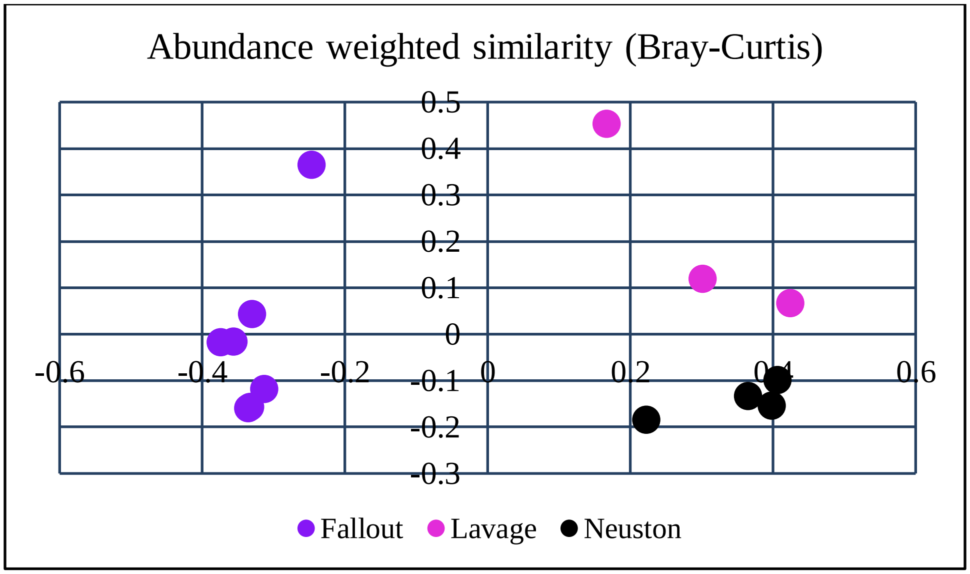

Figure 20. Principle Component Analysis for fallout, lavage, and neuston samples.

Chapter Five: Discussion

An assessment of stream habitat is important when evaluating salmon abundance and survival. This assessment must include the quality of habitat, but also a consideration of food resources because salmon growth potential can be limited by the availability of invertebrate food resources (Bacon et al., 2005). Food is often a limiting factor to salmon production. In-stream experiments where food was abundant reported increased growth rates compared to juvenile Coho at ambient food levels and survival of Coho was higher even when population densities were high (Rosenfeld et al., 2005). Clear Creek is a unique habitat type that supports short-term use for hatchery fish, long-term use for resident trout, natal and non-natal Coho and Chinook, and is critical habitat for spawning and rearing.

In three restored sites, 42 vegetation species were recorded. In three unrestored sites, 11 vegetation species were recorded. Site 1 is a restored site and 14 different plant species were recorded during the vegetation survey. Site 5 and site 1 have four vegetation species in common, not including reed canarygrass. Most of the species in site 6 are emergent plants such as tufted hairgrass, ovate spikerush, and marsh horsetail, or scrub-shrub such as Pacific willow, redosier dogwood, sitka willow, and vine maple. Site 1 is primarily forested species over 20 feet tall such as Red Alder and Black Cottonwood. There were 22 vegetation species recorded in site 5 and 20 vegetation species recorded in site 6. There are seven species that occur in both sites. There are more woody species under 20 feet tall in site 5 and more emergent plants in site 6. The vegetation combination in site 6 produced a more even distribution of the two terrestrial preferred prey taxa, Hymenoptera and Hemiptera, compared to the other two restored sites. Restored sites produced a more diverse community of terrestrial invertebrates and a more even distribution of invertebrate taxa. This is especially evident in the restored site 6.

The regression analysis (Figure 5) for years since restoration and percent invasive vegetation for each site shows a downward trend over time. As years since restoration increases, invasive vegetation decreases. The regression analysis indicates that invasive vegetation responds to restoration by decreasing over time and decreasing quickly. Restoration in sites 5 and 6 were completed only three years ago and invasive vegetation was just over 3 percent in each site. Invasive vegetation remained low even after 20 years. Restoration in site 1 was completed 20 years ago and the survey indicated 8.5 percent invasive species of the vegetation observed. The slight increase over time suggests a need for occasional maintenance of restored sites to remove any invasive vegetation that might re-colonize over time. The correlation between restoration and terrestrial invertebrate taxa diversity suggests that restoration in Clear Creek works to recruit a diverse community of invertebrates in a few as three years.

