Lower Columbia River Ecosystem Monitoring Program
Annual Report for Year 17

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Technical Contacts: Sarah Kidd & Ian Edgar
Lower Columbia Estuary Partnership
400 NE 11th Ave
Portland, OR 97232
Phone: (503) 226-1565 x 239
skidd@estuarypartnership.org
iedgar@estuarypartnership.org

BPA Project Manager: Anne M. Creason
Fish & Wildlife Project Manager
Bonneville Power Administration
905 NE 11th Avenue
Portland, Oregon – 97208
Phone: (503) 230-3635
amcreason@bpa.gov

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Lower Columbia River Ecosystem Monitoring Program
Annual Report for Year 17 (October 1, 2021 to September 30, 2022)

Editors:
Sarah A. Kidd[1]
Ian Edgar[1]
Sneha Rao[1]

Active Authors (alphabetical by last name):
Kerry Accola[5]
Paul M. Chittaro[3]
Jeff Cordell[5]
Ian Edgar[1]
Jeffery Grote[7]
Susan A. Hinton[3]
Sarah A. Kidd[1]
Joseph A. Needoba[4]
Tawnya D. Peterson[4]
Sneha Rao[1]
Curtis Roegner[3]
Jason D. Toft[5]

Past Contributors/Authors (alphabetical by last name):
Amy B. Borde[6,8], Catherine A. Corbett[1], Lyle P. Cook[4], Valerie I. Cullinan[6], Roger N. Fuller[2], Amanda C. Hanson[1], David Kuligowski[3], Daniel Lomax[3], Lyndal L. Johnson[3], Regan A. McNatt[3], Katrina Poppe[2], Gina M. Ylitalo[3], Shon A. Zimmerman[6]

[1]Lower Columbia Estuary Partnership
[2]Estuary Technical Group, Institute for Applied Ecology
[3]Northwest Fisheries Science Center, NOAA-National Marine Fisheries Service
[4]Oregon Health & Science University
[5]University of Washington
[6]Pacific Northwest National Laboratory
[7]Ocean Associates, Inc
[8]Columbia Land Trust

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Lower Columbia Estuary Partnership
400 NE 11th Ave
Portland, OR 97232

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Executive Summary

The Ecosystem Monitoring Program (EMP) is managed by the Lower Columbia Estuary Partnership and is an integrated status and trends program for the lower Columbia River. Under the EMP, researchers collect key information on ecological conditions for a range of habitats throughout the lower river characteristic of those used by migrating juvenile salmon and provide information to aid the recovery of threatened and endangered salmonids. The program inventories the different types of habitats within the lower river, tracks trends in the overall condition of these habitats over time, provides a suite of reference sites for use as end points in regional habitat restoration actions, and places findings from management actions into context with the larger ecosystem. The EMP is implemented through a multi-agency collaboration, focusing sampling efforts on examining temporal trends within a study area that extends from the mouth of the river to Bonneville Dam. The goal of this executive summary is to provide a brief synopsis of the ecological conditions observed in the trend sites in 2022. The full report linked throughout this report should be consulted for detailed scientific methods and findings.

In 2022, data were collected on fish and fish prey, habitat, hydrology, food web, abiotic site conditions, and mainstem river conditions at Ilwaco Slough (river kilometer; rkm 6), Welch Island (rkm 53), Whites Island (rkm 72), Campbell Slough (rkm 149), and Franz Lake (rkm 221). Habitat and hydrology data were also collected at Cunningham Lake (rkm 145) along with with primary production and hydrology data collected at Steamboat Slough (rkm 57, a restoration site included in our long-term biomass study). The trends sampling sites are minimally disturbed, tidally influenced freshwater emergent wetlands with backwater sloughs that represent a subset of the eight hydrogeomorphic reaches across the lower river. In addition to tracking ecological changes in the Lower Columbia River, this year a collaborative effort has been made to study the effect of varying flow regimes over the monitoring period, of the mainstem on site-specific biotic and abiotic conditions as well as answering specific longterm questions about the lower Columbia river. The primary research questions we have attempted to answer with this report are "What are the longterm status and trend conditions we see across the estuary and how can we use these data to address the uncertainties brought forth by the ERTG and others about restoring sustainable habitat conditions in the estuary?" We believe that exploring this question provides crucial information to restorative planning in the face of rising water levels and shifting climate patterns.

In a significant advancement this year, the EMP report has adopted a hybrid format leveraging the capabilities of Tableau, an interactive data visualization platform. This ensures that the data and analyses presented in the report are not just static but can be interacted with online, providing a more immersive experience for readers and stakeholders. The integration of Tableau allows for dynamic engagement, facilitating deeper exploration of the data and insights, thereby enriching the understanding and interpretation of our findings. Below you will find a summary of results, for the full hybrid report, please see this link. For archival purposes and to ensure long-term accessibility, we have provided a static snapshot of the Tableau dashboards in the appendix of this document.

This report is a collaborative effort by many researchers. Habitat structure research leads from Lower Columbia Estuary Partnership are Dr. Sarah Kidd, Ian Edgar, and Sneha Rao. Water Quality and Food Web dynamics research leads from Oregon Health and Science University are Dr. Joseph A. Needoba and Dr. Tawnya D. Peterson. Salmon Prey and Diet research leads from University of Washington are Dr. Jeff Cordell, Dr. Jason Toft, and Kerry Accola. Fish community and genetic composition research leads from NOAA – Fisheries are Dr. Curtis Roegner and Susan A Hinton. Dr. Sarah Kidd, Ian Edgar, and Sneha Rao, are the lead report Editors.

Mainstem Conditions of the Columbia River

Mainstem conditions are evaluated through measures of river discharge at Bonneville Dam and at Beaver Army Terminal (river mile 53). In addition, temperature data and other variables are provided through *in situ* sensor measurements at the Port of Camas (river mile 122) and at Beaver Army Terminal (BAT).

River Discharge

The 2022 water year in the Columbia River was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average flows in the early spring, and higher-than-average flows associated with the spring freshet, which peaked in mid-June.

Columbia River discharge at Bonneville Dam was close to the 2009-2022 average during the winter months; after mid-March flows were lower than average and reached minimum values for the time period in mid-April. Flows increased from early and peaked in mid-June at volumes close to the long-term maximum, observed in 2017. The decline in river discharge following peak flows was steeper than in 2017, but flow remained above average through the end of August after which they were close the long-term average. River discharge associated with the Willamette was higher than average during a few peaks in winter and spring (early January, early March, early May and early June) and was otherwise close to or below average values observed between 2009-2022.

Water Quality

The average daily water temperature in 2022 was average in the winter, slightly below average in the spring leading up to the freshet, average during the freshet, and higher than average after the freshet. There were 50 days having temperatures exceeding 19oC, similar to the long-term average. At the off-channel EMP sites, temperatures were highest after July at Campbell Slough and Franz Lake Slough.

Water quality was generally good at the off-channel EMP sites in 2022, with pH being in the acceptable range except at Campbell Slough after early August where values exceeded 8.5 units, alongside peaks in dissolved oxygen saturation and chlorophyll, indicating that environmental conditions were dominated by biological activity.

Tidal Wetland Habitat Conditions of the Columbia River

Native and non-native Plant Communities

Native and non-native Plant Communities

Overall, 2022 total plant cover was relatively stable across Ilwaco Slough, Welch Island, Whites Island, and Franz Lake compared to historic, long-term averages. Cunningham Lake total cover has continued to increase through 2022, beginning to rebound from the heavy cattle grazing observed in 2017. Campbell Slough exhibited a slight increase in total cover levels in 2022; however the overall cover at Campbell is still low compared to non-grazed conditions; cattle grazing has continued at Campbell Slough since 2017, with fencing efforts failing to keep the cattle out of the wetland.

Between 2012-2022 the six most common plant species identified throughout the tidal estuary (across the 6 trend sites) in order of overall abundance are Phalaris arundinacea (PHAR, non-native), reed canarygrass, *Carex lyngbyei* (CALY, native), lyngby sedge, *Eleocharis palustris* (ELPA, native), common spikerush, *Sagittaria latifolia* (SALA, native), wapato, *Leersia oryzoides* (LEOR, native), rice cut grass, and *Ludwigia palustris* (LUPA, native), water purslane. While these species are the most common and abundant across all sites over the years, they are not necessarily present at all sites every year.

In 2022, *P. arundinacea* cover levels stayed relatively consistent to those observed in 2021 and previous years. Data continues to support our findings that annual shifts in *P. arundinacea* cover are strongly correlated with Columbia River discharge levels and site water levels during the growing season, with lower water levels (and lower discharge levels) favoring *P. arundinacea* growth and observed abundance. These findings indicate that annual flooding conditions within sites and across the river (freshet accumulated discharge) are important mechanisms driving much of the observed annual variability in *P. arundinacea* dominance across the estuary. The long-term trends in the abundance of native species *Carex lyngbyei*, *Sagittaria latifolia*, *Polygonum amphibium* have also been found to be strongly (and significantly) linked to annual river discharge conditions. Generally, *C. lyngbeyi* abundance has been found to increase in years of greater freshet and discharge levels, especially in Ilwaco Slough, where salinity levels are reduced during large discharge years, making growing conditions more favorable for *C. lyngbeyi*. *S. latifolia* has been found to have a delayed reaction to freshet and river discharge conditions, with lower discharge years resulting in an increase in *S. latifolia* abundance the following year. Additionally, *P. amphibium* levels at Franz Lake have also been found to follow a similar trend to *S. latifolia* with a one-year delayed reaction (increase in abundance) to decreased river discharge conditions. For both species, this might be a result of increased rhizome stores from positive growing conditions (low water levels), providing for more robust growth in the following growing season.

Phytoplankton and Zooplankton

Total algal biomass, as estimated by concentrations of chlorophyll a, tends to be highest in March or April, prior to the spring freshet, at Welch Island and Whites Island; in contrast, the highest algal biomass at Campbell Slough and Franz Lake Slough is usually observed in July-August. Similar to previous years, the highest chlorophyll concentrations observed in 2020-21 were found at Campbell Slough and Franz Lake Slough. These sitse are prone to the development of algal blooms in the summer months, which often discolor the water. No chlorophyll measurements in 2020 or 2021 exceeded 25 $\mu g\ L^{-1}$, a level above which is associated with poor water quality. If a benchmark of 15 $\mu g\ L^{-1}$ is used, four observations were above the recommended threshold over the 2020-21 time period, suggesting poor water quality (Oregon State Water Quality Standards). However, since a body of water is only considered impaired when the threshold is exceeded in observations from three consecutive months, no site met this criterion.

Typically, observations show that chlorophyll concentrations are highest in March at Welch Island and Whites Island, while at Campbell Slough and Franz Lake Slough the highest algal biomass is observed in July-August. In 2020 and in 2021, peak chlorophyll concentrations were observed in March or April at Campbell Slough. Similar to previous years, the relative proportion of diatoms at the EMP trends sites was higher in the spring compared to summer, when chlorophytes and cyanobacteria made significant contributions to the total assemblages.

Often, cyanobacteria can account for a large proportion of the phytoplankton assemblage in the summer; in 2020, relatively high densities of cyanobacteria were also observed in February and March at Campbell Slough, and in June at Franz Lake Slough. Data for 2021 are not yet available for comparison. The lack of temporal data makes it difficult to discern patterns related to season or to the hydrograph; cell densities were higher in March compared to August, at the sites where data are available and this is consistent with observations from previous years.

Similar to previous years, analysis of relationships between environmental variables and phytoplankton assemblages revealed that high relative proportions of diatoms are associated with high concentrations of dissolved oxygen. Diatom growth is also associated with a reduction in nutrient concentrations and are indicative of good water quality. Diatoms tend to dominate in the spring months, where populations can get quite large; most of the annual growth of phytoplankton occurs in the spring and is accomplished by diatoms.

Zooplankton assemblages differ along the spatial gradient from Ilwaco Slough to Franz Lake Slough and over time from early spring to summer. Ilwaco Slough is consistently dominated by copepods, with inputs from rotifers, but very few cladoceran taxa. At the other sites, copepods generally dominated the zooplankton assemblages. At Welch Island and Whites Island, there was an increase in the proportional contribution by cladocerans from spring to summer in each of 2017, 2018, and 2019. At Campbell Slough and Franz Lake Slough, an increase in the proportional contribution of cladocerans was observed from March to June; however, by July, the relative proportions of cladocerans decreased at both sites in 2017 and 2018 and 2019.

Stable isotopes ratios of Carbon and Nitrogen

Stable Isotope Ratios (SIR) is used to determine the relative importance of food sources including algae and wetland plants to the food web supporting juvenile salmonids at trends sites. Carbon and Nitrogen isotope ratios yield different information: $\delta^{13}C$ ($^{13}C/^{12}C$) ratio used to identify the primary source of organic matter (i.e., primary producers). In contrast, $\delta^{15}N$ ($^{15}N/^{14}N$) values are useful in determining trophic position. The SIR of C and N were measured in juvenile Chinook salmon muscle tissues and several potential food sources to provide information on the food web supporting juvenile salmonids. These were studied for influence of cumulative mainstem discharge.

Isotopic values of carbon in particulate organic matter ($\delta^{13}C$-POM) collected onto filters revealed $\delta^{13}C$ signatures in the range of freshwater phytoplankton most of the time, with values closer to terrestrial vascular plants in May and June at Campbell Slough and Franz Lake Slough. $\delta^{13}C$-POM at Ilwaco was closer to marine values.

When stable isotope signatures for carbon and nitrogen associated with all primary producers is combined, two broad patterns emerge. The average $\delta^{13}C$ for all primary producers is slightly higher in very dry years (for example, 2015) as well as very wet years (for example, 2017), and lower for more moderate years. In the case of nitrogen, this effect is more pronounced. Heavier carbon isotope signatures in particulate organic matter (POM) were associated with dry years. In contrast, there were no significant differences in the stable isotope signatures of nitrogen in POM. The stable isotope signatures of periphyton collected across the trends sites between 2011 and 2019 varied widely across the data set. Average values of $\delta^{13}C$ for periphyton were higher during moderately wet and wet years. There was an increase in the average $\delta\ ^{15}N$ for periphyton over a gradient of dry to wet years, with the largest spread in data observed for wet years. When the samples from EMP trend sites were grouped according to whether they came from years with low, moderate, or high cumulative discharge (very dry, dry, moderate, wet), there were significant differences in average $\delta^{13}C$, but not in $\delta^{15}N$.

According to a Bayesian Inference stable isotope mixing model, phytoplankton carbon contributes to the juvenile salmonid food web as part of the diet of chironomid prey, based on stable isotope signatures of carbon; this carbon is incorporated as particulate organic matter and as periphyton. Models looking at how different sources of primary production contribution to additional prey sources are being investigated as more data are gathered, but analysis thus far suggests that periphyton constitutes an important source of organic matter for the preferred prey of juvenile salmonids (i.e., amphipods and chironomids). Estimates of dietary contributions from different prey items inferred from stable isotope mixing models suggest that juvenile salmonid growth is supported by amphipods, chironomids, and other crustacean prey, which is consistent with observations derived from stomach analysis.

Macroinvertebrates

Juvenile salmon diets in the Lower Columbia estuary consist mostly of amphipods, dipterans, and cladocerans.

Young salmon consume primarily wetland insects (dipterans) at Franz Lake, the uppermost site, incorporate cladocerans at Campbell Slough, transition to dipterans and amphipods at Welch Island and Whites Island, and consume primarily amphipods near the estuary mouth at Ilwaco Slough.

Diets are most metabolically beneficial to small salmon (30 - 59 mm). Larger salmon have higher metabolic costs that are directly influenced by larger body mass and higher water temperatures. Top salmon prey sources have small yet consistent contributions from benthic core and neuston tow samples.

Fish Communities

Examinations of fish communities for all years of sampling show that all five trend sites are different from each other. The one exception is that Welch and Whites, when compared directly to each other, are similar. Thirteen major families of fish have been consistently present at the trend sites. Within those families, the fish species range from native marine species at Ilwaco Slough, to freshwater native and non-native species at the remaining EMP trend sites sampled through 2022. Chinook salmon are captured at all five trend sites and are often the numerically dominant salmonid species. Chum salmon (primarily at Ilwaco Slough) and coho salmon (primarily at Franz Lake) have also been captured at the five sites in low numbers.

Ilwaco Slough, sampled for fish since 2011, is the only trend site that is influenced by marine waters due to its proximity to the mouth of the Columbia River (rkm 6). The species most consistently captured (eight or more of the last 10 years of sampling) are the native threespine stickleback, staghorn sculpin and shiner perch and the non-native banded killifish. Two salmon species, chum and Chinook, are regularly captured at this site. Chum salmon was the dominant species (>= 90% of the total salmon numbers) except during 2012 and 2015, when few salmon were captured. Through 2022, six or less individual Chinook salmon were captured during eight of the eleven years of sampling. Most were unmarked salmon (presumed wild); however, marked salmon (presumed hatchery reared) were captured in 2017 and 2018. The majority of Chinook salmon captured at Ilwaco Slough were subyearlings (fork length <60mm,

weight < 2 grams). Genetic analysis of unmarked and marked Chinook salmon captured at Ilwaco Slough has identified two stocks, Spring Creek group-fall and West Cascade-fall.

Welch Island, sampled for fish since 2012, is a tidally influenced, freshwater marsh habitat in the lower Columbia River (rkm 53). The species most consistently captured (11 out of the 11 years of sampling) are the native Chinook salmon, threespine stickleback, and the non-native banded killifish. Chinook salmon comprised 96% or greater of the total numbers of salmon captured within a year and were captured each year. Chum were the second most frequently seen salmon, making up 4% or less of all salmon in a given year, and have been captured in seven of ten years of sampling. Each year 70–100% of the Chinook salmon captured at Welch Island were unmarked (presumably wild) juveniles. Genetic composition of unmarked Chinook salmon captured at Welch Island has been dominated by West Cascade-fall followed by upper Columbia River-summer/fall. There have been minimal instances of Snake River-fall, Spring Creek-fall, and Rogue River. Genetic composition of marked Chinook salmon at Welch Island had been comprised primarily of two genetic stock groups, West Cascade-fall and Spring Creek Group-fall.

Whites Island, sampled for fish since 2009, is a freshwater, tidally influenced marsh, located on the north side of Puget Island in the Columbia River (rkm 72). The species most consistently captured in all years are the native Chinook salmon and threespine stickleback and the non-native banded killifish. Five different species in the Salmonidae family have been identified at Whites Island since 2009. The site has been dominated by juvenile Chinook, followed by chum salmon. Coho, sockeye and mountain whitefish are other species of the Salmonidae family caught at the site. The majority of Chinook salmon captured were unmarked, making up 70–100% of the yearly total. For eight of the sampling years, unmarked juvenile Chinook fry have made up over half of all Chinook catches. Marked Chinook (presumed hatchery origin) were primarily fingerlings with the occasional yearling seen in 2009, 2010 and 2019. From the genetic stock analysis of unmarked Chinook salmon, seven different stocks have been identified since 2009. West Cascade-fall stock is the predominant group, comprising 80% or more of the fish analyzed. For marked Chinook, four genetic stocks have been identified at Whites Island since 2009. The two major groups are West Cascade-fall and Spring Creek Group fall.

Campbell Slough (rkm 149), sampled for fish since 2008, is a freshwater area that is highly influenced by Bonneville Dam discharge, and minimally influenced by standard tidal fluctuations. The species most consistently captured in all years are the native Chinook salmon, threespine stickleback, and the non-native banded killifish. Six species of the family Salmonidae have been observed in Campbell Slough since 2008. The most common species is Chinook salmon followed by chum salmon. Coho, cutthroat trout, sockeye salmon, and mountain whitefish are the remaining species in the Salmonidae family. Fry and fingerling unmarked juvenile Chinook make up most of the salmon catches at the site. No marked juvenile fry chinook have been captured at the site. Marked juvenile Chinook are primarily fingerlings. Seven distinct genetic stocks of marked and unmarked Chinook salmon have been found in Campbell Slough. The most consistent stocks for both marked and unmarked Chinook are Spring Creek Group-fall, followed by West Cascade-fall, although percentage contribution in catches vary extensively over the monitoring years.

Franz Lake, sampled since 2008, is a freshwater site located at the confluence of the Franz Lake outlet channel and the Columbia River (rkm 221). The water levels at this site are almost exclusively controlled by discharge from the nearby Bonneville Dam. High water levels in the spring and warm water temperatures in the early summer regularly prevent monthly fish sampling. The most consistently captured fish species (9 out of 11 years of sampling) are the native threespine stickleback, largescale sucker, northern pikeminnow, and the non-native banded killifish. Nine species of Salmonidae have been captured at this site in the past years, contributing to less than 5% of total catches per year at this site. This could be an outcome of lack of optimal conditions for sampling at this site, among other environmental factors. Salmon catches predominantly consisted of juvenile Chinook and coho. Juvenile

Chinook at Franz Lake are primarily unmarked, and Chinook catches were strong in 2022, despite only sampling one month. The unmarked category of Chinook was predominantly fry (<60 mm fork length) making up more than 70% of those captured followed by fingerlings (60-100 mm fork length). Marked (presumed hatchery origin) Chinook have only been captured in 2008 and 2009. Genetics analysis of Chinook salmon over the course of the 14 years of sampling has been conducted on very few unmarked (23) and marked (41) individuals. No one group is dominant, and no discernable pattern can be seen among the stock groups identified. For unmarked Chinook salmon, stock groups include Spring Creek Group-fall, upper Columbia River-fall, Snake River-fall, West Cascade-fall, mid and upper Columbia-spring, and Willamette River-spring. For marked Chinook salmon, Spring Creek Group-fall are the most common, and West Cascade-fall and Willamette River-spring have also been present.