Fallout traps were batched to increase sample size within each category. Fallout traps in sites 1, 5, and 6 are considered restored sites (n = 18). Fallout traps in sites 2, 7, and 8 are unrestored sites (n = 18). Site 3 is partially restored (n = 9). Tests for taxa richness between sites was not statistically significant. The null hypothesis that taxa richness does not differ between sites will be accepted. Taxa richness was highest in restored sites, followed by unrestored sites, and finally the partially restored site. While no statistical significance was found for taxa richness, it is worth noting that even with high abundance at the Diamond site, taxa richness in all restored sites is higher compared to taxa richness in all unrestored sites.

The results of this study demonstrated a significant relationship between terrestrial invertebrate taxa diversity and restoration. I will reject the null hypothesis that invertebrate taxa diversity does not differ between habitat types. These results suggest that diverse prey resources are associated with diverse plant communities (Figure 19). Invertebrate taxa diversity was lowest in unrestored sites and highest in restored sites. Evenness was lowest in unrestored sites, increased with partially restored sites, and was highest in restored sites. Evenness scores indicate that relative abundance was higher in restored sites even considering the average number of Hymenoptera and Diptera in fallout traps were at least three times higher in site 8, the unrestored Diamond property, compared to any other site. The high counts of taxa in site 8 was driven by dense vegetation. The taxa at site 8 were primarily highly mobile terrestrial species that have the ability to colonize suitable habitat. The reed canarygrass was in full bloom during the survey in June and likely recruited many of the Hymenoptera and Diptera collected in fallout traps at this site. Although taxa counts were high in site 8, overall diversity and evenness were low. The PCoA also indicates that the invertebrate community in site 8 was different compared to other fallout samples (Figure 20). Site 8 differs from the other sites in vegetation and surrounding influences. The invasive vegetation in site 8 is rampant and the adjacent farm could be affecting the invertebrate community at this site. Future sampling outside the bloom period for reed canarygrass would be helpful in understanding potential variability in terrestrial invertebrates at this site.

High taxa diversity in both vegetation and terrestrial invertebrates in site 7 drives higher diversity values for the unrestored category. There was high taxa diversity in site 7. Site 7 is unrestored because no native planting has occurred in this site, but it is considered forested when using Cowardin plant classes. In June 2019, when fallout samples were placed, the traps were primarily surrounded by reed canarygrass, however there were Black cottonwood, red alder, and Oregon ash species within 12 meters. These are woody species over 20 feet tall. There is an access road separating Clear Creek from the trees, however the forested vegetation could have influenced the invertebrate community in the fallout traps by increasing taxa diversity values. Because the plant classification in site 7 is more similar to restored sites than unrestored, a change in categorization of site 7 from unrestored to restored or partially restored should be considered. The correlation between fallout diversity and vegetation (Figure 19a) would support this re-categorization. Terrestrial invertebrate diversity was lowest in site 8 where a single vegetation species covered the area and highest in the restored sites, 5, 6, and 1.

For neuston tows, taxa richness and diversity were higher in unrestored sites compared to restored sites. Due to the nature of flow and drift, these metrics may not be the most relevant for correlating richness and diversity in neuston tows to restoration. Neuston tows were placed centrally in sites 1, 6, 7, and 8 and at the downstream end of site 5 (Figure 3). It is more difficult to relate taxa richness and diversity to restoration condition because aquatic invertebrates and water move. Geographic location is less useful for evaluating correlation between restoration and invertebrate taxa diversity compared to fallout traps.