Closing Summary

The Ecosystem Monitoring Program is the only study in the lower Columbia river that collects long-term habitat data from relatively undisturbed tidal freshwater marshes to upper freshwater reaches to allow researchers and restoration practitioners to differentiate between variability associated with natural conditions and variability resulting from human influence, and enhance our understanding of the degree to which these wetlands aid in supporting life-cycle and recovery of endangered and threatened salmonids. In both 2022we monitored water quality, habitat structure, food web dynamics, and fish use at five trend sites from the mouth of the Columbia River to the Bonneville dam to assess habitat function at these sites. We also began a focused effort to evaluate the influence of river discharge on wetland habitat conditions. Results from our collective analyses indicate that differences in annual Columbia River discharge and climate conditions are correlated with significant shifts in wetland food web and habitat conditions including plant community, plankton, and zooplankton abundance; as well as composition, food web nitrogen, and carbon dynamics. These findings are critical for evaluating how future environmental fluctuations predicted to be associated with climate change may impact salmonid habitat and food web dynamics. Future EMP research will focus on synthesizing these environmental observations and identifying how shifting climatic, and habitat conditions will impact the salmonid food web.

Management Implications

There are a number of questions that emerge based on several years of observations in the lower Columbia. Some of these include:

- ***How important are biogeochemical processes upstream of Bonneville Dam for the tidal freshwater estuary?*** It is unclear how conditions above Bonneville Dam influence water chemistry and plankton stocks observed downstream. Measurements of water quality and food web components from above the dam would help to determine the degree to which advection is important versus in situ processes such as growth and gas equilibration with the atmosphere.
- ***What is the importance of decomposition of organic matter by microbial organisms in determining its quality for salmon prey?*** Microbial decomposition often results in "trophic upgrading", whereby less labile compounds are transformed through microbial metabolism to compounds that are more easily assimilated. How are these processes influenced by water chemistry, temperature, and nature of the organic matter (e.g., non-native vs. native plant species)?
- ***What factors contribute to cyanobacteria blooms in Franz Lake Slough? Do these blooms pose a problem for wildlife, and if so, what is the extent of the problem?*** Over the last few years, elevated phosphorus concentrations have been observed at Franz Lake Slough in advance of cyanobacteria blooms, although the source is unknown.
- ***How do pulses in primary production from different sources vary in space and time, and how does this influence secondary production and salmon food webs?*** The timing of availability of different sources of organic matter produced through primary production varies between pelagic phytoplankton and marsh vegetation. It would be helpful to compare the magnitude of these stocks to identify patterns that could inform food web models. In addition, pulse events, such as the production and deposition of pollen, could produce reservoirs of organic matter originating from vascular plants in the water column that is independent of detritus transport.
- ***How does prey quality and quantity vary spatially and temporally across the estuary?*** While studies have shown that emergent wetlands are important for prey production and export, accurate assessments of information on prey source in the mainstem and floodplain habitats are yet to be made in the lower Columbia river. The spatial and temporal variation of energy densities of chironomids and amphipods in these undisturbed sites of the lower Columbia river would provide an important functional tool for restoration design. Maintenance metabolism and energy ration calculations from juvenile salmon diet data, or future calculations of modeled growth, may address questions about habitat quality for juvenile Chinook salmon. High prey quality and quantity may help mitigate effects of suboptimal temperatures and hydrological conditions.
- ***How does mainstem cumulative discharge affect prey availability and juvenile salmon health and habitat use?*** Additional information is needed to explore the effect of different mainstem hydrologic conditions on the food web and habitat structure for the EMP. Since many EMP sites serve as reference sites for restoration projects, additional information about changes in habitat use and structure under various freshet conditions would help determine crucial actions in restoration design, and mitigate effects of climate change.

- ***How much do specific environmental factors impact growth, fish condition, residence time, age at maturation and survival of anadromous salmonids in the estuary?*** Habitat use in the lower Columbia depends on a myriad of abiotic conditions, and a closer look into specific characteristics such as temperature, DO, discharge, etc. would provide critical information about juvenile salmonid behavior which can be used to inform landscape principles in restoration planning. Bioenergetics analysis of subyearling Chinook could be a useful tool for determining impacts of temperature, flow-based variation in food availability, and habitat availability on subyearling growth and presumed survival. (links with topic above on discharge and prey availability).
- ***How does sediment carbon interact with Greenhouse gases in EMP Trend Sites?*** In order to understand the effects of climate change on the EMP sites, another aspect that needs to be explored further are the exchanges between carbon and greenhouse gases in emergent wetlands. While some data is available from sediment analysis, further exploration is required in terms of accretion and nutrients and carbon sequestration.
- ***How does discharge and river flow impact availability of off-channel habitat including restored areas?*** Availability of alternate migration pathways and rearing opportunities is important for building population resiliency. Impacts of climate change may limit access to rearing habitat as flows decrease. Applying habitat connectivity models used in Puget Sound to the lower Columbia River could help identify under what flows habitat connectivity is constrained or maximized throughout the entire lower river or specific reaches.

The Estuary Partnership shares results from the monitoring program with other resource managers in the region and results from this multi-faceted program are applied to resource management decisions. Results from the EMP are presented and discussed at an annual Science Work Group meeting. The Science Work Group is composed of over 60 individuals from the lower Columbia River basin representing multiple regional entities (i.e., government agencies, tribal groups, academia, and private sector scientists) with scientific and technical expertise who provide support and guidance to the Estuary Partnership. In addition, EMP results will also be shared with regional partners at various conferences throughout the year. Data are often provided to restoration practitioners for use in restoration project design and project review templates (e.g., ERTG templates). Finally, data from the EMP are used to compare and contextualize results from the Action Effectiveness Monitoring Program (see 2023 AEMR report, link). Furthermore, the Estuary Partnership is working on shifting all EMP and AEMR data into a regional database to store, share, and conduct additional, largescale synthesis analyses of these data by utilizing Tableau.

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1 Introduction

1.1 Background

The Columbia River supported diverse and abundant populations of fish and wildlife and is thought to have been one of the largest producers of Pacific salmonids in the world (Netboy 1980). Anthropogenic changes since the 1860s encompassing dike construction, land use conversion, and the construction of the hydropower system on the Columbia River basin have resulted in alterations to the hydrograph (i.e., timing, magnitude, duration, frequency, and rate of change in river flows); degraded water quality and increased presence of toxic contaminants; introduction of invasive species; and altered food web dynamics. These changes have subsequently significantly reduced the quantity and quality of habitat available for fish and wildlife species. The availability of suitable habitats affects the diversity, productivity, and persistence of salmon populations (Fresh et al. 2005). Degradation and loss of suitable estuarine habitats can threaten salmon population viability, thus highlighting the importance of identifying limiting factors to salmon survival and filling key knowledge gaps across the habitat gradient of the lower Columbia River to promote salmon recovery.

Threatened and endangered salmonids utilize the shallow water wetland habitats of the lower Columbia River for rearing and refugia, with some stocks utilizing these habitats for long time periods before completing their migratory journey to the ocean (Bottom et al. 2005, Fresh et al. 2005, 2006, Roegner et al. 2008, McNatt et al. 2016). Traditionally, fish and fish habitat research and monitoring efforts have been concentrated in the lower reaches of the estuary, particularly near the mouth of the river, leaving knowledge gaps in the basic understanding of fish habitat use and benefits within the upper, freshwater-dominated reaches of the Columbia River.

Tidal emergent wetland vegetation provides rearing and refuge habitat for juvenile fish and a source of organic matter to the mainstem and downstream habitats, while tidal channels provide access to wetlands and to foraging opportunities. Most emergent wetlands in the lower river cover a narrow elevation range of 0.8 to 2.6 m, relative to the Columbia River Datum (CRD). The annual fluctuations in hydrology drive the spatial and temporal variability of wetland vegetation, specifically the cover and species composition, and affect overall wetland inundation (Sagar et al. 2013). The vegetation species composition in the lower river is spatially variable, with the middle reaches generally showing the greatest species diversity; although some areas are dominated by non-native species such as reed canarygrass (*Phalaris arundinacea*), particularly in the river-dominated upper reaches (Sagar et al. 2013). Identification and quantification of vital habitat metrics allow for a greater predictability in biotic responses to changing environmental conditions and improves our overall understanding of the ecological functions in the lower river.

Salmonids occupy the upper trophic levels in the Columbia River system. They spend portions of their life cycle in fresh, estuarine, and oceanic waters. Threats to their survival could arise from a variety of sources or stressors occurring at any one of several life stages or habitat types. Large-scale changes to the ecological characteristics of the lower Columbia River food web as a consequence of wetland habitat loss have resulted in a significant reduction of microdetritus inputs to the system that historically formed the basis of the aquatic food web (Sherwood et al. 1990). Organic matter derived from fluvial phytoplankton (rather than microdetritus) may be a seasonal driver of the salmon food web (Maier and Simenstad 2009). The consequences of the apparent shift in the type of organic matter fueling food web dynamics are uncertain, and the understanding of shifts in the food web requires a detailed examination of the interactions between multiple trophic levels and environmental conditions. Studying the abundance and assemblage of phytoplankton and zooplankton over space and time provides crucial information on the diets of preferred salmon prey, such as chironomids and benthic amphipods. In turn, characterizing the abiotic conditions within emergent wetlands, and in the river mainstem is essential for elucidating spatial and temporal patterns in the primary and secondary productivity in the lower river.

The Lower Columbia Estuary Partnership (Estuary Partnership), as part of the Environmental Protection Agency (EPA) National Estuary Program, is required to develop and implement a Comprehensive Conservation and Management Plan. This Management Plan specifically calls for sustained long-term monitoring to understand the ecological conditions and functions, to evaluate the impact of management actions over time (e.g., habitat restoration), and to protect the biological integrity in the lower Columbia River. The Estuary Partnership implements long-term monitoring through the Ecosystem Monitoring Program (EMP). Ultimately, the goal of the EMP is to track ecosystem conditions over time and allow researchers and managers the ability to distinguish between the variability associated with natural conditions and variability resulting from human influence. The EMP partnership collects on-the-ground data from relatively undisturbed emergent wetlands to provide crucial information about habitat structure, fish use, abiotic site conditions, salmon food web dynamics, and river mainstem river conditions to assess the biological integrity of the lower river, enhance our understanding of the estuary functions, and ultimately support recovery of threatened and endangered salmonids. The creation and maintenance of long-term datasets are vital for documenting the history of change within important resource populations. Therefore, through the EMP, we aim to assess the status (i.e., spatial variation) and track the trends (i.e., temporal variation) in the overall conditions of the lower Columbia River, to provide a better basic understanding of ecosystem functions, to provide a suite of reference sites for use as end points in regional habitat restoration actions, and to place findings from other research and monitoring efforts, such as the Action Effectiveness Monitoring into context within the larger ecosystem.

Ecosystem-based monitoring of the fish habitat conditions in the lower river is a regional priority intended to aid in the recovery of historical productivity and diversity of fish and wildlife. In addition to tracking ecological changes in the lower Columbia River, we also measure and study the effect of varying flow regimes over the monitoring period, of the mainstem on site-specific biotic and abiotic conditions. This year, we are specifically addressing uncertainties brought forward by the Expert Regional Technical Group (ERTG). The hydrology of the mainstem Columbia is strongly influenced by winter snow melt and precipitation between the months of October and March (Arelia Werner et al., 2007). The resulting cumulative discharge of the spring freshet depends on the magnitude, frequency, and duration of precipitation (Nilsson and Renöfält, 2008). Several studies indicate that river discharge exerts a significant influence on ecosystem processes like nutrient, sediment, and organic matter transport, as well as biotic structures. Moreover, studying these relationships will allow us to inform impacts associated with extreme high and low flow events, informing restorative actions (Bonada et al., 2006; Larned et al., 2007; Leigh et al., 2010; Rolls et al., 2012). The primary research question we have attempted to answer with this report is "*What are the longterm status and trend conditions we see across the estuary and how can we use these data to address the uncertainties brought forth by the ERTG and others about restoring sustainable habitat conditions in the estuary?"* Additionally, this year, in FY22, we transitioned our databases into a new format to allow additional large-scale synthesis analyses for the 2023 report as well as increasing the public accessibility of the EMP project through the use of Tableau Dashboards.

The EMP is funded by the Northwest Power and Conservation Council/Bonneville Power Administration (NPCC/BPA) and a primary goal for the action agencies (i.e., the BPA and US Army Corps of Engineers) is to collect key information on ecological conditions for a range of habitats and whether the habitats in the lower river are meeting the needs of outmigrating juvenile salmonids for growth and survival. Such data provide information toward implementation of the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008). Specifically, NPCC/BPA funding for this program focuses on addressing BPA's Columbia Estuary Ecosystem Restoration Program (CEERP) goal of improving habitat opportunity, capacity and realized function for aquatic organisms, specifically salmonids.

The EMP addresses Action 28 of the Estuary Partnership Comprehensive Conservation and Management Plan; Reasonable and Prudent Alternatives (RPAs) 161, 163, and 198 of the 2000 Biological Opinion for the Federal Columbia River Power System; and RPAs 58, 59, 60, and 61 of the 2008 Biological Opinion. The Estuary Partnership implements the EMP by engaging regional experts at Battelle-Pacific Northwest National Laboratory (PNNL), National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA-Fisheries), Estuary Technical Group (ETG), University of Washington (UW), and Oregon Health & Science University (OHSU).

1.2 Study Area

The lower Columbia River and estuary is designated as an "Estuary of National Significance" by the Environmental Protection Agency (EPA) and as such, it is part of the National Estuary Program (NEP) established in Section 320 of the Clean Water Act. The EMP study area encompasses that of the NEP (a.k.a., the Estuary Partnership), including all tidally influenced waters, extending from the mouth of the Columbia River at river kilometer (rkm) 0 to Bonneville Dam at rkm 235 (tidal influence is defined as historical tidal influence, relative to dam construction in the 1930s). The Estuary Partnership and monitoring partners collect data for the EMP from habitats supporting juvenile salmonids, in tidally influenced shallow water emergent wetlands connected to the Columbia River.

The Estuary Partnership and monitoring partners use a multi-scaled stratification sampling design for sampling the emergent wetland component of the EMP based on the Columbia River Estuary Ecosystem Classification (Classification). The Classification, a GIS-based data set, is a six-tier hierarchical framework that delineates the diverse ecosystems and component habitats across different scales in the lower river. The primary purpose of the Classification is to enable management planning and systematic monitoring of diverse ecosystem attributes. The Classification also provides a utilitarian framework for understanding the underlying ecosystem processes that create the dynamic structure of the lower river. As such, it aims to provide the broader community of scientists and managers with a larger scale perspective in order to better study, manage, and restore lower river ecosystems. The EMP sampling design has been organized according to Level 3 of the Classification, which divides the lower river into eight major hydrogeomorphic reaches (Figure 1).

More recently, subsequent to the development of the sampling design, data collected as part of the EMP and other studies (Borde et al. 2011; Borde et al. 2012) have been used to define five emergent marsh (EM) zones based on spatial variation of the hydrologic regime and vegetation patterns observed in the lower river (Jay et al. 2016). Vegetation species assemblages vary temporally and spatially and are broadly grouped into categories, or EM zones, based on vegetation cover and species richness. EM zones are used here to evaluate vegetation patterns within the tidal wetlands of the lower river because they are more representative of vegetation patterns than hydrogeomorphic reach. The zone boundaries are meant to be broad, and variation of the zone boundaries is observed between years. The following river kilometers are currently used to delineate the zones:

EM Zone	River Kilometer (rkm)
1	0 – 39
2	39 – 88
3	89 – 136
4	137 – 181

5	182 – 235

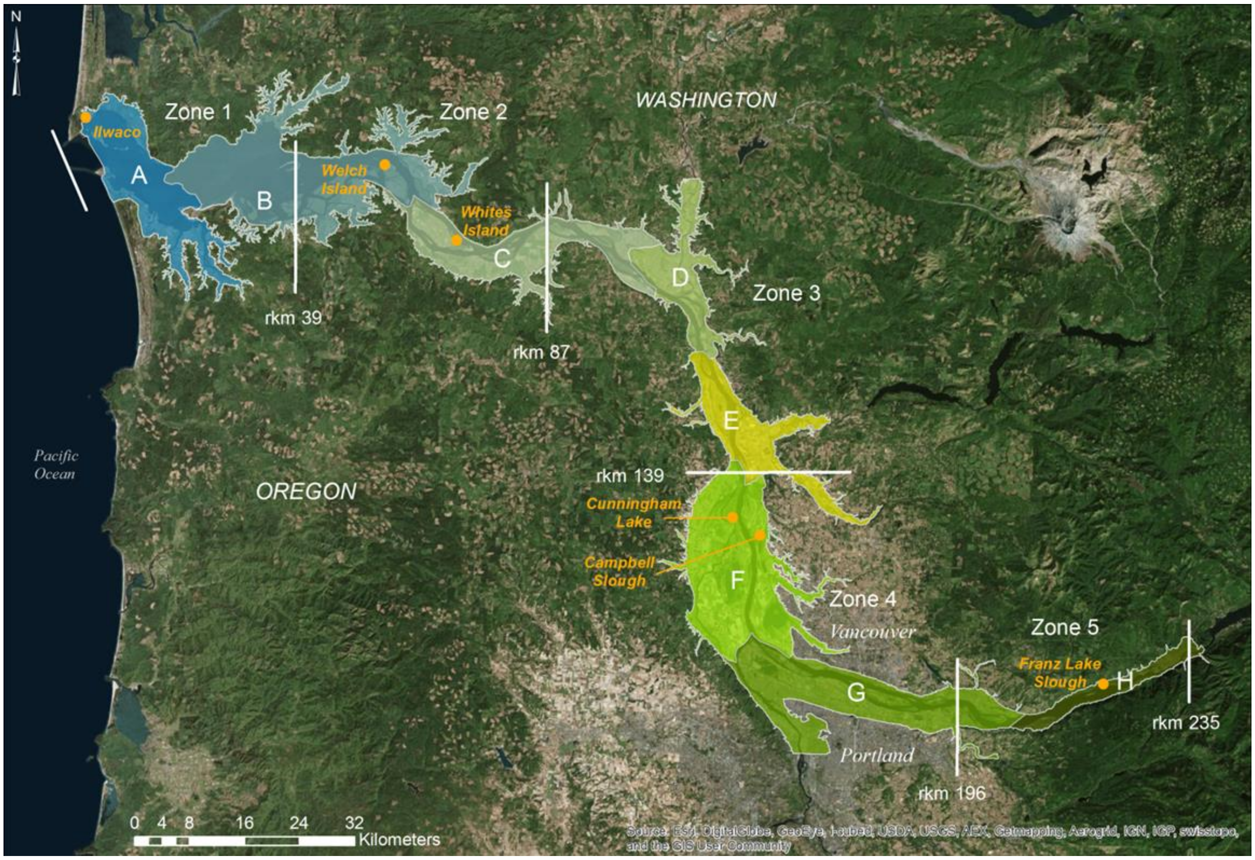


Figure 1. Lower Columbia River and estuary with hydrogeomorphic reaches (A-H) specified by color (Simenstad et al. 2011) and wetland zones (1-5) delineated by white lines (Jay et al. 2016). The 2022 EMP trends sites are shown in orange.

1.3 Characterization of Emergent Wetlands in the Lower Columbia River

1.3.1 Sampling Effort, 2005-2022

The objective of the EMP is to characterize habitat structure and function of estuarine and tidal freshwater habitats within the lower river in order to track ecosystem condition over time, determine ecological variability in these habitats, and provide a better understanding of ecosystem function. The EMP is largely focused on characterizing relatively undisturbed tidally-influenced emergent wetlands that provide important rearing habitat for juvenile salmonids, which also serve as reference sites for restoration actions. The Estuary Partnership and its monitoring partners have focused on providing an inventory of salmon habitats (or “status”) across the lower river and including a growing number of fixed sites for assessing interannual variability (or “trends”). Between 2005 and 2012, three to four status sites in a previously unsampled river reach (as denoted in the Classification described above) were selected for sampling each year, along with ongoing sampling of a growing number of trends sites (Table 1). Since 2007, we have conducted co-located monitoring of habitat structure, fish, fish prey, and basic water quality metrics at multiple emergent wetland sites throughout the lower river. In 2011, the Estuary Partnership added food web and abiotic conditions (i.e., conditions influencing productivity such as temperature, turbidity, dissolved oxygen, nutrients) sampling and analysis in both the mainstem Columbia River and at the trend sites.

In 2013, the EMP sampling scheme was adjusted to no longer include data collection at status sites and monitoring efforts focused solely on the six trends sites. The six trends sites selected based on EM Zones were Ilwaco Slough (2010-2021), Secret River (2010-2016), Welch Island (2010-2021), Whites Island (2009-2021), Campbell Slough in the Ridgefield National Wildlife Refuge (2005–2021), and Franz Lake (2008-2009, 2011-2021). Habitat and hydrology data were collected at Cunningham Lake (in addition to the trends sites) as a reference site for habitat and hydrology representative of Reach F sites because vegetation has been periodically trampled by livestock at Campbell Slough in past years. Sampling efforts was discontinued in Secret River from 2017. Beginning in 2018, Steamboat Slough, an Action Effectiveness Monitoring and Research site, was included in the habitat biomass data collection efforts to aid in the applied interpretation of these data (Schwartz et al. 2019). Methods from the protocol Lower Columbia River Habitat Status and Trends (v1.0, ID 85) were used to monitor the status and trends of specified metrics.

Activities Performed, Year 17 Contract (October 1, 2021 – September 30, 2022):

- Salmonid occurrence, community composition, growth, condition, diet, prey availability, and residency
- Habitat structure, including physical, biological and chemical properties of habitats
- Food web characteristics, including the primary and secondary production of shallow water habitats and in the mainstem lower river and,
- Biogeochemistry of tidal freshwater region of the lower river for comparison to the biogeochemistry of the estuary, key for assessing hypoxia, ocean acidification, and climate change impacts.

Table 1. Summary of sampling effort by site and year(s) conducted at EMP sampling sites. Bold text indicates that data were collected in 2022.

Reach	**Type of Site**	**Site Name**	**Site Code**	**Vegetation & Habitat[1]**	**Fish &Prey[5]**	**Abiotic Conditions**	**Food Web[4]**
A	Trend	**Ilwaco Slough**	BBM	2011-2022	2011-2013, 2015-2022	2011-2013, 2015-2022	2011-2013, 2015-2022
B	Trend	Secret River	SRM	2008[2], 2012-2016	2012, 2013		2012, 2013
	Tributary	Grays River, lower	-		2015		2015
	Trend	**Welch Island**	WI2	2012-2022	2012-2022	2014, 2019-2022	2012-2022
C	Status	Ryan Island	RIM	2009	2009		
	Status	Lord-Walker Island 1	LI1	2009	2009		
	Status	Lord-Walker Island 2[3]	LI2	2009			
	Trend	**Whites Island**	WHC	2009-2022	2009-2022	2009, 2011-2022	2011-2022
	Status	Jackson Island	JIC	2010	2010		
	Status	Wallace Island	WIC	2010	2010		
	Status	Bradwood Landing	BSM		2010		
D	Status	Cottonwood Island small slough	CI2	2005			
	Status	Cottonwood Island large slough	CI1	2005			
	Status	Dibble Slough	DSC	2005		2005	
E	Status	Sandy Island 1, 2	SI1, SI2	2007	2007		
	Status	Deer Island	DIC	2011	2011		
	Status	Martin Island	MIM	2007			
	Status	Goat Island	GIC	2011	2011		
	Status	Burke Island	BIM	2011	2011		
	Tributary	Lower Lewis River	-		2015		
	Status	Lewis River Mouth	NNI	2007			
F	Status	Sauvie Cove	SSC	2005			
	Status	Hogan Ranch	HR	2005			
	Trend	**Cunningham Lake**	CLM	2005-2022	2007-2009		
	Trend	**Campbell Slough**	CS1	2005-2022	2007-2022	2008-2022	2010-2022
G	Status	Water Resources Center	WRC	2006			

Reach	Type of Site	Site Name	Site Code	Vegetation & Habitat[1]	Fish &Prey[5]	Abiotic Conditions	Food Web[4]
	Status	McGuire Island	MIC	2006			
	Status	Old Channel Sandy River	OSR	2006			2006
	Status	Chattam Island	CIC	2006			
	Status	Government/Lemon Island	GOM	2012	2012	2012	
	Status	Reed Island	RI2	2012	2012	2012	
	Status	Washougal Wetland	OWR	2012	2012	2012	
	Trend	**RM122**	-			2012-2022	
H	Trend	**Franz Lake (slough)**	FLM	2008-2009, 2011-2022	2008-2009, 2011-2022	2011-2022	2011-2022
	Status	Sand Island	SIM	2008	2008	2008	
	Status	Beacon Rock		2008	2008		
	Status	Hardy Slough	HC	2008	2008		

[1] Vegetation biomass data were not collected at any EMP sites in 2014. Only the four upstream trends sites were sampled for biomass in 2015.
[2] Site sampled as part of the Reference Site Study; thus, only vegetation and habitat data were collected.
[3] Lord-Walker Island 2 was sampled by the EMP in conjunction with the Reference Site Study; thus, only vegetation and habitat data were collected.
[4] Phytoplankton and zooplankton only sampled from 2011 – 2019.
[5] Fish prey data were not collected for juvenile Chinook salmon diet and prey availability analyses in 2014 or 2020.

1.3.2 Site Descriptions

In 2022, the EMP focused primarily on the five trends sites that were monitored over multiple years: Ilwaco Slough, Welch Island, Whites Island, Campbell Slough, and Franz Lake Slough. Habitat and hydrology data were collected at all five trends sites plus Cunningham Lake, which is typically sampled for habitat and hydrology metrics as a control site since livestock grazing activities occasionally occur at Campbell Slough (Table 1). Coordinates for trends sites sampled in 2022 are listed in Table 2. The 2022 trends monitoring sites are described in order below, starting at the mouth of the Columbia River and moving upriver towards Bonneville Dam (Figure 1). Maps of the sites, including vegetation communities, are provided in Appendix A and photo points from all sampling years are provided in Appendix B.

Ilwaco Slough. This site is located in Reach A, EM Zone 1 at river kilometer (rkm) 6, southwest of the entrance of Ilwaco harbor, in Baker Bay, WA. The property is currently owned by Washington Department of Natural Resources. The site has developed in the past century as the bay filled in, likely due to changes in circulation from the construction of the jetties at the mouth of the Columbia River, the placement of dredge material islands at the mouth of the bay, and changes in river flows. Ilwaco Slough marsh is dominated by lush fields of Lyngby's sedge (*Carex lyngbyei*) with higher portions occupied by tufted hairgrass (*Deschampsia cespitosa*) and cattail (*Typha angustifolia*). Being so close to the mouth of the Columbia River, the tidal channel is regularly inundated with brackish water (average salinity < 10 Practical Salinity Units (PSU), however salinity up to 20 PSU occur in the late summer). Selected as a long-term monitoring site in 2011, Ilwaco Slough was sampled for all EMP metrics every year except 2014 when only habitat and hydrology were monitored.

Welch Island. The monitoring site on Welch Island is located in Reach B, EM Zone 2 on the northwest (downstream) corner of the island at rkm 53, which is part of the Lewis and Clark National Wildlife Refuge. The island was present on historical late-1800's maps; however, the island has expanded since then, and wetland vegetation has developed where there was previously open water near the location of the study site. The site is a high marsh dominated by *C. lyngbyei*, but with diverse species assemblage and a scattering of willow trees. Small tidal channels grade up to low marsh depressions within the higher marsh plain. The area was selected as a long-term monitoring site in 2012; two other areas of the island were monitored as part of the Reference Sites Study in 2008 and 2009 (Borde et al. 2011).

Whites Island. The Whites Island site is Reach C, EM Zone 2 located on Cut-Off Slough at the southern (upstream) end of Puget Island, near Cathlamet, Washington at rkm 72. A portion of the island is owned by Washington Department of Fish and Wildlife (WDFW) and is maintained as Columbia white-tailed deer habitat. Whites Island is not present on historical maps from the 1880s and was likely created from dredge material placement. The site is located at the confluence of a large tidal channel and an extensive slough system, approximately 0.2 km from an outlet to Cathlamet Channel; however, according to historic photos, this outlet was not present prior to 2006 and the connection to the river mainstem was approximately 0.7 km from the monitoring site. The site is characterized by high marsh, some willows, scattered large wood, and numerous small tidal channels. This long-term monitoring site has been surveyed annually since 2009.

Cunningham Lake. Cunningham Lake is a floodplain lake located in Reach F, EM Zone 4 at rkm 145 on Sauvie Island in the Oregon DFW Wildlife Area. The site is a fringing emergent marsh at the upper extent of the extremely shallow "lake" (Figure 2f) and at the end of Cunningham Slough, which meanders approximately 8.7 km from Multnomah Channel (a side channel of the Columbia River). The mouth of the Slough is located between rkm 142 and 143 near where Multnomah Channel meets the Columbia River. This long-term monitoring site has been sampled exclusively for habitat and hydrology data annually since 2005. In some years, the “lake” is covered with wapato (*Sagittaria latifolia*), however, in all years since 2005, this cover has been sparse or non-existent until 2016 when cover increased once again. In 2017 Cunningham Lake was heavily grazed by cattle. In 2018, greater efforts were made to keep the cattle out; however, some grazing still continued at a lesser extent through 2022 and is expected to continue.

Campbell Slough. The Campbell Slough site is located in Reach F, EM Zone 4 at rkm 149 on the Ridgefield National Wildlife Refuge in Washington. This long-term monitoring site has been surveyed annually since 2005. The monitoring site is an emergent marsh adjacent to the slough, approximately 1.5 km from the mainstem of the Columbia River. The site grades from Wapato up to reed canarygrass. The US Fish and Wildlife Service manages the impact of reed canarygrass within the extensive refuge by allowing cattle grazing in some areas. The site is usually fenced off from cattle except for times during and immediately after high freshets, which can cause holes in the fencing due to high flows and occasional woody debris. Extensive grazing occurred at the site in 2007, but vegetation appeared to recover in subsequent years. In 2010 and 2011, slight evidence of grazing was again observed. Since 2012 the site has been periodically grazed and trampled by cows, affecting primarily the upper marsh portion of the site that is dominated by reed canarygrass. In 2017 this site was heavily impacted by cattle grazing due to the removal of the protective fence in the previous winter (2016). In 2018 an electric fence was installed, however it failed to keep cattle out, and the wetland was grazed during the growing season prior to habitat monitoring. The electric fence was updated in 2019 in an attempt to prevent further grazing, but it failed. Due to COVID-19, no fence was installed in 2020 and grazing has continued to impact the site through 2021 and is expected to continue. In 2021, a secondary area of the site, named Campbell Slough-Channel, located just across the main slough channel from the historic monitoring area, was established in a region of the site where minimal grazing appears to occur.

Franz Lake. The long-term monitoring site located in Reach H, EM Zone 5, the furthest up river site at rkm 221 is Franz Lake, which is part of the Pierce National Wildlife Refuge. The site has an expansive area of emergent marsh extending 2 km from the mouth of the slough to a large, shallow ponded area. Several beaver dams have created a series of ponds along the length of the channel resulting in large areas of shallow-water wetland with fringing banks gradually sloping to an upland ecosystem. The sample site is located approximately 350 m from the channel mouth, spanning an area impacted by a beaver dam. The site is primarily high marsh with scattered willow saplings, fringed by willows, ash, and cottonwood. The beaver dam has come and gone throughout the monitoring years but remained somewhat stable between 2017-2020, and then was breached in 2021 impacting the habitat conditions. The dam was rebuilt by beaver in the fall of 2021 and was observed in place during the winter 2022 field sampling.

Table 2. Coordinates of the trend sites sampled in 2022.

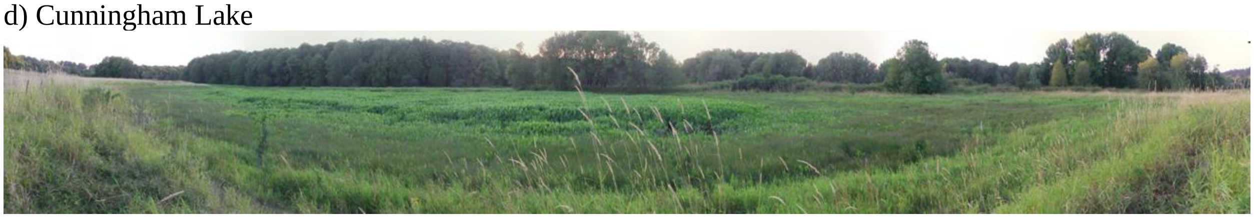
Site Name	Latitude	Longitude
Ilwaco Slough	46°18.035'N	124° 2.784'W
Welch Island	45° 47.032'N	122° 45.291'W
Whites Island	45° 9.561'N	122° 20.408'W
Cunningham Lake	45° 48.448'N	122° 48.285'W
Campbell Slough	45° 47.032'N	122° 45.291'W
Franz Lake	45° 36.035'N	122° 6.184'W


a) Ilwaco Slough


b) Welch Island


c) Whites Island


d) Cunningham Lake


e) Campbell Slough


f) Franz Lake Slough

Figure 2. Ecosystem Monitoring sites sampled in (photos taken in 2016): (a) Ilwaco Slough; (b) Welch Island; (c) Whites Island; (d) Cunningham Lake; (e) Campbell Slough; (f) Franz Lake Slough. Updated site photos were unavailable at the time this report was compiled, UAV images from 2019-2022 are available upon request and within the tableau dashboards.

1.3.3 Water Year

River flows in the Columbia and its tributaries are influenced by a combination of winter snowpack and pluvial flows driven by rainfall. High snowpack arises from cold and wet winters, while low snowpack arises from dry conditions throughout the winter, which can be either warm or cold. The timing of precipitation and whether it falls as snow or rain influences the timing and magnitude of the spring freshet. Typically, the freshet begins in late April/early May and persists into June. After that, the summer period tends to be dry and river flows are low between June and October.

This section has been updated to include 2022 in the Tableau Dashboard with interactive figures. Compared to the previous nine years (Figure 3), discharge at Bonneville Dam during the freshet in 2022 was most similar to those seen in 2011, however the peak of the freshet wasn't as high or lasting as long as those conditions observed in 2011. There were periods in 2022 where flows were quite low; river flows from February, April, and late September were some of the lowest on record; however, the onset of the spring freshet in June peaked at a record-breaking rate (based on the historic data back to 2009), for a short duration. In contrast, flows in 2021 were extremely low and 2020 were more inline with long-term average conditions.

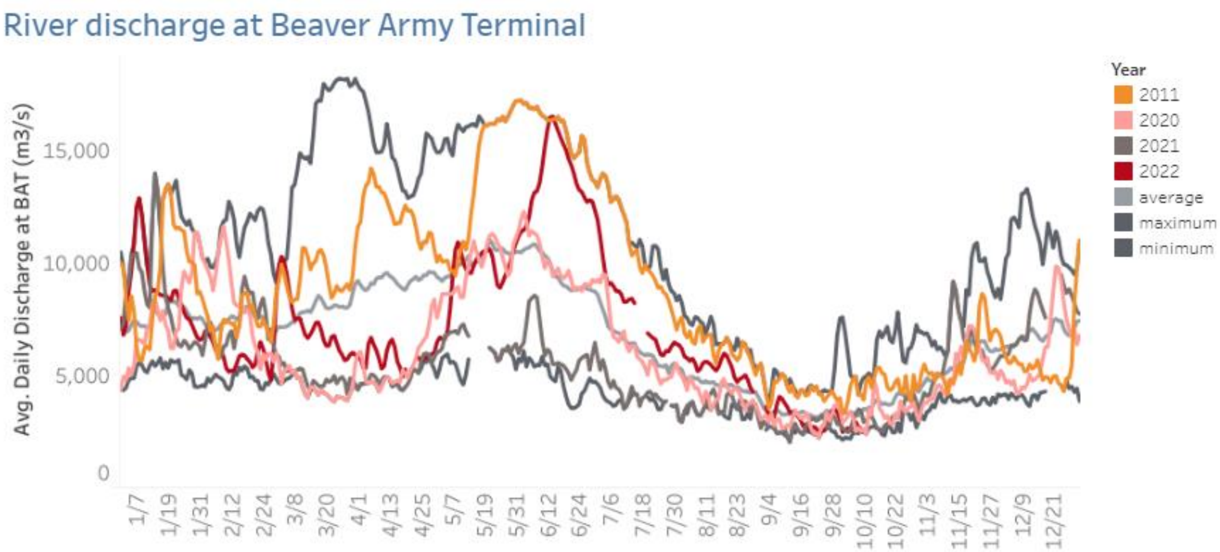


Figure 3. Daily average discharge volume (in $m^3 s^{-1}$) in blue for the years 2011, 2020, 2021, 2022. Each panel represents one year (Jan – Dec). Also shown in each plot is the maximum and minimum daily average flows for all years combined. If the years line matches either the minimum or maximum, those are the values that constitute the lowest or highest, respectively, in the time series.

Based on Figure 3 an NMDS plot of differences in river discharge and river temp between years, hydrologic conditions or cumulative discharge of the Mainstem since 2010 were classified into four categories (Table 3). The results presented in this report have compared the evolution of abiotic and biotic conditions over the monitoring years and differentiated the results between the tabulated categories. Any additional or modified freshet categories have been included in respective sub-sections.

Table 3: Classification of Monitoring years according to cumulative river discharge during the spring freshet between 2010-2022

Year	Cumulative River Discharge ($m^3 \times 10^{10}$) for May – Aug[2]	River Temperature[1] (days)	Classification
2022	7.7	55	**Mid/Wet**
2021	5.4	73	**Very dry**
2020	7.5	50	**Mid**
2019	5.9	85	**Dry**
2018	7.8	79	**Mid/wet**
2017	8.7	78	**Wet**
2016	5.5	85	**Dry**
2015	4.7	102	**Very dry**
2014	7.3	86	**Mid**
2013	6.7	84	**Mid**
2012	9.2	59	**Wet**
2011	10.4	59	**Wet**
2010	6.3	47	**Mid**

[1]River temperature: Number of days days that the river temp was >19 °C May –Sep
[2]Freshet: cumulative river discharge ($m^3 \times 10^{10}$) for May – Aug. Also referred to as "Freshet condition" in this report

1.4 Report Organization

We have divided this report into six sections, excluding References and Appendices. In section 2, we describe methods used to collect data from the mainstem and site-specific abiotic and biotic aspects. Methods of analysis are also described in this section. Section 3 presents results of the 2022 monitoring effort. We begin by describing abiotic and nutrient characteristics of the mainstem, and then move onto site-specific abiotic conditions. We then report on site–specific hydrological patterns, sediment dynamics, habitat structure, and channel morphology. We then move on to food web dynamics at the trend sites, reporting on primary and secondary productivities, plankton assemblages, as well as isotope analyses of carbon and nitrogen for vegetation and plankton. Stable isotope ratios for salmon prey and whole body salmon have also been presented in this report. Section 3.5 describes prey availability for 2021 and Section 3.6 reports out on Juvenile Chinook community and genetic stock composition for 2022 at the trend sites. GLM models have been used to study the influences of environmental variables and genetic stocks on growth rates in juvenile salmon. Salmon health were determined by lipid content in body samples. Due to a lack of significant differences between freshet conditions (Table 3), salmon community composition, influence on growth rates or health, and COVID-19 lab closures, no results have been included for this aspect in this report. Based on the overall results, trends observed over the years have been discussed in Section 4. In order to inform restorative actions in the study area, Adaptive Management measures have been provided in Section 5.

1.5 Data Visualization and Reporting

Our mission to enhance data visualization, accessibility, and reporting for the Columbia Estuary Ecosystem Restoration Program (CEERP) has guided our transition to Tableau, an interactive and user-friendly data visualization software. Capable of processing, summarizing, and displaying both geospatial and non-geospatial data, this robust tool has become an integral part of our efforts in salmon habitat monitoring in the Lower Columbia River Estuary.

The move to Tableau aligns with the objectives of the Ecosystem Monitoring Program (EMP). It offers a platform for data exploration, empowering researchers to delve deeper into the data, and providing our target audience with an engaging, data-driven narrative.

Tableau Desktop, in particular, has proven indispensable for our needs, facilitating the storage and querying of extensive data from the EMP and the CEERP Action Effectiveness Monitoring and Research Program (AEMR) in a user-friendly manner. Its compatibility with other languages like SQL, Python, and R, even without advanced coding knowledge, enables complex queries and analyses. The collaborative functionality of Tableau further strengthens our approach, allowing multiple researchers to connect, analyze, and contribute to the same datasets seamlessly.

In our efforts to effectively transition to Tableau, we have taken strategic steps to format and clean our salmon habitat monitoring data for compatibility. We're also refining best practices for crafting dynamic visualizations and dashboards, and working collaboratively with project partners and stakeholders to design customized dashboards and reports.

Our hybrid reporting approach takes advantage of Tableau's ability to manage a variety of datasets, encompassing hydrology, vegetation, sediment accretion, drone analysis, macroinvertebrates, and fish. We have publicly disseminated these datasets and their corresponding analyses in the form of interactive Tableau dashboards designed to supplement our reports. Our inaugural hybrid Tableau report for the AEMR Program was published in 2022 and is accessible online.