For Chinook, stomach content samples from April to July showed 20 percent of diets were Chironomidae larvae, followed by 9 percent Chironomidae pupae, and 3 percent of each Chironomidae adults, Ceratopogonidae larvae, Aphididae adults, and Hymenoptera larvae. Chironomidae larvae consumption peaked in June and fell off in

July. Adult Chironomidae consumption was highest in July. Chironomidae adults are short-lived. Many only survive 3-5 days at which time they swarm and mate (Resh and Rosenberg, 1984). A longer season of data collection is necessary to confirm a trend; however, it appears that emergence of Chironomidae adults in July leaves a void in Chinook diets that is filled by terrestrial species such as Aphididae adults and Hymenoptera larvae.

Coho diets were similar to Chinook. From April to July, Coho diets were 12 percent Chironomidae pupae, 5 percent Chironomidae larvae, and 3 percent Ceratopogonidae pupae. Coho consumption of Chironomidae pupae and larvae peaked in June. Consumption of adult Chironomidae was highest in July. At this time, Coho diets had more variation including Aselidae, an aquatic taxon of isopods, and terrestrial taxa Hymenoptera and Hemiptera.

The abundance of Chironomids in Chinook and Coho diets is likely an indication of opportunity rather than preference. The substrate in Clear Creek is primarily fine sediment with few gravels or cobbles. The soft and silty mud is ideal habitat for immature Chironomids. Fork lengths for 61 Chinook of various mark types ranged from 64 to 111 millimeters. Fork lengths for 31 Coho of various mark types ranged from 83 to 97 millimeters. The Chinook range was larger, but the average size of Coho was bigger. Since Chironomid larvae are more immature than Chironomid pupae, the presence of larva in smaller Chinook diets and pupae in larger Coho could be a due to a change in gape size as juvenile salmon grow.

Invertebrate life cycles are fleeting compared to juvenile salmon residence in streams. Chinook have the longest migration period compared to other juvenile salmon in the Puyallup watershed. Juvenile Chinook have been observed migrating out of the Puyallup River as early as January and as late as August (Berger and Conrad, 2019). Although Coho spend an entire year in freshwater, their outmigration window is narrower. These two life history strategies indicate a need to provide invertebrate prey resources throughout the year. A diversity of invertebrates could improve outcomes for juvenile salmon in Clear Creek by facilitating feeding opportunities throughout the seasons. The terrestrial taxa Hymenoptera and Hemiptera were 19 and 14 percent of invertebrates in fallout traps (Figure 7). Terrestrial invertebrates could supply a food source when Chironomidae adults emerge and die (Table 16). Bottom up food webs are limited by resources like space. Diverse vegetation that provides habitat for more terrestrial invertebrates improves the opportunities for colonization of multiple taxa that partition their life cycles temporally.

A variety of invertebrate taxa whose life cycles overlap, and the combination of both aquatic and terrestrial invertebrates can provide a broad range of prey for juvenile salmon in Clear Creek who are opportunistic feeders. Chinook in Clear Creek consumed 70 different prey taxa from April to July and Coho consumed 41 different prey taxa. Many of these prey items made up less than 1 percent of total stomach contents individually but combined were between 7 and 37 percent of salmon diets from April to July. Stomach content sampling was performed from April to July and in these months, there were indications of seasonal changes in diet for both Chinook and Coho. There was a combination of aquatic, benthic, and terrestrial species in Chinook and Coho diets suggests that these juvenile salmon will eat what is available to them. The PCoA results show differences between lavage samples and neuston and fallout samples (Figure 20). It is necessary to include gastric lavage as a part of habitat assessment because neuston and fallout samples independently will not accurately describe salmon diets. Salmon diets are more complex than what was observed in neuston and fallout samples alone. Including benthic invertebrates into the study could provide a more complete description of available prey.

Chinook and Coho are partitioning Clear Creek spatially (Figure 16). In five seines, 93 percent of Chinook were collected at the downstream sites (LCC and Tidegate) and 78 percent of Coho were collected in upstream sites (Tribe, UCC). There are two possibilities that explain this result. For Chinook, 1) natal Chinook hatched in Clear Creek moved downstream and were collected in seines at site 1, or 2) non-natal Chinook from elsewhere in WRIA 10 are leaving the mainstem Puyallup River and entering Clear Creek where they were collected in seines at site 1. For Coho, 1) natal Coho hatched in Clear Creek stay in upstream sites and were collected in seines at sites 3 and 5, or 2) non-natal Coho from elsewhere in WRIA 10 are leaving the mainstem Puyallup River and entering Clear Creek where they were collected in seines at sites 3 and 5. The majority of juvenile salmon collected in April seines at site 3 were hatchery Coho. Those Coho moved past Chinook in lower reaches to locations farther upstream to partition habitat.