This 2023 report signifies the first step in our ongoing initiative to integrate the EMP report and program onto the Tableau platform. As we advance with this integration across our research teams, our ultimate goal is to have the data linked and ready for synthesis analyses across all our EMP research partners by summer 2024.

These dashboards offer stakeholders and other interested parties an immersive way to visualize and self-explore the evolution of restoration sites from pre-monitoring to their current states. They also render these results more accessible and comprehensible to a broader audience.

For a more interactive experience, the layout of the Methods and Results sections has been adapted to be directly accessible in Tableau (link). For static results, refer to the appendices, please note that these static results are preliminary as of the writing of this report and the user should check the active link for updates and corrections. The methodologies for the EMP and AEMR have now been integrated into a separate, continuously updated document, available alongside our other resources on MonitoringMethods.org. You can access this document here: Kidd et al. 2023.

2 Methods

Methods for the Ecosystem Monitoring Program and the Action Effectiveness Monitoring Program have now been integrated into a separate living document in addition to being available on MonitoringMethods.org:

Kidd, S., I. Edgar, S. Rao, and A. Silva (Eds.). 2023. Protocols for Monitoring Juvenile Salmonid Habitats in the Lower Columbia River Estuary. Portland, Oregon: Lower Columbia Estuary Partnership. https://www.estuarypartnership.org/our-work/monitoring

Visit the tableau dashboards for additional context (link) and data availability. The methods below hold true for all data collected prior to 2022.

2.1 Mainstem Conditions

2.1.1 Overview

There are two in-situ water quality monitoring platforms in the mainstem Columbia River that provide baseline water quality measurements in support of the Ecosystem Monitoring Program. The first platform, funded by the National Science Foundation, was installed in July 2009 at River Mile 53 (in Reach C) and is physically located on a USGS Dolphin piling (46 11.070 N, 123 11.246 W; Figure 4). A second platform, funded by the Ecosystem Monitoring Program, was installed in August 2012 at River Mile 122 (in Reach G) and is physically located on the outer-most floating dock at the Port of Camas-Washougal (45 34.618 N, 122 22.783 W; Figure 4). The monitoring protocol can be found on monitoringmethods.org (Protocol ID 459). Each instrument platform consists of a physical structure, sensors, sensor control, power supply and distribution, and wireless communication. Data transmitted from the sensors is available within 1–2 hours of collection. Raw data can be downloaded in near-real time from a dedicated webpage (http://columbia.loboviz.com/), and data that have been examined for quality assurance is available upon request). In addition to capturing spatial and temporal resolution of basic water quality and biogeochemical observations for the mainstem Columbia River, an outcome of this effort is to provide daily estimates of parameters necessary for the assessment of ecosystem conditions at sites upstream and downstream of the Willamette-Columbia confluence. Knowledge of daily conditions at these sites allows the identification of contributions from lower river tributaries. Availability of these data enables the calculation of fluxes of various inorganic and organic components, such as nitrate concentration or chlorophyll, and an estimate of phytoplankton biomass. Knowledge of nutrients and organic matter flux for a large river is important for a variety of applications, including assessment of pollution, an indication of eutrophication, and quantification of material loading to the coastal zone, where many important ecological processes may be affected. Another product is the assessment of Net Ecosystem Metabolism (NEM), which provides a daily measure of the gross primary production and aerobic respiration occurring in the river as measured by hourly changes in dissolved oxygen. NEM is often used by managers to identify changes or impairments to water quality (Caffrey 2004).

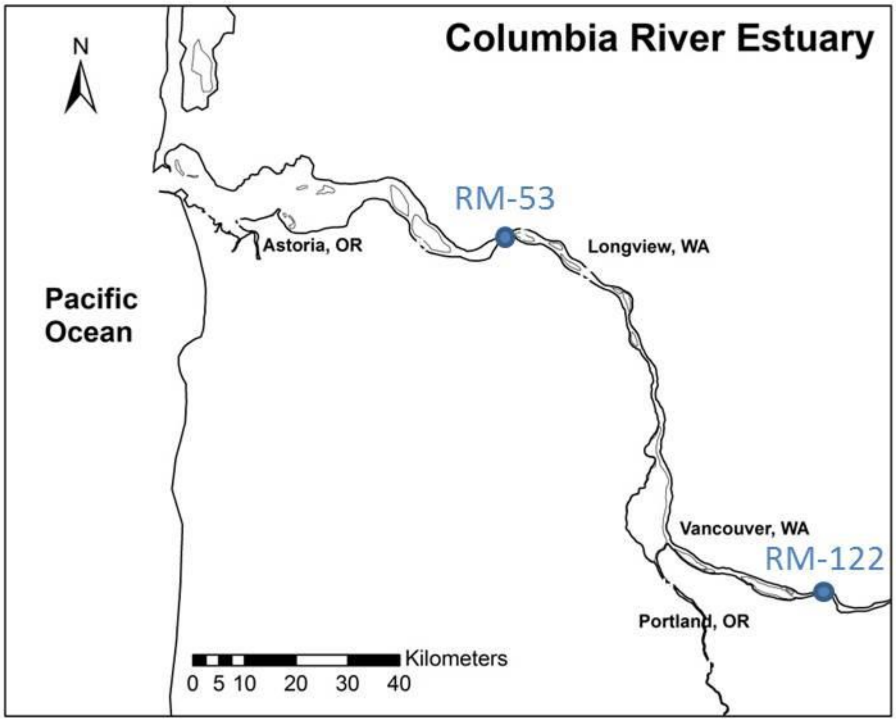


Figure 4. Station locations for the two in-situ water quality monitoring platforms in the mainstem Columbia River that support the Ecosystem Monitoring Program. RM-53 (river mile 53) is Beaver Army Terminal, while RM-122 (river mile 122) is located in Camas, WA.

2.1.2 Operation of RM-122 Platform at Port of Camas-Washougal

Water quality was measured by a YSI sonde equipped with temperature and dissolved oxygen (DO) sensors at the Port of Camas-Washougal (RM-122). At Beaver Army Terminal (RM-53) the platform is a LOBO (Land-Ocean-Biogeochemical-Observatory) equipped with temperature sensors. These data provide information about conditions in the Columbia River mainstem for comparison with the off-channel, EMP sites both upstream (RM-122) and downstream (RM-53) of the Willamette-Columbia confluence.

2.1.3 Sensor Configuration

Instruments and sensors deployed at Camas are described in Table 4. Sensors are configured to collect a sample every hour.

Table 4. Description of the components on the LOBO sensor platforms located at RM-53 and RM-122. Note that the LOBO system was deployed from January through June; after this, the system consisted of a YSI sonde equipped with temperature, conductivity, and dissolved oxygen.

Company	Sensor	Parameters
SeaBird (formerly Satlantic)	LOBO	Power distribution Sensor control Wireless communication Data management

SeaBird (formerly WET Labs)	WQM Water Quality Monitor	Conductivity, Temperature, Dissolved Oxygen, Turbidity, Chlorophyll *a* Concentration

2.1.4 Sensor Maintenance

The sensors are designed to operate autonomously, at high temporal resolution (hourly), and over long periods between maintenance (estimated at three months, although sensors are typically maintained at shorter intervals). This is achieved through a design that maximizes power usage and minimizes biofouling. Antifouling is achieved through the use of sunlight shielding (to prevent algae growth), window wipers, copper instrument surfaces, and bleach injection of the internal pumping chamber. Maintenance trips include cleaning of all sensors and surfaces and performing any other needed maintenance. Additionally, water samples are collected for laboratory analysis of nutrients and chlorophyll *a*. Maintenance activities took place approximately every three weeks in order to change the batteries, clean and calibrate the instruments, download data, and make any necessary adjustments.

2.1.5 Quality Control

Initial sensor calibration was performed by the manufacturer. Each instrument is supplied with a certificate of calibration, and where appropriate, instructions for recalibration. For example, the Seabird SUNA for nitrate measurements operates with a calibration file determined at the factory under strictly controlled environmental conditions but which can be periodically checked and modified for sensor drift by performing a “blank” measurement at our OHSU laboratory using deionized water. At longer intervals (every 1–2 years) the sensors are returned to the factory for maintenance and recalibration.

During periodic sensor maintenance, samples are collected for additional quality control criteria. At RM-53, nutrients, and chlorophyll *a* samples are returned to the laboratory at OHSU and analyzed using established laboratory techniques. Laboratory-based chlorophyll *a* measurements are used to correct the in situ fluorometer measurements. The discrete samples and the corresponding sensor data for nitrate and chlorophyll *a* are shown in Table 5.

Table 5. Comparison of in situ data with laboratory measurements of water samples.

Location/Parameter/# measurements	Regression equation
RM-122/Nitrate/46	$Y = 0.95x + 1$ $r^2 = 0.99$
RM-122/Chl/13	$Y = 0.8x + 1$ $r^2 = 0.93$

2.2 Abiotic Site Conditions

2.2.1 Continuous Water Quality Data (Temperature, DO, pH, Conductivity)

Water quality continues to be continuously monitored at five trends sites, Ilwaco Slough, Welch Island, Whites Island, Campbell Slough, and Franz Lake (Table 6). The monitoring protocol can be found on monitoringmethods.org (Method ID 816). Figure 5 shows how the sensors were deployed to ensure ready access for servicing, and data downloads and Figure 6 shows the periods of deployment of in situ sensors between 2008-2021.

Table 6. Locations of water quality monitors (YSI sondes) at trends sites. Deployment periods for sensors at each of the sites is shown in Figure 6

Site name*	USGS site number	Site name*	Reach	Latitude	Longitude
Ilwaco Slough			A	46° 18’ 19”	-124° 02’ 06”
Welch Island	461518123285700	Unnamed Slough, Welch Island, Columbia River, OR	B	46° 15' 18.4”	-123° 28' 56.8"
Whites Island	460939123201600	Birnie Slough, White’s Island, Columbia River, WA	C	46° 09’ 39”	-123° 20’ 16”
Campbell Slough	454705122451400	Ridgefield NWR, Campbell Slough, Roth Unit, WA	F	45° 47’ 05”	-122° 45’ 15”
Franz Lake	453604122060000	Franz Lake Slough Entrance, Columbia River, WA	H	45° 36' 04"	-122° 06’ 00”

*Site names used in this report differ from official USGS site names to be consistent with site names used by other EMP partners.

Figure 5. Images are showing deployment of water quality monitors (YSI sondes) at study sites.

The water quality monitors were Yellow Springs Instruments (YSI) models 6600EDS and 6920V2, equipped with water temperature, specific conductance, pH, and dissolved oxygen probes. In addition, YSI EXO2 units equipped with fluorometer were installed at Campbell Slough and Franz Lake Slough. Addition of a fluorometer provides a capability to detect and monitor chlorophyll and phycocyanin, pigments that approximates the biomass of total phytoplankton and cyanobacteria, respectively. Table 7 provides information on the accuracy and effective ranges for each of the probes. The deployment period for the monitors was set to characterize water quality at the trend sites during the juvenile salmonid migration period. The monitors are generally deployed from mid-March through mid-September (Table

7). Data gaps reflect issues in data acquisition, which were unfortunately not caught early due to travel limitations associated with the covid-19 pandemic. In this report, given that the majority of the trends sites are located within Washington State, site-specific water quality data are compared to standards for temperature, pH, and dissolved oxygen set by the Washington Department of Ecology to protect salmonid spawning, rearing, and migration, available at http://www.ecy.wa.gov/programs/wq/swqs/criteria.html. Note that water temperature standards set by the Washington Department of Ecology (threshold of 17.5°C) are more conservative than those outlined by the maximum proposed by Bottom et al. (2011) used for comparisons in the mainstem conditions section of this report (Section 2.1).

Table 7. Range, resolution, and accuracy of water quality monitors deployed at four trends sites. m, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter.

Monitoring Metric	Range	Resolution	Accuracy
Temperature	-5–70°C	0.01°C	±0.15°C
Specific conductance	0–100,000 µS/cm	1 µS/cm	±1 µS/cm
ROX optical dissolved oxygen	0–50 mg/L	0.01 mg/L	±0–20 mg/L
pH	0–14 units	0.01 units	±0.2 units

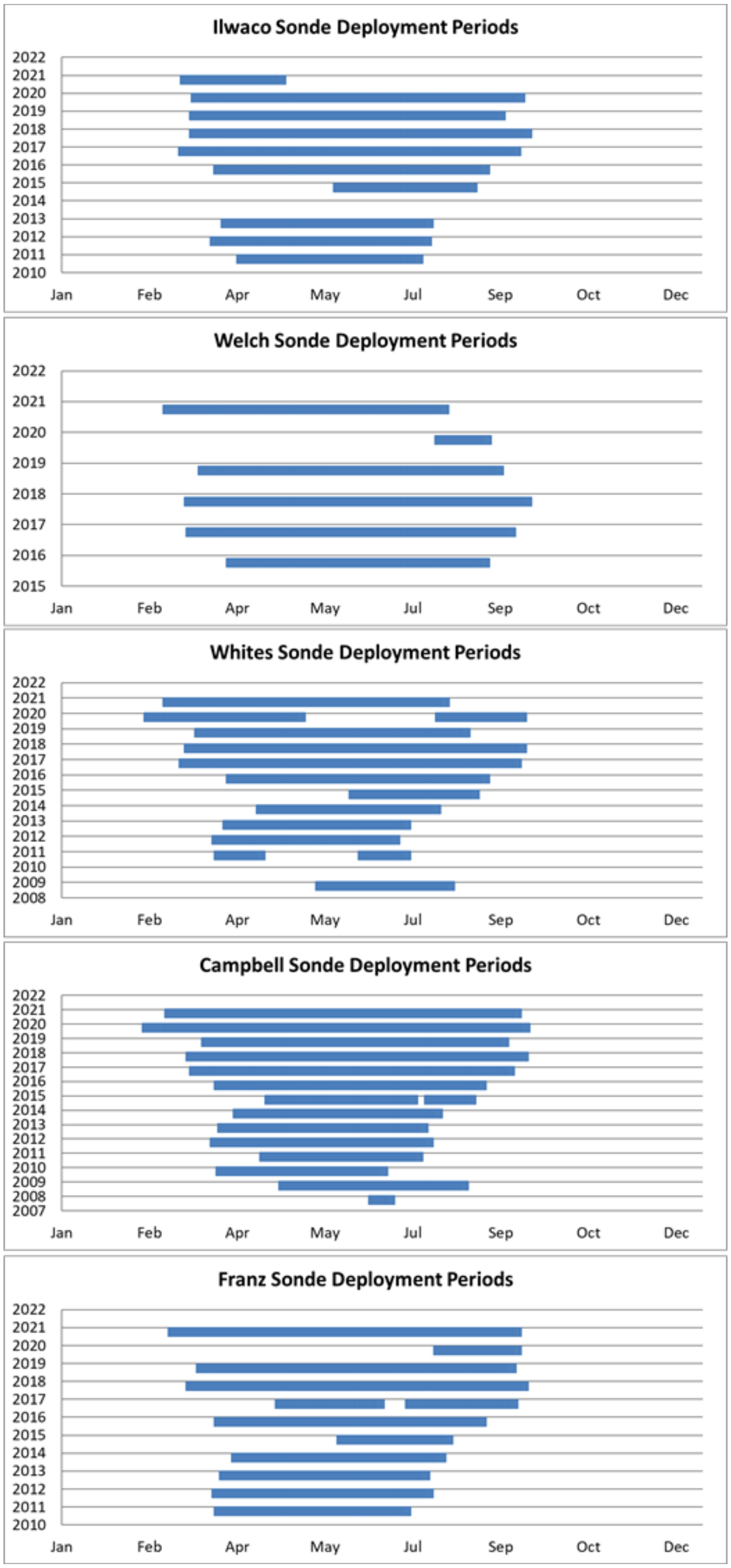


Figure 6. Time periods are corresponding to sensor deployments at five trends sites (2008–2021).

2.2.2 Nutrients (N, P)

Nitrogen and phosphorus are dissolved nutrients that are often present at low enough concentrations to limit plant and phytoplankton growth in aquatic environments relative to other growth requirements. Conversely, in many water bodies, high levels of these nutrients arise from fertilizer and other inputs, which leads to the impairment of water quality following the stimulation of algal and bacterial growth. To analyze water column nutrient concentrations, two 1 L water grab samples were collected from representative open water areas within the sites and subsampled before processing. Three fractions were determined from the subsamples: (1) dissolved inorganic species of nitrogen and phosphorus (nitrate, nitrite, ortho-phosphate, ammonium), (2) total dissolved nitrogen and phosphorus (TDN, TDP), and (3) total nitrogen and phosphorus (TN, TP). Nitrate+nitrite and orthophosphate were determined according to EPA standard methods (EPA 1983a), ammonium was determined colorimetrically (APHA 1998), and total phosphorus were determined according to USGS (1989). Detection limits for each ion or species are given in Table 8. The dates corresponding to sample collection are discussed in Section 2.4.1.2. The monitoring protocol can be found on monitoringmethods.org (Method ID 1591).

Table 8. Detection limits for colorimetric analysis of nitrogen and phosphorus species. TDN = total dissolved nitrogen, TN = total nitrogen, TDP = total dissolved phosphorus, TP = total phosphorus.

Ion or element	Detection limit (mg/L)
Ammonium	0.00280134
Nitrate + Nitrite	0.00700335
Nitrite	0.00140067
TDN	0.01540737
TN	0.1960938
Phosphate	0.00619476
TDP	0.00619476
TP	0.9601878
Silicic acid	0.0280855

2.3 Habitat Structure

LCEP and ETG collected field data on vegetation and habitat conditions at the six trends sites (Figure 1). Monitoring dates are provided in Table 9, and detailed maps of the monitoring sites are presented in Appendix A.

Table 9. Site location and sampling dates for each site sampled in 2021. All habitat and hydrology metrics were sampled at these sites except as otherwise noted.

Site Name	Site Code	River kilometer (rkm)	Site Type	Sampling Date
Ilwaco Slough (Baker Bay)	BBM	6	Trend	
Welch Island	WI2	53	Trend	
Whites Island	WHC	72	Trend	
Cunningham Lake	CLM	145	Trend	
Campbell Slough	CS1	149	Trend	
Franz Lake	FLM	221	Trend	

2.3.1 Habitat Metrics Monitored

The habitat metrics in this study were monitored using standard monitoring protocols developed for the lower Columbia River (Roegner et al. 2009). Monitoring efforts continue to be focused on vegetation cover, elevation, hydrology, sediment accretion, and the quantification of vegetative biomass production and breakdown. These metrics have been determined to represent important structural components, which can be used to assess habitat function. The rationale for choosing these metrics is discussed below.

Elevation, hydrology, and substrate are the primary factors that control wetland vegetation composition, abundance, and cover. Knowing the elevation, soil, and hydrology required by native tidal wetland vegetation is critical to designing and evaluating the effectiveness of restoration projects (Kentula et al. 1992). In the lowest part of the estuary, salinity is also an important factor determining vegetation composition and distribution. Sediment accretion is important for maintaining wetland elevation. Accretion rates can vary substantially between natural and restored systems (Diefenderfer et al. 2008, Borde et al., 2012); therefore, baseline information on rates is important for understanding the potential evolution of a site. Evaluating vegetative composition and species cover indicates the condition of the site. Vegetation composition is important for the production of organic matter (released to the river in the form of macrodetritus), food web support, habitat for many fish and wildlife species including salmon, and contributions to the biodiversity of the Columbia River estuarine ecosystem. Likewise, vegetative biomass is being collected at the trends sites to begin to quantify the contribution of organic matter from these wetlands to the ecosystem.

Assessment of channel cross sections and channel networks provides information on the potential for many important estuarine functions including fish access (i.e., habitat opportunity; Simenstad and Cordell 2000) and export of prey, organic matter, and nutrients. This information is also necessary to develop the relationship between channel cross-sectional dimensions and marsh size, which aids in understanding the channel dimensions necessary for a self-maintaining restored area (Diefenderfer and Montgomery 2009).

2.3.2 Annual Monitoring

The monitoring frequency for the habitat metrics depends on the variability of the metric between years. The composition, cover, and elevation of vegetation have been monitored annually since 2005. Plant species composition and cover can vary substantially from year to year, depending on climate and related water level differences. Beginning in 2009, we also measured channel cross sections, water surface elevation, and sediment accretion rates. Beginning in 2011 plant biomass was collected at the trends sites, excluding Cunningham Lake annually. In 2015, biomass was collected at the four upstream sites, including Cunningham Lake to maximize collection at sites with reed canarygrass. Sediment samples were collected once from each site to characterize sediment grain size and total organic content, but are not repeatedly collected.

Similarly, vegetation community mapping methods were used to characterize the landscape at the site. After repeated mapping at each site, we determined that large-scale changes were not occurring between years; therefore, this effort is no longer repeated during annual monitoring at trends sites unless vegetation changes are observed. Low inter-annual variability of channel morphology at the trends sites has been observed in prior sampling years. Thus only the cross-section at the channel mouth was measured in 2015. Photo points were also designated at each site from which photographs were taken to document the 360-degree view each year. Beginning in 2019, UAV photography began being used, generating high accuracy top-down orthomosaics of each site.

2.3.2.1 *Hydrology*

Continuous water level data is collected annually at all the trends sites.. Occasionally sensor failure or loss occurred; however, the sensors have been downloaded and redeployed every year since the initial deployment for the collection of a nearly continuous dataset (**Error! Reference source not found.**). The sensors were surveyed for elevation so that depth data could be converted to water surface elevation and evaluated against wetland elevations. The water surface elevation data was used to calculate the following annual hydrologic metrics for each site:

- Mean water level (MWL) – the average water level over the entire year
- Mean lower low water (MLLW) – the average daily lowest water level *(this may shift slightly with different annual deployment elevations of the data logger)*
- Mean higher high water (MHHW) – the average daily highest water level
- Annual water level range – the average difference between the daily high and low water levels
- Annual maximum water level – the maximum water level reached during the year

The monitoring protocol can be found on monitoringmethods.org (Method ID: 3982).

2.3.2.2 *Sediment Accretion Rate*

At each site beginning in 2008, PVC stakes were placed one meter apart and driven into the sediment and leveled. The distance from the plane at the top of the stakes to the sediment surface is measured as accurately as possible every 10 cm along the one-meter distance. The stakes were measured at deployment then subsequently on an annual basis. Additional stakes were deployed in Whites island in 2012. New stakes were deployed at four of the five trend sites in 2015 to measure accretion at additional elevations within site. A new set of PVC stakes were installed at Campbell Slough at a lower elevation in 2019, across the slough at Campbell Slough in 2021, and at Cunningham Lake in 2020 due to previous stakes going missing. The stakes, termed sedimentation stakes or pins, are used to determine gross annual rates of sediment accretion or erosion (Roegner et al. 2009).

The accretion or erosion rate is calculated by averaging the 11 measurements along the one-meter distance from each year and comparing the difference with past year's average. The accretion or erosion rates were plotted against marsh elevation (m, CRD) to test the hypothesis that high accretion is observed at lower marsh elevations. The accretion or erosion rates were also regressed against annual cumulative discharge from the mainstem over the monitoring period. The monitoring protocol can be found on monitoringmethods.org (Method ID 818).

2.3.2.3 *Salinity*

In order to better assess the influence of salinity on habitat, a conductivity data logger (Onset Computer Corporation) was deployed at the Ilwaco Slough site in August of 2011. The data logger records conductivity and temperature within the slough and derives salinity from those two measurements based on the Practical Salinity Scale of 1978 (see Dauphinee 1980 for the conversion). The monitoring protocol can be found on monitoringmethods.org (Method ID 816).

2.3.2.4 *Vegetation Species Assemblage*

The vegetation sampling areas at each site were selected to be near a tidal channel and to be representative of the elevations and vegetation communities present at the site. This was easier in the upper portions of the study area, where the sites were generally narrower, and the entire elevation range could be easily covered in the sample area. In the lower estuary, the sites are broad and covered a larger area, so in some cases, multiple sample areas were surveyed if possible to cover different vegetation communities (e.g., low marsh and high marsh). The monitoring protocol can be found on monitoringmethods.org (Method ID 822).

Along each transect, vegetative percent cover was evaluated at 2 – 10 m intervals. This interval and the transect lengths were based on the marsh size and/or the homogeneity of vegetation. At each interval on the transect tape, a 1 m^2 quadrat was placed on the substrate and percent cover was estimated by observers in 5% increments. If two observers were collecting data, they worked together initially to ensure their observations were "calibrated." Species were recorded by four letter codes (1st two letters of the genus and 1st two letters of species, with a number added if the code had already been used, e.g., LYAM is *Lysichiton americanus*, and LYAM2 is *Lycopus americanus*). In addition to the vegetative cover, features such as bare ground, open water, wood, and drift wrack were also recorded. When plant identification could not be determined in the field, a specimen was collected for later identification using taxonomic keys or manuals at the laboratory. If an accurate identification was not resolved, the plant remained "unidentified" within the database.

2.3.2.5 *Elevation*

Elevation has been measured many times in previous monitoring years at all trend sites at the locations of vegetation quadrats, water level sensor, sediment accretion stakes, and in the channels. While elevations change over time, the change from one year to the next is minimal, so high-resolution elevation measurements are not always collected each year (e.g., elevations were surveyed in 2016 so were not re-surveyed in 2017). The elevation is surveyed using a Trimble or TOPCON real-time kinematic (RTK) GPS with survey-grade accuracy. All surveying was referenced to the NAVD88 vertical datum; the horizontal position was referenced to NAD83. Data collected from the base receiver were processed using the automated Online Positioning User Service (OPUS) provided by the National Geodetic Survey. OPUS provides a Root Mean Squared (RMS) value for each set of static data collected by the base receiver, which is an estimate of error. A local surveyed benchmark was located whenever possible and measured with the RTK to provide a comparison between the local benchmark and OPUS-derived elevations.

Trimble Geomatics Office (TGO) software was used to process the data. Each survey was imported and reviewed. Benchmark information was entered into TGO and rover antenna heights were corrected for disc sink (measured at each survey point to the nearest centimeter) at each point. The survey was then recomputed within TGO and exported in a GIS shapefile format. Surveys were visually checked within TGO and GIS software for validity. Historically elevations were then converted from NAVD88 to the Columbia River Datum (CRD) based on conversions developed by the USACE (unpublished). Using the CRD alleviates elevation differences associated with the increasing elevation of the river bed in the landward direction. Sites below rkm 37, the lower limit of the CRD, were converted to mean lower low water (MLLW). Beginning in 2019, NAVD88 elevations were not converted to CRD to aid in the translation of wetland plant community and elevation results to project sponsors implementing restoration projects throughout the river (CRD not being as accessible of a datum as NAVD88).

Quality assurance checks were performed on all data. Elevations from the RTK survey were entered into an Excel spreadsheet and a Tableau Workbook to correspond to the appropriate transect and quadrat location. All elevations in this report are referenced to NAVD88 unless noted otherwise. The monitoring protocol can be found on monitoringmethods.org (Method ID 818).

2.3.3 Analyses

2.3.3.1 *Inundation*

The data from the water level sensors were used to calculate inundation metrics from the marsh and channel elevations collected at the sites. The percent of time each marsh was inundated was calculated daily across each marsh's elevation gradient. The average inundation daily, as measured by the average numbers of hours a day (converted to a %) the water surface level is above the marsh elevation, is a means of comparing sites to each other and over time. This is similar to the historic sum exceedance value (SEV) analysis; however, it is summarized by day instead of over the entire growing season (Kidd 2017).

The average inundation daily at each site is dependent on the elevation, the position along the tidal and riverine gradient, and the seasonal and annual hydrologic conditions. The average % of the day the mean marsh elevation is inundated for the month of August was calculated for all sites and years. The month of August was chosen because it is a critical time for plant development in the upper river sites, as the freshet draws down and exposes the marsh surface.

Additionally, we have the most consistent amount of data for the month of August all sites and all years monitored. Generally, the trends in % time inundated identified in August correlate well with average % daily inundation for the year. Freshet conditions were also used in the hydrologic analysis; Freshet conditions were defined as the accumulative river discharge at Bonneville Dam from May-August (m^3 x 1010), this metric was developed by J. Needoba at Oregon Health & Science University (OHSU).

We continue to perform a combination of the SEV analysis and the average inundation daily analysis by calculating the percent of hours during the month of august that the site was inundated at each elevation band.

The monitoring protocol can be found on monitoringmethods.org (Method ID 954).

2.3.3.2 *Vegetation Community Change Analysis*

Plant species composition and productivity in tidal wetlands respond to annual variability in key ecological processes such as hydrology, salinity, sediment dynamics, and biological interactions. These processes vary naturally but are also projected to change substantially with climate change. For this reason, understanding how key characteristics and functions of wetlands change in response to these processes is important to long-term salmon recovery.

Processes such as hydrology can vary due to normal inter-annual climate variation that affects the amount and form of precipitation. For example, the phases of ENSO (El Nino/Southern Oscillation) and PDO (Pacific Decadal Oscillation) differ regarding the volume of precipitation received in a year, and the relative ratio of snow to rain which affects the spring freshet. Similarly, sea level and the effects of storm waves can vary from year to year in response to ENSO and other climate patterns. Marsh inundation patterns also vary as a result of the actions of bioengineers such as beavers. Grazing by cattle or other herbivores can affect species composition and wetland biomass productivity. Finally, species interactions such as competition from invasive non-native species can alter vegetation composition and wetland function. The strength of biotic interactions is affected by environmental conditions such as inundation, so the effects of biotic elements like invasive species can also vary from year to year.

Data Classification

To begin to evaluate the spatial and temporal variations in vegetation composition, we calculated changes in species richness, percent cover, and relative % cover within and among trend sites over time. Species richness is simply the total number of plant species. Total richness was calculated for each site and each year, as well as average richness per plot. Percent cover is the % of the soil surface that is covered by a plant species. Total plant cover for a plot may exceed 100% when plants overlap. When recording percent cover, maintaining consistency among observers or between years can be difficult, and for this reason, we use relative percent cover to compare species with each other. The relative cover is the proportion of total vegetative cover represented by a species or guild of species. With relative cover, the sum of all species always adds up to 100. The relative cover is a more reliable method for comparing species with each other or evaluating the change in a species over time. We further segregated plant species by key characteristics including native/non-native provenance and wetland indicator status. Additionally, Shannon diversity (H) and evenness (J) indices were calculated from the relative plant cover data using the standard methods outlined by Magurran (1988).

Most plants were identified to the species level or finer, allowing for clear categorization as native or non-native. However, occasionally at some growth stages, certain plants could not be identified to species level. A few of these taxa contained both native and non-native species or varieties and were classified as “Mixed.” For example, at certain growth stages, several species of Agrostis (bentgrass) are difficult to tell apart and were lumped as “Agrostis species.” Since this genus includes both native and non-native species, it was classified as “Mixed.” In calculations involving native vs. non-native species, “Mixed” taxa were included with the non-native group.

Most species also have a clear wetland indicator status that has been identified in the literature. Wetland indicator values reflect how dependent on wetland hydrology a species may be (Reed 1988). Obligate wetland species (OBL) are those that appear in wetlands >99% of the time. Facultative-Wet wetland species (FACW) are those that occur in wetlands 67-99% of the time and occasionally are found in non-wetland habitats. Facultative wetland species (FAC) are those that appear in wetlands about half the time (34-66%), and in non-wetland habitats at other times. Facultative upland species (FACU) are those that occur mostly in upland habitats and less than 34% of the time in wetland habitats, and Upland species (UPL) are those that occur in wetlands less than 1% of the time. The relative proportion of species that fall into those categories, and their respective percent cover, change as the environmental conditions and biotic interactions vary. These changes can indicate changes in wetland functions and values with respect to salmon.

Long-term Trends and Drivers Analysis

Long-term plant community change analysis was conducted across all active EMP sites including annual plant community data starting in 2011 through 2022. When applicable plant community metrics were transformed and correlated with hydrologic conditions such as annual freshet conditions and daily inundation, only significant (p-value < 0.05) correlation and regressions were reported. Data analysis was conducted using Microsoft Office Excel (2016), Exploratory (2017), R (2020), and Tableau (2022-present) softwares.

2.4 Food Web

2.4.1 Primary Productivity

2.4.1.1 *Emergent Wetland Vegetation*

2.4.1.1.1 Aboveground Vegetation Biomass, Macrodetritus, and Soil

Starting in the summer of 2017 detritus sampling was included in the biomass sampling and analysis to evaluate detrital production and export. In the winter of 2018 (and all sampling events to follow through 2021) biomass sampling protocols changed slightly to accommodate detrital sampling and streamline data collection (Table 10, Table 11). This included shifting from “strata” mixed species designations to simple high and low marsh strata descriptions across all sites sampled. This change has also included species biomass weights to be recorded individually to assess species-specific contributions to each high and low marsh stratum (in the past mixes of species were assessed together). In general, these changes will allow for a more detailed understanding of species-specific biomass contributions and still allow for long-term comparisons to overall site, high, and low marsh contributions.

Table 10: Seasonal data collection schedule Winter 2018-Summer 2021. Sp= Species. Some data is still under analysis.

Season	Live Sp Cover	Live Sp Weights	Detritus Lignin	Detritus C:N	Live Sp Lignin	Live Sp C:N	Soil C:N	Soil Bulk Density	Soil Grain Size
Winter 2018	X	X	X	X			X		
Spring 2018	X	X	X	X					
Summer 2018	X	X	X	X	X	X	X	X	X
Winter 2019	X	X	X	X					
Summer 2019	X	X	X	X	X	X			
Winter 2020	X	X	X	X	X	X			
Summer 2020	X	X	X	X	X	X			
Winter 2021	X	X	X	X	X	X			
Summer 2021	X	X	X	X	X	X			

Field Methods

From Summer 2011 to Summer 2022, aboveground biomass was sampled to estimate the primary productivity at three trends sites. Samples were collected in the summer (July or August) during the peak biomass period and again during the winter (January,February, or early March) during the winter low biomass period. In 2018, Spring sampling also took place in late March. For the emergent marsh biomass sampling, a 1m^2 plot was randomly placed along the established vegetation transect, but off-set 2 m from the transect to ensure that the biomass plots did not intersect the vegetation percent cover plots. Biomass was randomly sampled within distinct vegetation strata as determined by plant species dominance, to 1) more clearly associate the samples with vegetation type, and 2) reduce the variability between samples within strata. Within the 1m^2 biomass plot, a 0.1m^2 quadrat was placed in a randomly selected corner and all rooted vegetation, live and dead, was removed using shears. Each sample was sorted in the field to separate the primary strata species from other species and to distinguish live from dead plant material. The biomass samples were placed in uniquely numbered bags and held in a cooler until samples were transported to the laboratory. Dominant vegetation species were recorded along with the corresponding biomass sample number. Submerged aquatic vegetation (SAV) plots were sampled in 2011-2013 using similar methods; however, due to the relatively low contribution of this strata to the overall macrodetritus production, the collection did not continue in subsequent years.

Beginning in Summer 2018 at each site, we collected data and samples from at least 18 plots, nine high marshes, and nine low marshes. Plots were located in such a way to sample the dominant plant species present at each site in the high and low marsh and were distributed across the site while avoiding the permanent vegetation transects. During summer 2018, vegetation composition was assessed in a 1m^2 plot by quantifying % cover for each species that had at least 5% cover and noting any species that was present with less than 5% cover (species denoted as “Other”). If a species had dead biomass present (dead stems or leaves that were still attached to the root system), the % cover of dead biomass was measured separately from the % cover of live biomass. For species with greater than 5% cover, we recorded the average maximum height for both live and dead biomass. The % of the plot that was covered by water was noted, and its depth in cm. The % cover of bare ground and detritus was also noted. Biomass and detritus collection occurred in a $0.1m^2$ subplot in one of the corners of the larger plot. For this subplot, we noted which of the "Other" species were present since these were collected for biomass analysis. Beginning in winter 2019, the field data methods were changed, and vegetation height, species cover, water, bare ground, and detritus cover data were collected only for the small $0.1m^2$ plot.

Beginning in Summer 2020, due to COVID-19, we reduced the number of plots from 18 plots, 9 high marsh and 9 low marsh plots to 10 plots, 5 high and 5 low marsh plots. The number of plots remains consistent at aproximantly 6 high plots and 6 low plots per site.

Biomass and Detritus Collection

In a $0.1m^2$, we used clippers to cut all plant biomass at the soil surface. Plant matter was cut around the outer edge of the quadrat frame, and all material that was in or over the subplot was collected, whether or not it was rooted in the subplot. For plants rooted in the plot, only material that was in or over the plot was collected. The material was laid out on a plastic sheet in the field and separated by species and according to whether it was alive or dead. Species with cover >5% in the large plot were separated into separate plastic bags for analysis, while all species that were <5% in the large plot were combined into a single bag. All detritus within each subplot was also collected into a single plastic bag. Detritus was defined as any organic material that was not attached to roots. Samples were stored in coolers on ice until they returned to the lab where they were stored at <5ºC until processing.

Beginning in Winter 2020, we began storing samples under 0ºC until processing due to issues with samples molding.

Soil Collection

Soils were collected during summer 2018 at five high marsh and five low marsh biomass plots at each site. PVC coring tubes were made with sharpened ends to facilitate soil penetration with minimal effects on soil compaction. Coring tubes had an internal diameter of 5.1cm and were marked around the outside at 10cm from the lip to indicate the depth of the sample to be collected. Spades and sharp knives were used to cut the soil around and beneath the cores. Samples were placed in plastic bags and stored on ice in a cooler until return to the lab.

Beginning Winter 2019, soils were tested at each plot for pH, temperature, salinity, conductivity, and oxidation reduction potential. We used an Extech TE300 ExStik ORP Meter and an Extech EC400 ExStik Waterproof Conductivity, TDS, Salinity, and Temperature Meter to measure the soil properties. The probes were pushed into the soil to a depth of 2cm. They were left to acclimate for 5 minutes before the values were recorded. These data are still under analysis at the time of this report.

Table 11. The number of samples collected in each year and season (S=summer, F=fall, W=winter, Sp=Spring) for all sample sites and vegetation strata. In 2017-2021 we also sampled at Steamboat Slough, a restoration site located near Whites Island.

		2011-12		2012-13			2013-14		2015-16			2016-17		2017-18			2018-19		2019		2020	2021	
Site[1]	**Strata**	**S**	**W**	**S**	**F**	**W**	**S**	**W**	**S**	**S**	**W**	**S W**	**W**	**S**	**W**	**Sp**	**S**	**W**	**S**	**W**	**S W**	**S W**	**Total**
BBM	CALY	3	4	6		6	4	4				6	6										39
BBM	CALY/AGSP	4	3	4		4	6	6				6	6										39
BBM	SAV	4	4	6		6	6																26
SRM	HM			5		5	9	9				9	9										46
SRM	LM			5		5	9	9				9	9										46
SRM	SAV			6		6	6																18
WI2	HM			5		9	9	9				1 2	12	1 4	1 2	12	9	9	9	9	9 9	5 9	152
WI2	LM			4													9	9	9	9	9 9	5 9	72
WI2	SAV			4		4	6																14
WHC	CALY		1	3		3	3	3	3		3	3	3	3	3	3							31
WHC	HM													1		1	9	9	9	9	9 9	5 9	70
WHC	PHAR													1	1	1							2
WHC	PHAR/HM	6	4	5		5	6	6	9		9	9	9	9	8	8							85
WHC	SALA	2	3	3		3	6	6	6		6	6	6	6	6	6							59
WHC	SAV	8	8	6		6	6																34
WHC	LM																9	9	9	9	9 9	5 9	68
CLM	ELPA/SALA								6		6	6		5									23
CLM	PHAR								7		7	7		6									27
CLM	SALA													1									1
CS1	ELPA/SALA	5	4				6		6		6	7	6										40
CS1	PHAR	3	4				6					6	6										25
CS1	SALA						5		6		6	6	6	6									35
CS1	SAV	8	8				6																22
FLM	HM																9	9	9	9	9 9	6 9	69

FLM	PHAR/HM	4	7	3	2	4	3	5	6	6	6							46
FLM	PHAR/POA M	2	5		2													9
FLM	POAM			3	2	1	6	4	6	6	6							34
FLM	SAV			5	8	6	6											
FLM	LM											9	9	9	9	9 9	4 9	67

[1]BBM – Ilwaco Slough, SRM – Secret River Marsh, WI2 – Welch Island, WHC – Whites Island, CLM – Cunningham Lake, CS1 – Campbell Slough, FLM – Franz Lake.

Laboratory Methods

Biomass and Detritus, dry weight

In the laboratory, live, dead, and detritus samples were stored in a refrigerator prior to processing. Samples were individually rinsed of all non-organic material over a 500µm sieve, and any obvious root material was removed. Pre-weighed paper bags or tinfoil were used to secure the individual biomass samples, a wet weight was measured, and the samples were placed in a drying oven set at 90°C for at least four days. When samples were deemed completely dry (checked by reweighing a subset of samples on consecutive days), a dry weight was measured for each sample and its corresponding bag or foil tray. If paper bags were used, they were re-weighed empty to account for any weight loss of the bag. The final sample dry weight was determined by subtracting the dry bag or foil weight from the dry weight of the container with the sample.

Beginning in Summer 2020, wet weight was no longer measured and recorded. Additionally, the drying oven temperature was adjusted to 60°C.

CN Analysis

All detritus samples and a subset of live and dead summer biomass samples were analyzed for carbon and nitrogen content. Live and dead summer biomass samples from each plot were selected for analysis if they covered at least 20% of that plot. Dried samples were pulverized with a small food processor and stored in a desiccator prior to analysis. Carbon and nitrogen content were analyzed with a FlashEA 1112 CN analyzer (Thermo Elecron Corp.). Approximately 18-22 mg of each subsample was packaged in a tin capsule. Chemical and soil standards were analyzed approximately every ten samples, and at least 10% of the samples were randomly selected and reanalyzed on a different day. Replicate measurements were averaged for reported results.

Beginning in Winter 2020, all live and dead summer biomass samples with a dry weight greater than 20 mg were analyzed for carbon, and nitrogen content.