The absence of hatchery Coho in May, June, and July seines could speak to a reduction in prey resources when density dependence issues emerge. The hypothesis being that hatchery Coho swam upstream in search of food resources and when they were exploited, they left. Another strategy that salmon use is to broaden their diets as their preferred food declines (Werner and Hall, 1974). PCoA suggests that diets from juvenile Chinook and Coho in the partially restored site is different than the restored sites.

Whether traveling upstream or downstream, salmon had to swim through the partially restored site to get to the restored sites. Taxa diversity in diets was higher in the restored sites compared to the partially restored site. Salmon follow the food. Not just food but it seems they seek out a diversity of food resources. Diversity of prey resources helps to provide different prey items for juvenile salmon at different times of the year and in different locations along Clear Creek. Diversity can reduce the “feast or famine” conditions that produce abundant prey resources followed by periods of scarcity due to shifting invertebrate life cycles.

Even with spatial disparity in distribution, Chinook and Coho diets were similar (Figure 15). Both species consumed between 53 and 63 percent Diptera. The diet overlap could suggest that juvenile salmon growth while residing in Clear Creek may be comparable between Chinook and Coho. However, growth rate is highly variable and juvenile salmon adapt feeding strategies based on density, food availability, and environmental conditions. A future study that assesses the caloric value of prey resources and a bioenergetic model would inform juvenile salmon growth on Clear Creek.

Chapter Six: Conclusion

Many juvenile Chinook do not travel far up Clear Creek, preferring instead to remain close to the mainstem confluence. Diversifying forested habitat in site 1 to include more vegetation under 20 feet tall could recruit more preferred prey and provide better prey resources to Chinook that forage near the confluence and do not migrate farther upstream. Improving lateral flow in site 1 and installing vegetation classes of similar composition and diversity to vegetation in site 6 may improve prey resources for Chinook that hold in downstream reaches. Scrub shrub and emergent vegetation under 20 feet were correlated to high diversity of terrestrial invertebrates and second highest abundance of terrestrial invertebrates. The habitat in the site 6 produced a more even distribution of preferred terrestrial prey items compared to other restored sites. Modeling restoration throughout Clear Creek with the plant classes at the site 6 is the best chance for producing similar results of invertebrate communities.

Coho travel farther upstream in search of food and habitat. Coho need prey resources throughout the year to survive. The peak Chironomidae and Ceratopogonidae consumption in June and absence of Hymenoptera in stomachs lavaged in April and May suggests a seasonality to invertebrate prey consumption. Ensuring terrestrial prey availability to Coho throughout the spring and summer can improve survival during critical times: overwinter and the first year at sea. Prey resource availability in the spring and summer will also prevent the liver hormone atrophy that occurs with starvation and thwarts growth even after regular feeding resumes in the fall (Beamish and Mahnken, 2001).

Clear Creek is one of the few places for juvenile salmon to retreat from the mainstem in the lower Puyallup River. However, there may be density dependent consequences if fish become concentrated here. Increasing the availability of habitat and prey resources may offset some of these density dependence issues. Initial observations from beach seines in Clear Creek show that hatchery and natural origin Coho and Chinook are using the stream. Because there are limited opportunities for juvenile salmon to rear in the lower Puyallup River, restoration managers should improve habitat and food sources in areas where fish have access. Restoration on Clear Creek is correlated with high terrestrial invertebrate taxa diversity. In reaches that have been restored, the invertebrate community responded quickly. In as few as three years, terrestrial invertebrate diversity was significantly higher compared to unrestored reaches. Even with no other changes to sediment or channel complexity, diverse plant communities will help to improve diversity of invertebrate prey resources on Clear Creek.

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