ADF Lignin

Dried and ground detritus samples were tested for ADF lignin following Soiltest 2016 Standard Operating Procedures for feed lignin (Section 50.400.600). Soiltest uses an acidified detergent solution with the Ankom digester to dissolve cell solubles, hemicellulose, and soluble minerals leaving a residue of cellulose, lignin, heat-damaged protein, a portion of cell wall protein, and minerals. This residue is then placed in an acid wash, and lignin is determined gravimetrically as the residue remaining after extraction, followed by an ash correction. Reference samples were run with each batch, and a duplicate sample was analyzed every ten samples.

Soil Bulk Density

Soil cores were frozen in the laboratory until processed. Each sample was oven-dried at 60°C for at least four days. The mass of each dried sample was recorded, and bulk density was calculated as the ratio of dry weight to wet volume. Wet volume was assumed to be 204.28 cm^3 based on a coring tube internal diameter of 5.1 cm and a coring depth of 10 cm.

Soil TOC/N Analysis

A subsample of each dried soil sample was pulverized and homogenized with a mortar and pestle, and large root fragments were removed. Soil subsamples were tested for the presence of inorganic carbon with a few drops of hydrochloric acid (HCl), which would cause the sample to effervesce with CO_2 bubbles if a significant quantity of carbonate were present. No effervescence was observed; therefore all soil samples were analyzed for total carbon under the assumption that total carbon measurements were representative of organic carbon content. Carbon and nitrogen content were analyzed with a FlashEA 1112 CN analyzer (Thermo Elecron Corp.). Approximately 100 mg of each subsample was packaged in a tin capsule. Chemical and soil standards were analyzed approximately every ten samples, and at least 10% of the samples were randomly selected and reanalyzed on a different day. Replicate measurements were averaged for reported results.

Soil Texture Analysis
Dried soil samples were sent to Materials Testing & Consulting, Inc. (MTC) in Olympia, Washington for particle size distribution following recommended protocols for measuring conventional sediment variables (PSEP Report TC-3991-04, 1986). Samples were shaken in appropriately sized sieves to separate gravel (>2000 microns), sand (between 62.5 - 2000 microns), and fines (<62.5 microns). The fines were further separated into silt (3.9 – 62.5 microns) and clay (<3.9 microns) using a pipetting technique to measure the differential settling rates of different sized particles. Samples were processed in batches of a maximum of 20 per batch. Each batch included one sample that was analyzed in triplicate.

Analysis

Average dry weight was calculated for various strata and site values. For 2020 to 2021 data (Table 11), the proportion of the dominant species comprising each sample was calculated. Those data were used to identify samples that were primarily a single species. Those samples were then used to make estimates of the aboveground biomass for specific species within the study area. For long-term comparative analysis, all biomass data collected prior to 2021 was assigned wetland elevations based historic RTK survey data collected at plant community plots when elevation could not be determined it was left blank, and the biomass data point was not included in the high vs. low marsh long-term biomass assessment. Starting in 2021 all biomass plots were surveyed in directly with RTK equipment.

When applicable biomass, detritus, and soil metrics were transformed and correlated elevation and with hydrologic conditions such as annual freshet conditions and daily inundation, only significant (p-value < 0.05) correlation and regressions were reported. Data analysis was conducted using Microsoft Office Excel (2016), Exploratory (2017), R (2018), and Tableau (2019-2022) software.

2.4.1.2 *Phytoplankton*

Abundance

Phytoplankton abundance was estimated in two ways: (1) from pigment concentrations, and (2) by direct counts using light microscopy. Phytoplankton abundance can be estimated by measuring the concentration of chlorophyll *a*, a photosynthetic pigment that is common to all types of phytoplankton. Surface water samples were collected into two 1 L brown HDPE bottles and sub-sampled prior to processing. A subsample of water (typically between 60–300 mL) was filtered onto a 25 mL glass-fiber filter (GF/F) for chlorophyll *a* and kept frozen (-80˚C) pending analysis. Chlorophyll *a* was determined fluorometrically using a Turner Designs Trilogy fluorometer using to the non-acidification method, which is highly selective for chlorophyll *a* even in the presence of chlorophyll *b* (Welschmeyer 1994).

Phytoplankton abundance was also determined by enumeration of individual cells using inverted light microscopy. The dates corresponding to sample collection for determination of nutrient concentrations, zooplankton abundance, and phytoplankton abundance are shown in Table 12. Duplicate 100 mL whole water samples were collected from each of the trends sites. The samples were preserved in 1% Lugol's iodine and examined at 100, 200 and 400x magnification using a Leica DMIL and Zeiss Axiovert 200M inverted light microscopes following concentration achieved through settling 2.5–50 mL of sample in Utermohl chambers (Utermohl 1958) overnight (~24 h). Cell counts were performed at 200 and 400x magnification, with an additional scan done at 100x magnification to capture rare cells in a broader scan of the slide. The estimated error in abundance measurements was <5% at the class level and ~10% for genus-level counts. The monitoring protocol can be found on monitoringmethods.org (Method ID 1589 and 1590).

Table 12. List of samples analyzed (Xs) and data of collection from five trends sites in the Lower Columbia River in 2021.

Site	Zone	Reach	Date	Nutrients	Zooplankton	Phytoplankton
ILWACO SLOUGH	1	A	3/13/19	X	X	X
			4/8/19	X	X	X
			5/5/21	X	X	X
			6/11/21	X	X	X
			7/9/21	X	X	X
			8/10/21	X	X	X
			9/--/21	X	X	X
WELCH ISLAND	2	B	3/1/21	X	X	X
			4/8/21	X	X	X
			5/7/21	X	X	X
			6/8/21	X	X	X
			7/6/21	X	X	X
			8/9/21	X	X	X
WHITES ISLAND	3	C	3/1/21	X	X	X
			4/9/21	X	X	X
			5/7/21	X	X	X
			6/8/21	X	X	X
			7/6/21	X	X	X
			8/9/21	X	X	X
			9/--/21	X	X	X
CAMPBELL SLOUGH	4	F	3/2/21	X	X	X
			4/5/21	X	X	X
			5/3/19	X	X	X
			6/10/21	X	X	X
			7/7/21	X	X	X
			8/10/21	X	X	X
			9/--/21	X	X	X
FRANZ LAKE SLOUGH	5	H	3/4/21	X	X	X
			4/6/21	X	X	X
			5/4/21	X	X	X
			6/10/21	X	X	X
			7/7/21	X	X	X
			8/10/21	X	X	X
			9/--/21	X	X	X

Multivariate Statistical Analyses

Nonmetric Multi-dimensional Scaling (NMDS) and Canonical Analysis of Principal Coordinates (CAP) routines were performed using PRIMER-E v.7 with PERMANOVA+. NMDS is a multivariate technique that identifies the degree of similarity among biological communities within a group of samples in a data set. In NMDS, samples are typically represented in 2-dimensional ordination space using the distance between sample points as a measure of similarity of biological communities; short distances represent the relatively high similarity between samples, while longer distances represent the relatively low similarity between samples.

Major phytoplankton taxa were selected for multivariate analyses if their abundance constituted at least 10% of total phytoplankton abundance in any sample. Taxa that did not meet these criteria were excluded from the analysis. Two NMDS analyses were run for this study that included (i) all major phytoplankton taxa ($NMDS_{total}$) and (ii) only major diatom taxa ($NMDS_{diatom}$). Abundances for 25 major phytoplankton taxa ($NMDS_{total}$) and ten major diatom taxa ($NMDS_{diatom}$) were standardized by sample, and the data were square-root transformed in order to achieve a normal distribution of the data prior to analysis. Canonical Analysis of Principal Coordinates (CAP) is an analytical technique that uses canonical correlation to determine the degree to which environmental factors explain variability among biological communities. A Bray-Curtis resemblance matrix was assembled using the standardized, square-root transformed phytoplankton abundance data and six environmental variables including NO_2^+ , NO_3^-, NH_4^+, PO_4^{3-}, mean daily water temperature, mean daily dissolved oxygen saturation, and mean daily discharge (at Bonneville Dam). Environmental data were normalized prior to analysis to compare variables on the same scale. Samples with missing environmental data were excluded from multivariate analyses. A total of 70 samples were analyzed in both NMDS analyses, and a total of 38 samples were included for CAP.

2.4.2 Secondary Productivity

2.4.2.1 *Zooplankton*

Secondary productivity (the rate of growth of consumers of primary production) was not measured directly but was estimated from the abundance of pelagic zooplankton. The samples were collected from near the surface of the water (< 1 m depth) using an 80 µm nylon mesh net with a mouth diameter of 0.5 m and a length of 2 m at five trend sites. A list of the collection dates and sampling sites are given above in Table 12.

Abundance

Zooplankton abundances collected via net tow were determined at each of the five trend sites. The net was fully submerged under the water and was dragged back and forth from a small boat through the water for approximately 3-5 min or over approximately 100 m. The samples were preserved in 1.5% formalin immediately after collection. A flow meter (General Oceanics Inc., Model 2030R) was mounted to the net's bridle to provide an estimate of the volume flowing through the net. The volume of water passing through the net was determined by knowledge of the distance of water passing through the net, the velocity of the water passing through the net, and the volume of water passing through the net, as calculated from both the distance traveled and the net diameter (as described in the flow meter manual). The distance covered (in meters) was determined from:

$$Distance = \frac{Difference\ in\ counts \times Rotor\ Constant}{999999} \quad (1)$$

where the difference in counts refers to the difference between the initial and final counts on the six-digit counter, which registers each revolution of the instrument rotor. The speed is calculated from:

$$Speed = \frac{Distance\ in\ meters \times 100}{Time\ in\ seconds} \quad (2)$$

The volume is determined as:

$$Volume\ in\ m^3 = \frac{3.14 \times net\ diameter^2 \times Distance}{4} \quad (3)$$

For each net tow, the volume of material collected in the cod end of the net was recorded. From this, a concentration factor was calculated, and a final estimate of the volume examined was determined by multiplying the concentration factor by the final volume of the concentrated sample examined under the microscope.

Taxonomy

Zooplankton taxa were broadly categorized into one of the following groupings: rotifers, cladocerans, annelids, ciliates, and copepods, and 'other.' Within these groups, individuals were identified to genus or species where possible (rotifers, cladocerans, ciliates, annelids), or to order (copepods). Eggs of rotifers, cladocerans, and copepods were enumerated separately.

2.4.3 Stable Isotope Ratios

The ratios of carbon (C) and nitrogen (N) stable isotopes in tissues of consumers reflect the stable isotope ratios (SIR) of their food sources (Neill and Cornwell 1992, France 1995). Therefore, SIR are useful in the determination of major food sources, as long as the latter have distinct isotopic ratios that allow them to be distinguished. Within the scope of the EMP, SIR analysis is used to estimate the relative importance of food sources including algae and wetland plants to the food web supporting juvenile salmonids at trends sites including Ilwaco Slough, Whites Island, Campbell Slough, and Franz Lake Slough. SIR are suitable for identifying food sources assimilated over a longer time frame compared to point-in-time techniques such as gut content analysis; ideally, a combination of the two approaches provides the best indicator of diet.

C and N isotope ratios yield different information: since the $^{13}C/^{12}C$ ($\delta^{13}C$) ratio varies by only a small amount (<1‰) during the assimilation of organic matter, it is used to identify the primary source of organic matter (i.e., primary producers). In contrast, the ratio of $^{15}N/^{14}N$ ($\delta\ ^{15}N$) changes markedly with trophic level, increasing by 2.2 to 3.4 parts per thousand (per mil, or ‰) with an increase of one trophic level (i.e., from a plant to an herbivore or an herbivore to a carnivore). Thus, $\delta\ ^{15}N$ values are useful in determining trophic position.

The SIR of C and N were measured in juvenile Chinook salmon muscle tissues and several potential food sources to provide information on the food web supporting juvenile salmonids (
Table **13**). Juvenile salmon were collected by NOAA Fisheries staff during monthly beach seine sampling and frozen (see Section **Error! Reference source not found.**). Skinned muscle samples were collected for analysis since SIR signatures are more homogeneous within muscle tissue and since muscle is a good long-term integrator of the food source.

Aquatic invertebrates were collected using a 250 μm mesh net with a rectangular opening in emergent vegetation at the water's margin. The aquatic midge, Chironomidae, and amphipods were selected because they have been found to be preferred food sources for juvenile salmonids in the lower Columbia River (Maier and Simenstad 2009, Sagar et al. 2013, 2014, 2015). Most invertebrate specimens were found attached to submerged portions of vegetation. Invertebrates were collected by rinsing the exterior of the vegetation with deionized water and removing the invertebrates from the rinse water using clean forceps. Invertebrate samples were then rinsed with deionized water to remove algae or another external particulate matter. Salmon and aquatic invertebrate samples were frozen for later processing.

Table 13. Potential food sources for marked and unmarked juvenile Chinook salmon and invertebrate consumers.

Potential food sources for fish (marked and unmarked)	Potential food sources for invertebrates
Chironomidae	Particulate organic matter
Amphipoda	Periphyton
Oligochaetes	Live vegetation
Nematodes	Dead vegetation
Gastropods	
Zooplankton	

	Hatchery food*

*Only applicable to marked fish

A variety of autotrophs were sampled to characterize the range of potential food sources for invertebrates. Samples of terrestrial and emergent vegetation, aquatic macrophytes, and macroalgae (*Ulva* and miscellaneous seaweeds) were collected from representative areas within each site. Vegetation samples were rinsed at least five times in deionized water to remove external material, such as invertebrates and periphyton, and were kept frozen (-20°C) for later processing. Samples of particulate organic matter (POM) and periphyton were filtered onto combusted 25 mm glass-fiber GF/F filters and frozen (-20°C) for later processing.

Frozen filters, salmon tissue, invertebrate, and plant material were freeze-dried using a Labconco FreezeZone 2.5 L benchtop freeze dry system (Labconco Corp., USA). Plants were categorized as live or dead during field collections based on whether they were attached and by their physical appearance; mixtures of live plants from the same sampling date were composited and ground using a mortar and pestle, as were mixtures of dead vegetation (designated when plant material was detached rather than rooted). Freeze-dried invertebrates of the same taxa from the same collection site and collection date were composited, ground using a clean mortar and pestle, and subsampled when enough material was present. Otherwise, whole bodies of all individuals of the same taxa from the same site were composited into a single sample. Skinned muscle tissue samples from individual juvenile salmonids were analyzed separately by the individual; muscle tissue samples from different bodies were not composited.

SIR of carbon ($\delta\ ^{13}C$) and nitrogen ($\delta\ ^{15}N$) were determined at the UC Davis Stable Isotope Facility using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). The atomic ratios of the heavy isotope (^{13}C, ^{15}N) to the light isotope (^{12}C, ^{14}N) were compared to universal standards (Vienna PeeDee Belemnite and air for C and N, respectively) and reported in per mil (‰) units.

To estimate the proportional contributions of different food sources for juvenile salmon, the stable isotope mixing model, simmr was implemented in R.

2.5 Macroinvertebrates

2.5.1 Salmon Prey Availability Sampling

2.5.1.1 *Open Water and Emergent Vegetation*

To assess the availability of salmon prey at the trends sites, we conducted neuston tows in both open water (OW; in the center of the channel) and emergent vegetation (EV; along the edge of the wetland channel among vegetation). For OW samples, a Neuston net (250 µm mesh) was deployed from a boat for an average distance of 100 m and positioned to sample the top 20 cm of the water column. For EV samples, the Neuston net was pulled through a 10 m transect parallel to the water's edge in the water at least 25 cm deep to enable samples from the top 20 cm of the water column. From 2008 – 2016, neuston tows were taken concurrently with monthly beach seine collections when juvenile Chinook salmon were present at a site (i.e., captured during seine sets). Beginning in 2017, neuston tows were completed during every beach seine collection regardless of whether salmon were captured. Two OW and two EV samples were collected at each site per month; although, occasionally one or three tows were performed in each habitat type depending on field conditions (Table 14). Samples were preserved in 95% ethanol. The monitoring protocol can be found on monitoringmethods.org (Method ID 1622).

Table 14. The number of invertebrate tow samples (OW and EV) collected at each site per sampling event, 2008-2013, and 2015-2018.

		Ilwaco Slough	Secret River	Welch Island	Ryan Island	Bradwood Slough	Jackson Island	Whites Island	Wallace Island	Lord/Walker Island	Burke Island	Goat Island	Deer Island	Campbell Slough	Lemon Island	Washougal	Sand Island	Franz Lake	Hardy Slough	Total Tow Samples
2008	April													3			6	6		15
	May													6				6		12
	June																		4	4
2009	May				3			4		4				5				4		20
	June													4						4
2010	April					4	4	4	4					4						20
	May					4	4	4	4					4						20
	June					4	4	4	4					4						20
	July					4		4	4					2						14
2011	April	2																		2
	May	8						10			4	4	4	4				2		36
	June	4						4												8
2012	February		4																	4
	March			2				2							3					7
	April		4	5				6							4	2				21
	May		1	4				4						4	4	4				21
	June		6	4				4						4	2	4				24
2013	March			4																4
	May		4	4				4						4						16
	June		4	4				3						4						15
	July			4				6												10
2015	April	5												6				6		17
	May			2				4						2				5		13
	June			6				4												10
2016	February			2				6										2		10
	March							2												2
	April			2				4						6				4		16
	May			4				4						4						12
	June			6				4						6						16
	July			4				6												10
	August			4																4
	September			4																4
(Table 13 continued)																				

		Ilwaco Slough	Secret River	Welch Island	Ryan Island	Bradwood Slough	Jackson Island	Whites Island	Wallace Island	Lord/Walker Island	Burke Island	Goat Island	Deer Island	Campbell Slough	Lemon Island	Washougal	Sand Island	Franz Lake	Hardy Slough	Total Tow Samples
2017	February	4						4						4						12
	March	4		4				4						4						16
	April	4		4				4						4						16
	May	4		4				4						4						16
	June	4		4				4						4						16
2018	February			4				4						4						16
	March	4		4				4						4				4		20
	April	4		4				4						4						16
	May	4		4				4						4						16
	June/July	4		4				4						4						16
	October	4		4				4						4						16
Total Tow Samples		39	23	81	3	16	12	117	16	4	4	4	4	96	13	10	6	35	4	487

2.5.1.2 *Benthic Macroinvertebrates*

To characterize the benthic macroinvertebrate assemblage, benthic core sites were selected to correspond to locations directly adjacent those where the fish community, food web metrics, and vegetation were sampled. Benthic cores were collected monthly at the trends sites (n = 5 per site) between April and July. Cores were collected to a depth of 10 cm by driving a 2-inch diameter PVC pipe into the ground at each sampling location. Each core was then placed in a jar and fixed in 10% formalin. Core samples were collected at low tide from exposed sediments and among emergent vegetation. The monitoring protocol can be found on monitoringmethods.org (Method ID 1593).

2.5.1.3 *Laboratory Methods*

Invertebrate samples collected in neuston tows (n = 36) and benthic cores (n = 77) were identified in the lab using high-resolution optical microscopy and taxonomic references (Mason 1993, Kozloff 1996, Merritt and Cummins 1996, Thorp and Covich 2001, Triplehorn and Johnson 2005). Most individuals were identified to family, although some groups/individuals were identified to coarser (e.g., order) levels. For each sample, the number of individuals in each taxonomic group was counted, then each group was blotted on tissue and weighed to the nearest 0.0001 g. Analysis of neuston tow data included all invertebrates. In benthic core samples, taxa that were not aquatic and/or benthic in their ecology (e.g., adult flies) were considered contaminants and were excluded from analyses of benthic core data.

Samples with an overabundance of taxa were subsampled via volumetric subsampling. The sample was diluted to a particular volume, a portion of the volume was processed, and total counts were calculated as a ratio of the volume sampled. Multiple subsamples were processed to ensure subsample counts were comparable.

2.5.2 Salmon Diet

2.5.2.1 *Field Data Collection*

When juvenile Chinook were captured at a site, fish were typically euthanized within an hour of collection. Fish were kept on ice until arrival at the NOAA field station laboratory where they were stored in a -80ºF freezer. Chinook salmon bodies were necropsied at the end of the sampling season. Whole stomach samples were preserved in 10% formalin until delivered to the laboratory for processing. The total number of diet samples collected at the EMP sites since 2008 is provided in Table 15. The current report is for sampling in 2020. Neither 2021 nor 2022 diets have been processed.

2.5.2.2 *Laboratory Methods*

Organisms in the diets were identified in most cases to the family level, although some groups/individuals were identified to coarser (e.g., order) levels, and crustaceans were usually identified to genus or species. Some contents were unidentifiable due to digestion. Each prey taxon was counted, blotted on tissue, and weighed to the nearest 0.0001 g.

Table 15. The number of Chinook salmon diet samples collected at each site per sampling event, 2008-2013, 2015-2018.

		Ilwaco Slough	Secret River	Welch Island	Ryan Island	Bradwood Slough	Jackson Island	Whites Island	Wallace Island	Lord/Walker Island	Burke Island	Goat Island	Deer Island	Campbell Slough	Lemon Island	Washougal	Sand Island	Franz Lake	Pierce Island	Hardy Slough	Total Tow Samples
2008	April													6			13	15	9		43
	May													19				7			26
	June																			13	13
2009	May				9			10		6				10				8			43
	June				10									9							19
2010	April					10	19	16	6					12							63
	May					17	15	14	14					24							84
	June					9	8	18	11					18							64
	July					10		19	11					15							55
	August					8		13													21
2011	May							10			10	13	10	22							65
	June							25													25
	July							2			2										4
2012	February		15	16																	31
	March			14				13							13						40
	April		15	14				10							7	15					61
	May			30				11						18	15	18					92
	June		14	15				15						15	15	36					110
2013	March			9																	9
	May		12	30				15						34							91
	June		1	23				13						9							46
	July		2	25										1							28
2015	April	6																			6
	May			15				15						15				4			49
	June			7				13													20

2016	April			13				13					7					12			45
	May			15				19					13								47
	July			3				8													11
		Ilwaco Slough	Secret River	Welch Island	Ryan Island	Bradwood Slough	Jackson Island	Whites Island	Wallace Island	Lord/Walker Island	Burke Island	Goat Island	Deer Island	Campbell Slough	Lemon Island	Washougal	Sand Island	Franz Lake	Pierce Island	Hardy Slough	Total Tow Samples
2017	February	2						2													4
	March	1						1													2
	April			15				8						1							24
	May			30				30						34							94
	June			32				5						23							60
2018	February			30				4													34
	March			30				30													60
	April			31				30													61
	May			30				30						32							92
	June/July													2							2
	October																				N/A
Total Tow Samples		9	59	427	19	54	42	412	42	6	12	13	30	319	50	69	13	46	9	13	1644

2.5.3 Salmon Prey Data Analysis

Descriptive statistical analysis of the invertebrate community was calculated, in addition to specific analyses of taxa that have been shown to be important prey of juvenile Chinook salmon in the lower Columbia River (Lott 2004, Spilseth and Simenstad 2011). These included Diptera (predominantly comprised of chironomids), Amphipoda (predominantly *Americorophium* spp.), and Cladocera (predominantly *Daphnia* spp.).

Benthic core and neuston tow invertebrate data were quantified by numeric composition (count proportion) and gravimetric composition (weight proportion). For benthic core data, the density and biomass of taxa in each sample were calculated as the total count or weight for a given taxon divided by the core volume (# individuals m^{-3}, g m^{-3}). For neuston tow data, the density and biomass of taxa in each sample were calculated as the total count or weight for a given taxon divided by the meters towed (# individuals m^{-1} towed, mg m^{-1} towed). To compare taxa densities and biomass between study sites, density and biomass data for each taxon were summed across replicate samples taken within a given site each month and then divided by the number of replicates to give an average total density and biomass at each sampling site per month. Averages of predominant juvenile salmonid prey in density/meter^2 were also included.

Juvenile Chinook diet composition was assessed with three variables, including prey numeric composition (NC), gravimetric composition (GC), and frequency of occurrence (F). These measurements were used to calculate an index of relative importance (IRI) and percent IRI, where IRI is the percentage of the total IRI for each prey taxa, and:

$$IRI = F * (\%\, NC + \%\, GC)$$

An IRI has the advantage of accounting for prey weight and numbers, as well as the likelihood of taxa appearing in the diet of individuals (Liao et al. 2001). Because the index incorporates taxa counts, items that were not countable (e.g., plant matter, unidentifiable, highly digested material), were removed from descriptive analyses of diet composition.
Instantaneous and energy ration (IR, ER) measure foraging performance of fish, incorporating prey weight, fish field weight, and energy density in the diet, calculated as:

$$IR = \frac{sum\ of\ prey\ weight}{fish\ weight} \quad ER = \frac{sum\ of\ prey\ energy\ density}{fish\ weight}$$

Instantaneous ration measures fish fitness and is the ratio of the total prey weight to the total fish mass. Total prey weight was calculated as the sum of the weights of all individual taxa counted in the diet. Energy ration measures energy consumption. For each juvenile Chinook salmon, the sum of individual prey taxon masses were multiplied by the energy density (kJ g^{-1} wet mass) of each prey taxon and divided by the total fish mass. Thus, energy ration equals kilojoule consumed per gram of fish. Energy densities of prey taxa were compiled and acquired from (David et al., 2016). For descriptive analyses, IR and ER was calculated for each individual salmon diet and averaged across all fish, by fork length, within 2020, by site, overall, among sites for February to March, and overall by year.

Following methods in Fiechter et al. (2015), maintenance metabolism was calculated for juvenile Chinook salmon used in diet analyses. Because sampling was attenuated in 2020 due to the coronavirus pandemic, direct comparison of 2020 data with other years was only possible for the months of February and March. Maintenance metabolism (J_m) represents the cost of metabolic upkeep where j_m is the mass specific maintenance costs at 0º C (0.003), d is the temperature coefficient for biomass assimilation (0.68), T is water temperature in ºC, and W is fish body mass.

$$J_m(maintenance\ metabolism) = j_m * e^{dt} * W$$

Maintenance metabolism and energy ration were plotted on a quadrant chart, divided by the 50th percentile, to provide a general assessment of habitat quality and juvenile Chinook salmon growth potential at a given site. For juvenile Chinook salmon, low metabolic cost and high energy assimilation represent relatively positive growing conditions (lower right quadrant), while high metabolic cost and low energy assimilation represent relatively poor growing conditions (upper left quadrant).

Multivariate analyses were used to examine differences in juvenile salmon diet composition among sites. A Bray-Curtis dissimilarity index was calculated on square-root transformed percent IRIs for each fish size class, by site and year. For analysis of community composition, taxa were sorted by Order. A non-metric multidimensional scaling (NMDS) plot was used to graphically represent variation in major prey species composition ($p = 0.05$) among sites in reduced-dimensional space. Points close together represent samples similar in composition and points at a greater distance from each other represent differing composition. Visual variation led to a direct gradient analysis, an analysis of similarities (ANOSIM), to explain statistical differences between groups. ANOSIM p-values and R-statistics showed within group object similarity compared to other groups (1 = all objects in group are more similar than objects from different groups; 0 = there was no difference among groups). Finally, paired sites were compared to identify the species that were contributing to at least 70% of the diet composition differences for each site pair. All multivariate analyses were performed using the Vegan software package in R (Oksanen et al. 2020, R Core Team 2019).

2.6 Fish

2.6.1 Fish Community

In 2022, NOAA Fisheries monitored habitat use by juvenile Chinook salmon and other fishes at five trends sites, Ilwaco Slough in Reach A (sampled in 2011-2021), Welch Island in Reach B (sampled in 2012-2021), Whites Island site in Reach C (sampled in 2009-2021), Campbell Slough in Reach F (sampled in 2007-2021), and Franz Lake in Reach H (sampled in 2008-2016, 2018, 2020-2021), in order to examine year-to-year trends in fish habitat use in the lower river. Coordinates of the sampling sites are shown in Table 16.

The project goal is to collect fish for six months of the year at all sites, March-June and October. Occasionally conditions at a site prohibit sampling, such as extremely high or low water levels, water temperatures become to high for handling fish, or road conditions prevent travelling to launch sites. Fish are collected using a 38 x 3-m variable mesh bag seine (10.0 mm and 6.3 mm wings, 4.8 mm bag). Bag seine sets were deployed using a 17 ft Boston Whaler or 9 ft inflatable raft. Up to three sets were performed per sampling month, as conditions allowed. At each sampling event, the coordinates of the sampling locations, the time of sampling, water temperature, weather, habitat conditions, and tide conditions were recorded. Fish sampling events conducted as part of our regular EMP sampling in 2021 are shown in Table 16. We also list the limited sampling we were able to complete in 2020 before NOAA COVID-19 safety protocols led to a suspension of fieldwork. The monitoring protocol can be found on monitoringmethods.org (Method ID 826). All non-salmonid fish were identified to the species level and counted. For salmonid species other than Chinook, up to 30 individuals were measured (fork length, nearest mm), weighed (nearest gram), and released. Up to 30 juvenile Chinook salmon were euthanized in the field, measured, weighed, and retained for subsequent laboratory analyses (diet, genetic, lipid, and otolith). If present, an additional 70 Chinook were measured and released. Any additional Chinook were counted and released. All salmonids were checked for adipose fin clips, or other external marks, coded wire tags, and passive integrated transponder tags to distinguish between marked hatchery fish and unmarked (presumably wild) fish.

Fish bodies retained in the field were frozen and stored at -80°C. At the end of the sampling, season fish were necropsied, and samples were collected for laboratory analyses. Stomach samples for taxonomic analyses were preserved in 10% neutral buffered formalin. Fin clips for genetic analyses were collected and preserved in alcohol, following protocols described in Myers et al. (2006). Otoliths for age and growth determination were also stored dry in a vial. Whole bodies (minus stomachs) for measurements of lipids remained frozen until processed.

Table 16. Location of EMP sampling sites in 2020 and 2021 and the number of beach seine sets per month (ns = not sampled). Sampling was stopped in mid-March 2020 through February 2021 due to COVID-19 pandemic safety protocols issued by NOAA.

	2020			2021						
Site	**Feb**	**Mar**	**Total**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Oct**	**Total**
Ilwaco Slough (Reach A) 46.300530° N, 124.045893° W	3	2	5	ns[1]	3	3	3	3	3	15
Welch Island (Reach B) 46.255011° N, 123.480398° W	1	3	4	ns[1]	3	3	1	2	3	12
Whites Island (Reach C) 46.159350° N, 123.340133° W	2	1	3	ns[1]	1	1	2	2	3	9
Campbell Slough (Reach F) 45.783867° N, 122.754850° W	3	3	6	ns[1]	3	3	2	ns[2]	3	11
Franz Lake (Reach H)* 45.600583° N, 122.103067W	2	ns[1]	2	ns[1]	3	5	1	2	3	14
Total	11	9	20	0	13	15	9	9	15	61

[1] pandemic safety protocols prevented sampling
[2] water temperature exceeded sampling criteria

Fish species richness (*S*; the number of species present) and fish species diversity for each site were calculated by month and year. Fish species diversity was calculated using the Shannon-Weiner diversity index (Shannon and Weaver 1949):

$$H' = -\sum(p_i \ln p_i)$$

Where

p_i = the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

Catch per unit effort (CPUE) and fish density were calculated as described in Roegner et al. (2009), with fish density reported in number per 1000 m^2.

Multivariate analyses were used to examine differences in the fish community between sites using the Primer-e version 7 (Plymouth Routines In Multivariate Ecological Research) software package (Clarke and Warwick 1994, Clarke and Gorley 2006). A Bray-Curtis index of similarity coefficients was calculated for the square-root transformed species abundance data at each site. A non-metric, multi-dimensional scaling (nMDS) plot was used to graphically examine variation in the fish community between sites. We used a multivariate analog to ANOVA called analysis of similarity (ANOSIM) to quantitatively assess the variation in fish community based on site. The global R-value generated from this analysis indicates the degree of separation, with 0 representing no separation and 1 representing complete separation. ANOSIM also produces pairwise tests which compute an R-value for comparisons of different site locations. Statistical probabilities of both R-values are generated through permutation.

2.6.2 Salmon Metrics

2.6.2.1 *Genetic Stock Identification*

Genetic stock identification (GSI) techniques were used to investigate the origins of juvenile Chinook salmon captured in habitats of the Lower Columbia River Estuary (Manel et al. 2005, Roegner et al. 2010, Teel et al. 2009). From 2008–2013 juvenile Chinook salmon stock composition was estimated by using a regional microsatellite DNA data set (Seeb et al. 2007). Beginning in 2014 stock composition was estimated by using a Single Nucleotide Polymorphism data set that includes baseline data for spawning populations from throughout the Columbia River basin (described in Hess et al. 2014). The overall proportional stock composition of Lower Columbia River samples was estimated with the GSI computer program ONCOR (Kalinowski et al. 2007), which implemented the likelihood model of Rannala and Mountain (1997). Probability of origin was estimated for the following regional genetic stock groups: Deschutes River fall; West Cascades fall; West Cascades spring; Middle and Upper Columbia River spring; Spring Creek Group fall; Snake River fall; Snake River spring; Upper Columbia River summer/fall; Upper Willamette River spring; Rogue River fall; and Coastal OR/WA fall (Seeb et al. 2007, Teel et al. 2009, Roegner et al. 2010). West Cascades and Spring Creek Group Chinook are Lower Columbia River stocks. The monitoring protocols can be found on monitoringmethods.org (Method ID 948)(Method ID 1356)(Method 1332) (Method 5446).

Multivariate analyses were used to examine differences in the genetic stock groups between sites using the PRIMER (Plymouth Routines In Multivariate Ecological Research) software package (Clarke and Warwick 1994, Clarke and Gorley 2006). A Bray-Curtis index of similarity coefficients was calculated for the square-root transformed stock abundance data at each site. A non-metric, multi-dimensional scaling (nMDS) plot was used to graphically examine variation in genetic stock abundance between sites. We used a multivariate analog to ANOVA called analysis of similarity (ANOSIM) to quantitatively assess the variation in salmon stock composition based on site. The global R-value generated from this analysis indicates the degree of separation, with 0 representing no separation and 1 representing complete separation. ANOSIM also produces pairwise tests which compute an R-value for comparisons of different site locations. Statistical probabilities of both R-values are generated through permutation.

2.6.2.2 *Lipid Determination and Condition Factor*

As part of our study, we determined total, nonvolatile, extractable lipid (reported as percent lipid) and lipid class content in Chinook salmon whole bodies. Lipid content can be a useful indicator of salmon health (Biro et al. 2004) and also affects contaminant uptake and toxicity (Elskus et al. 2005). Studies show that the tissue concentration of a lipophilic chemical that causes a toxic response is directly related to the amount of lipid in an organism (Lassiter and Hallam 1990; van Wezel et al. 1995); in animals with high lipid content, a higher proportion of the hydrophobic compound is associated with the lipid and unavailable to cause toxicity. While lipids may help sequester toxins and protect fish from contaminants, an overabundance of lipids can interfere with buoyancy regulation during early ocean entry and may increase vulnerability to surface predators (Weitkamp 2008).

Prior to analyses, whole body samples from salmon collected in the field were composited by genetic reporting group, date, and site of the collection into a set containing 3-5 fish each. The composited salmon whole body samples (~ 2 g) were homogenized, mixed with drying agents (sodium sulfate and magnesium sulfate), packed into extraction cells, and then extracted with dichloromethane using an accelerated solvent extractor. The sample extracts were collected into pre-cleaned, pre-weighed sample tubes. Approximately 1-2 mL of sample extract was transferred to a pre-weighed sample vial to determine the amount of total, nonvolatile, extractable lipid (reported as percent lipid) by gravimetric analysis as described in Sloan et al. (2014). Another sample extract aliquot (1- 2 mL) was transferred to a second pre-weighed sample vial to measured lipid classes (i.e., sterol esters/wax esters, triglycerides, free fatty acids, cholesterol, phospholipids/polar lipids) using thin-layer chromatography–flame ionization detection (TLC–FID) (Ylitalo et al. 2005; Sloan et al. 2014). In this method, each sample extract was spotted on a silica rod (Chromarod) and developed in a chromatography tank containing 60:10:0.02 hexane:diethyl ether:formic acid (v/v/v). The lipid classes were separated based on polarity and measured using flame ionization detection, using the mean of two measurements. The percent contribution of each lipid class to the total lipid were calculated by dividing the concentration of each lipid class by the total lipid measured.

For all salmonid species, Fulton's condition factor (*K*; Fulton 1902; Ricker 1975) was calculated as an indicator of fish health and fitness, using the formula:

$$K = [\text{weight (g)}/\text{fork length (cm)}^3] \times 100$$

The monitoring protocol can be found on monitoringmethods.org (Method ID 952).

2.6.2.3 *Otoliths (Growth Rates)*

Otoliths from fish ranging in fork length from 35-111 mm (mean = 66 mm, SD = 14.4 mm) were processed for microstructural analysis of recent growth (see Chittaro et al. 2018). Specifically, left sagittal otoliths were embedded in Crystal Bond and polished in a sagittal plane using slurries (Buehler©'s 600 grit silicon carbide, 5.0 alumina oxide, and 1.0 micropolish) and a grinding wheel with Buehler© 1500 micropolishing pads. Polishing ceased when the core of the otolith was exposed, and daily increments (Volk et al. 2010, Chittaro et al. 2015) were visible under a light microscope. We photographed polished otoliths using a digital camera (Leica DFC450) mounted on a compound microscope (Zeiss©). Using Image Pro Plus© (version 7, Mediacybernetics), we took two measurements from each otolith; distance from otolith core to edge (i.e., otolith radius at time of capture, *Oc*) and distance from otolith core to seven daily increments in from the otolith edge (i.e., otolith radius measured at seven days before capture, *Oa*). For each individual, fork length at seven days prior to capture (*La*) was estimated using the Fraser-Lee equation:

$$La = d + \frac{Lc - d}{Oc} Oa$$

where *d* is the intercept (3.98mm) of the regression between fish length and otolith radius ($R^2 = 0.81$, n = 855) where *Lc* represents fork length (mm) at capture. Next, the average daily growth rate (mm/day) was calculated for an individuals' last seven days of life (*a*),

$$Average\ daily\ growth = \frac{Lc - La}{a}$$

Seven days of growth was a reasonable amount of time to estimate growth while in estuarine habitats because, depending on migratory type (i.e., ocean-type versus stream-type) and timing of migration (i.e., sub-yearling versus yearling migrant), Chinook salmon may inhabit estuaries for weeks or months (Healey 1991, Thorpe 1994, Weitkamp et al. 2014).

We used a generalized linear modeling (GLM) approach to investigate the extent to which variability in somatic growth rate (dependent variable) was explained by a suite of independent variables; collection year and day, river discharge, off-channel distance, river kilometer, genetic stock, hatchery or unmarked classification, and fork length. River kilometer and off-channel distance are defined as the distance (km) a site is from the mouth of the Columbia River and the distance (m) between a site and the Columbia River channel respectively. If an individual had a clipped fin or coded wire tag, then it originated from a hatchery and was categorized as "hatchery." If a fish did not have a mark or tag, then the individual was labeled as "unmarked." The term "unmarked" is used instead of "naturally produced" or "wild" because some hatcheries do not clip fins nor inject coded wire tags or mark only a fraction of their releases (Sagar et al., 2013).

For all models, we used a gamma family distribution with a log link to account for the normally distributed, but positive, growth rate data. Preliminary analyses indicated a nonlinear relationship between growth rate and day of the year, and therefore, the day of the year was also included in our analyses. In addition, fork length was included in our analyses so as to account for the linear relationship we observed between growth rate and fish size. We ran all possible GLM model combinations of the independent. All model parameters were estimated by maximizing the likelihood function. To compare models, we calculated four values for each model; Akaike's information criterion (AIC), delta AIC, relative likelihood, and AIC weight. Smaller AIC values indicate "better" models, and when comparing two models, we calculated the difference in AIC values (delta AIC; Akaike, 1973; Burnham & Anderson, 2002). A delta AIC of less than 2 indicates little difference between competing models; a delta AIC of 2–10 indicates moderate support for a difference between the models, and a delta AIC of greater than 10 indicates strong support (Burnham & Anderson, 2002). Relative likelihood represents the likelihood of a model given the data, whereas AIC weight is the discrete probability of each model (Burnham & Anderson, 2002). The best model was defined as having a delta AIC of 0.00, although preference was given to the simplest model if two or more models had a delta AIC of less than 2.

2.6.2.4 *PIT Tag Array*

Currently (as of 2023) the only operational PIT Tag funded under the EMP and AEMR programs is the Steigerwald Pit-tag, installed in the spring of 2023. These data are reported under our AEMR program, the first annual report from this PIT Tag system will be in 2024.

A passive integrated transponder (PIT) tag detection system has been operating at Campbell Slough since June 2011, with a hiatus in 2012 and 2017 and is no longer operational as of 2020. It is located approximately 150 m into the slough channel from the mainstem Columbia River. The system consists of a Destron-Fearing FS1001-MTS multiplexing transceiver, which simultaneously receives, records and stores tag signals from six antennas measuring 4' by 10'. The system is powered by a 470W solar array with battery backup and is also connected to a wireless modem that allows for daily data downloads. The array is intended to monitor the presence and to estimate residency of PIT tagged fish in Campbell Slough. Unfortunately, due to COVID-19 protocols, we were unable to power up and maintain the site in 2020. Furthermore, once we were able to access the site in October of 2020 we discovered that a large tree and root wad had disabled some of the antennas and a few electrical components and our solar panels were missing. Plans are currently underway to rebuild the PIT system utilizing updated technology with possible installation in 2022. Regretfully, the Campbell Slough PIT array has been decommissioned in early 2023 due to significant damage.

The previous detection system at Campbell Slough, consisting of two antennas measuring 4’ by 20’ was in place from 2011-2017. It was not operational in 2017 due to power cables having been severed by rodents and failed structural integrity of one of the antennas. We revamped the PIT detection array at Campbell Slough in 2018 by installing six antennas measuring 4’ x 10’. The antennas were arranged in a vertical “pass-through” configuration (Figure 7) which allowed greater detection capability at a larger range of water levels. An elevated platform was installed to keep the electronic telemetry equipment above potential water levels. The system continued to run a Destron-Fearing FS1001-MTS multiplexing transceiver and was powered by a 470W solar array with battery backup. A new modem was installed to update the equipment from 3G technology, which is no longer supported by cellular providers, to 4G technology. The location of the interrogation site was moved approximately 90 m further upstream.

Figure 7. Image of the new PIT detection system at Campbell Slough, installed February 2018.

From 2013-2020, a second PIT detection system was installed near the confluence of Horsetail and Oneonta Creeks in the Columbia River Gorge where substantial restoration actions were completed. The Horsetail PIT detection arrays aids in evaluating the effectiveness of the restoration actions by monitoring use of the habitat by fish in the mainstem Columbia River (*Horsetail Restoration Project*). Antennas are located on both sides of the culvert allowing determination of whether salmon pass through the culvert to access the restored floodplain.

The array consists of a Biomark FishTRACKER IS1001-MTS distributed Multiplexing Transceiver System (MTS), which powers ten antenna units mounted within the culvert system at Horsetail/Oneonta Creek site (Columbia River, OR) beneath Interstate-84. The MTS unit receives, records and stores tag signals from these ten antennas, which all measure approximately 6’ by 6’ and are mounted on both ends of the 5-barrel culvert system running under the freeway. The system is powered by an 840 watt (W) solar panel array and supported by a 24-volt, 800 amp-hour battery bank back up. The unit is also connected to a fiber optic wireless modem that allows for daily downloads of tag data and system voltage monitoring updates.

3 Results

All results for this reporting period are presented using Tableau. Tableau is an interactive data visualization platform that encourages self-exploration. Click here to view the overview dashboard: (link).

3.1 Mainstem Conditions

View Mainstem Conditions at the online Tableau Dashboard here. (link)

3.2 Abiotic site conditions

View Abiotic Site Conditions at the online Tableau Dashboard here. (link)

3.3 Habitat Structure

View Habitat Structure at the online Tableau Dashboard here. (link)

3.4 Food Web

View Food Web results at the online Tableau Dashboard here. (link)

3.5 Macroinvertebrates

View Macroinvertebrate results at the online Tableau Dashboard here. (link)

3.6 Fish

View Fish communities at the online Tableau Dashboard here. (link)

4 Status and Trends Discussion

4.1 Maintem conditions

The 2022 water year was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average Columbia River flows in the early spring, and higher-than-average Columbia River flows associated with the spring freshet, which peaked in mid-June. Summer flows in the Columbia were similar to the long-term average.

4.1.1 Seasonality

During 2022, daily river discharge in the Columbia River mainstem was close to the long-term average in the winter months. Winter flows – and in particular, flow variability associated with climate change – can be an important influence on salmonid populations, as demonstrated in an analysis of predictors of Chinook salmon productivity across the Pacific Northwest (Ward et al., 2015) and southeast Alaska (Sloat et al., 2016). Increased variability in winter flows over the last several decades has been associated with a decline in Chinook salmon populations; flow variability has been shown to be a stronger predictor of Chinook population growth across rivers in Washington State that other metrics such as changes in average winter flows (Ward et al., 2015). This relationship is hypothesized to stem from the timing of spawning relative to egg development. In ocean-type Chinook populations, spawning tends to occur at low flows in the early fall; eggs spawned during this time are at risk of being scoured away if flows are too high (DeVries, 1997). This is particularly risky when very low flows encourage spawning near river channels, which are more susceptible to high velocity as flows increase (Haschenburger, 1999). The winter period is not only the time when river flows in the Paciifc Northwest tend to be most variable (Mote, 2003), but also coincides with the timing of spawning and early life-stage development of ocean-type Chinook salmon when the greatest threat of mortiality occurs (Quinn, 2005; Ward et al., 2015). Predictions suggest that variability in winter flows is likely to increase with climate change (Mote & Salathe, 2010).

In March, discharge was much lower than average; minimum discharge volumes approaching half the long-term averaged were observed in mid-April (3500 $m^3 s^{-1}$ compared to 6625 $m^3 s^{-1}$). The period of very low flows lasted approximately two weeks. In early May, flows increased rapidly at a rate of ~400 $m^3 s^{-1} d^{-1}$ to approach the long-term average; this rate of increase continued until peak flows were reached in mid-June (12,740 $m^3 s^{-1}$). Peak flows in the Columbia in 2022 were ~30% higher than the long-term average. Flows increased from early and peaked in mid-June at volumes close to the long-term maximum, which was observed in 2017. The decline in river discharge following the spring peak (mid-June to early July) was steeper than in 2017, but flows remained above average through the end of August. From early September until October, flows were at or below average.

4.1.2 Ecosystem impacts of flow variation

Having multiple years of data allows for inter-annual comparisons of flow as a driver of ecosystem processes. Notably, in the time series of discharge data between 2008 to 2022, there are a number of years where a distinct pre-freshet peak in flows is observed (compare hydrographs for each year in Tableau); these peaks are associated with reductions in elevation at Roosevelt Lake behind Grand Coolee Dam in Washington in April (Figure 4-1). Looking at chlorophyll data from 2018, a year similar to 2022 and a year that had low elevation in the reservoir in mid-April, there was a peak in chlorophyll a that coincided with the low elevation at Franz Lake Slough; there was a similarly timed peak in chlorophyll at Welch Island (Figure 4-2). Since chlorophyll values at Campbell Slough appeared to be higher then the mainstem, the peak was not visible there.

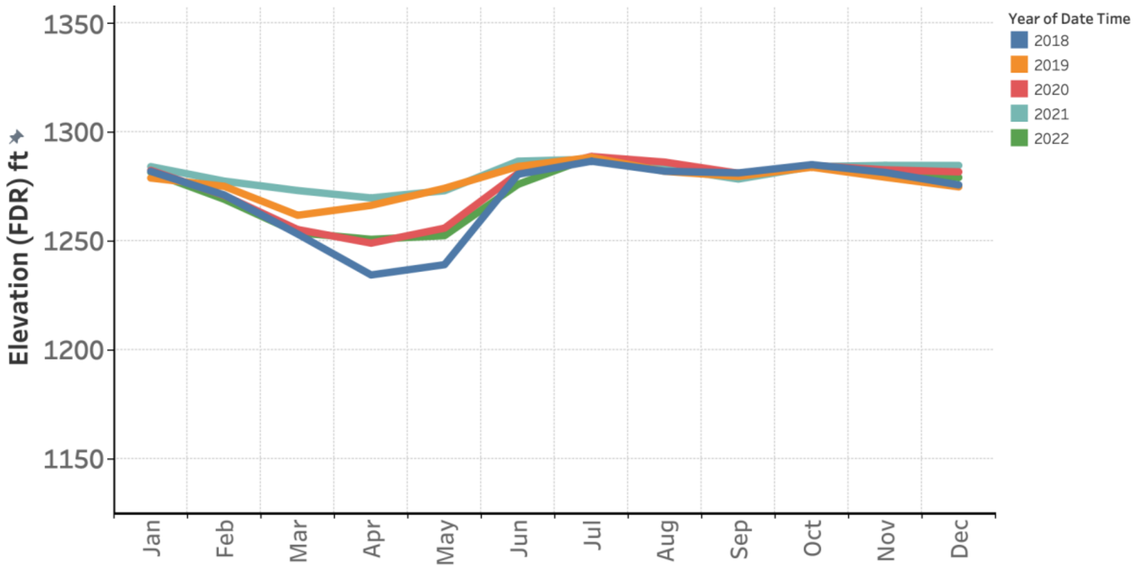


Figure 4-1. Elevation (ft) at Roosevelt Lake behind Grant Coolee Dam in Washington, where water is stored for flood control and hydroelectric power generation. Reduced elevation at Roosevelt Lake in April coincides with peaks in flow prior to the spring freshet in some years, including 2018, 2020, and 2022.

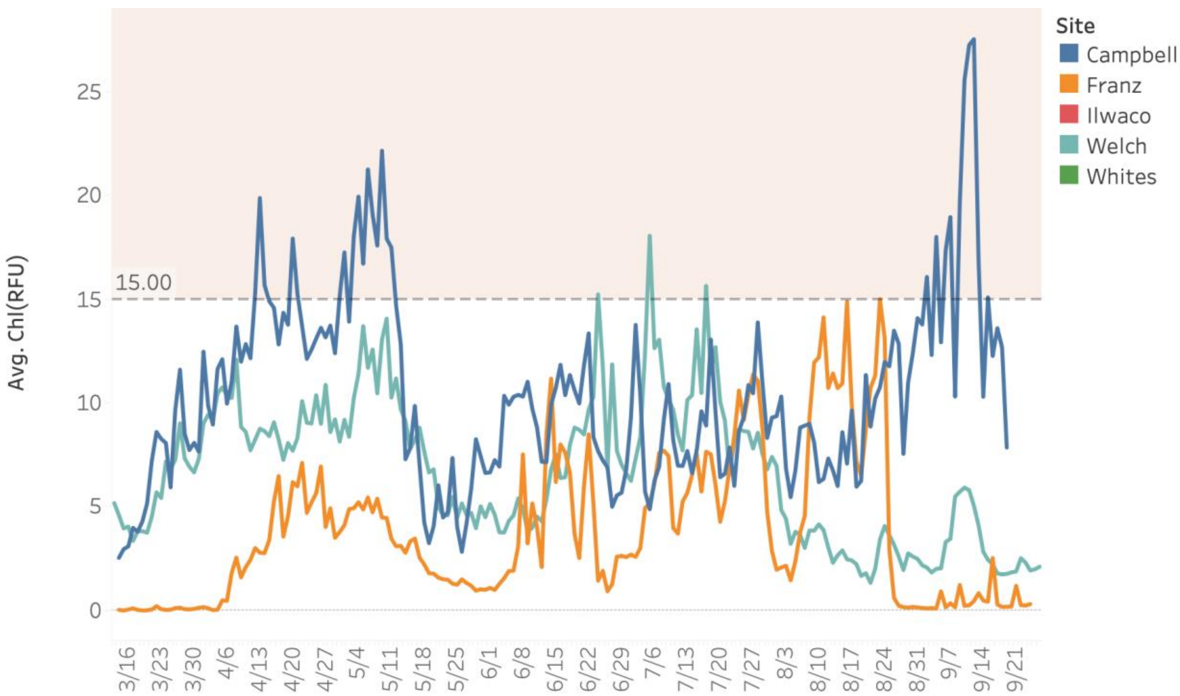


Figure 4-2. Chlorophyll a fluorescence at EMP sites in 2018.

There have been a few years since 2009 where river temperatures have exceeded 19ºC, the optimum temperature for juvenile salmonid survival; these include 2015 and 2021. Aside from 2020, where river temperatures were cooler than average, the years between 2015 and 2021 were generally above average. The number of days with average temperatures exceeding 19ºC (n=55) in 2022 was similar to the long-term average.

4.2 Abiotic Site Conditions

4.2.1 Temperature

Temperatures at the off-channel site tend to be highest, or else stay warm for longest, at Campbell Slough and Franz Lake Slough. When grouped in clusters of similar temperature, only Campbell and Franz had observations in the highest temperature cluster (average temperature of 25.1^{o}C). Moreover, temperature variability was greater earlier in the season at Campbell and Franz, with observation of higher temperatures included in cluster 1 (average = 14.7^{o}C) and 2 (average = 20.8^{o}C) observed in April 2022. According to the deviation from average values shown by z-score calculations, the warmest years in the time series were 2015 and 2021. 2022 was closer to average in terms of temperature, and the hydrograph closely resembled that of 2020 and 2018, although with an approximate month-long lag relative to the latter.

4.2.2 pH

Low pH values were observed during the period of peaks flows at both Campbell Slough and Franz Lake Slough, but otherwise, pH values were within the range considered acceptable by water quality standards set by the Washington Department of Ecology.

4.2.3 DO

Percent saturation of dissolved oxygen relative to air was most variable at Campbell Slough, which had both the lowest and the highest values. Whites and Welch Island were the least variable. There were two time periods at Campbell Slough and Franz Lake Slough were DO saturation values were very low, posing a risk to aquatic life. The period of concern at Campbell Slough was associated with the spring freshet, close to the end of the peak. Based on observations over the last several years, water elevation appears to be an important driver of dissolved oxygen at Campbell Slough, which is a highly productive habitat. During periods of high elevation, wind-driven and temperature-driven convection is reduced, resulting in less overturn and exchange with the overlying atmosphere. In contrast, when water levels are low, there is greater vertical mixing associated with wind-driven and convective overturn.

4.2.4 Chlorophyll

Chlorophyll fluorescence is a good proxy for algal biomass in aquatic habitats, which drives biological production and, in excess, can lead to large swings in dissolved oxygen and pH. A water quality standard of three consecutive monthly measurements >15 $\mu g\ L^{-1}$ is set to determine whether a water body is impaired and/or eutrophic. Because our measurements are collected hourly and over the period of March through September, it is somewhat difficult to compare the 3-month measurement metric versus hourly or daily values. The data clearly show a high level of daily variability, with some values exceeding 15 $\mu g\ L^{-1}$ significantly. The two sites that historically have shown elevated algal biomass are Campbell Slough and Franz Lake Slough; in 2022, Campbell Slough showed three chlorophyll peaks: one in April, one in May, and one in September. The time between the April and May peaks coincided with the release of reservoir waters from Roosevelt Lake behind Grand Coolee Dam and likely contributed to interruption of the bloom that began in April.

4.3 Habitat Structure

4.3.1 Hydrology and Sediment Dynamics

Marsh Hydrology

Hydrologic processes are the primary environmental driver dictating wetland sediment accretion and erosion dynamics, soil biogeochemistry, plant species assemblages, vegetation productivity, and overall wetland condition. Understanding hydrologic processes and variability across tidal wetland sites in the lower Columbia River is critical to informing conservation and restoration efforts throughout the estuary.

The maximum flood levels in recent years occurred during the peak freshet for all upper river sites: Franz Lake, Campbell Slough, and Cunningham Lake. As one progresses down the river, the high flow conditions become less apparent during the freshet periods, specifically at Whites Island, Welch Island, and Steamboat Slough. The mid river sites see their maximum flood conditions in the winter at peak tide events during winter storms. Ilwaco has little to no influence from the freshet. These trends are similar to past years.

In general, we have found that inter-annual variation in inundation patterns are much greater at the upper river sites, Franz Lake, Campbell Slough, and Cunningham Lake where seasonal flooding (both winter and freshet) can result in months of continuous inundation during high-water years. In contrast, the mid and lower estuary sites, Whites Island, Welch Island, Steamboat Slough, and Ilwaco Slough, are dominated by tidal patterns where inundation lasts just a few hours during high tide, but occurs frequently, usually two times daily. Inundation, as measured as a percent of time that the water surface level exceeds the ground surface is a means of comparing sites to each other and over time. The average inundation daily at each site is dependent on the elevation, the position along the tidal and riverine gradient, and the seasonal and annual hydrologic conditions. The average % of the day the mean marsh elevation is inundated for the month of August is critical for plant development in the upper river sites because the freshet draws down and exposes the marsh surface. Generally, the trends in % time inundated identified in August correlate well with average % daily inundation for the year (unpublished data). It does not, however, always correlate with the overall magnitude of the annual freshet. This is because the timing of the freshet can vary from year to year, in some years such as 2011 and 2012, the high flows from the freshet have lasted into August, resulting in significantly greater daily inundation patterns at the upper river sites, while other years, such as 2017, freshet levels were high but receded quickly resulting in low inundation levels in August and generally more of the growing season. These shifts in daily inundation are critical for plant community development and can have major implications for not only plant species composition by also biomass production. Lower water years (in August), such as 2015, 2017, and 2021, produce greater plant biomass than high August water years. We hypothesize that the annual timing, magnitude, and duration of the freshet may also impact the long-term status and trends of tidal wetland fish utilization, macroinvertebrate assemblages, and plankton productivity.

Sediment Dynamics

Sediment accretion rates are variable within the Columbia River estuary and within individual sites, likely due to variation in elevation, sediment loading, and flood inundation frequency (Kadlec & Robbins, 1984, Chmura et al., 2003, Woods & Kennedy, 2011) and may even be affected by the vegetation present (Larsen et al., 2010; Mudd et al., 2010 , Marani et al., 2013). The greatest sediment accretion rates at the 5 trends sites have been measured at Campbell Slough and can likely be explained by the large bovine presence in the years before. The next largest accretion rate, and the highest average accretion rate, occurs at Whites Island in a patch of *C. lyngbyei* located at a mid- to low-marsh elevation (2.46 m, NAVD88) very close to the primary tidal channel at the site (<10 m from marsh edge). This is a good example of conditions conducive to high accretion rates: proximity to the tidal channel, high inundation frequency (about 50 percent), and vegetation that produces high amounts of organic material and effectively traps mineral and organic material, both important sources of sediment accretion in tidal freshwater marshes (Neubauer 2008). Additionally, Campbell Slough had an average erosional rate of around 0.2 cm/year with a standard deviation of 2.73. The high variability in the data set is likely explained by the open grazing, the higher energy system with close proximity to the channel, the very high inundation frequency, as well as the high sediment supply.

Overall, the erosion rates at Campbell slough and Cunningham Lake can be attributed to constant cattle grazing trampling, which affects soil compaction and removal of above ground biomass (Trimble, 1994; Nolte et al., 2013). In recent years, large variation in accretion and erosion rates were observed at all five trend sites and Cunningham lake. The 2020 and 2021 sediment accretion and erosion data for the EMP were included with the 2021 sediment dataset, and were included into the long-term dataset. This inclusion is one possible cause of change in trends observed in the tableau dashboard. Similar observations were noticed in a study researchers in the marshes along Gulf of Mexico (Callaway et al., 1997).

When combining long-term sediment accretion rates across sites we found that marsh elevation (m, CRD) was negatively correlated with sediment accretion rates, meaning that low-marsh zones accrete more sediment than high marsh zones. This pattern of sediment accretion is well supported by other studies (Harrison & Bloom, 1977; Cahoon et al., 1996). Locally, Kidd (2017) found similar patterns within wetland sites in Young Bay. The mechanism diving these observations are the differences in daily and seasonal tidal ranges that can manifest in differences in sediment loading across the marsh elevation gradient. Sediment depositions being more pronounced in low marshes near marsh channels, which receive more daily inundation and sediment exposure than high marsh zones (Hassan et al., 2005; Larsen et al., 2010; Jay et al., 2015).

While we have found a significant trend in sediment accretion across the EMP sites, in general our study of sediment dynamics at the trend sites is has limitations. Firstly, the overall lack of sufficient sedimentation stakes prevents us from making definitive connections with inundation and flooding frequency, effects of vegetation of accretion rates as well as studying the influence of cumulative discharge. Secondly, there are still several questions that need to be answered.

The interplay of mineral sediment accretion and the accumulation of organic material is important in determining the rates of sediment accretion and also the rates of carbon sequestration (Craft 2007). In Tidal Freshwater marshes, carbon accumulation in the sediment comes from organic material associated with mineral sediments in the water column and from in situ biomass production and breakdown (Neubauer 2008). Similar to sediment accretion variability, carbon density and accumulation rates are likely variables in the Tidal Freshwater marshes of the LCRE. Carbon density is often greater at higher marsh elevations with lower flooding frequency and lower sediment loading; however, the inverse may be true of carbon accumulation rates (Chmura et al., 2003). Overall, in LCRE marshes, carbon in the surface sediments (~10 cm) accounts for approximately 3 to 10 percent of the sediment (Borde et al., 2011; Sagar et al., 2013). This carbon content is similar to those amounts found in a prograding riverine brackish marsh with high mineral sediment accretion rates (Thom 1992), but lower than some other Tidal Freshwater marsh sediments (Craft 2007; Thom 1992) where organic material may account for more of the accretion. In general, Tidal Freshwater wetlands store more carbon and have higher carbon accumulation rates than salt marshes (Craft 2007), but understanding the variability of this process in the LCRE will be important to gain a better understanding of the overall storage capacity of these wetlands now and in the future.

In the future, it may be informative to relate site hydrology and sediment dynamics between and among both EMP sites as well as AEMR sites throughout the lower Columbia. This effort may require more detailed tracking of sediment accretion and erosion rates within and across sites due to the high level of variability seen in the historic data and generally inherent to monitoring sediment dynamics (Takekawa et al. 2010). Furthermore, it is vital to compare rates of sediment accretion to forecasted sea level rise to determine the rate of drownage across wetlands; we have found that many sites across the lower Columbia are not keeping pace with forecasted sea level rise. Further study to quantify the rates of accretion across all sites of the lower Columbia, including both the AEMR and EMP sites; additional analyses of forecasted sea level rise; and the impact of both on overall extent and quality of marsh habitats are planned for 2024.

4.3.2 Vegetation Community Condition and Dynamics

Overall trends in plant community composition

Overall, 2022 total plant cover was relatively stable across Ilwaco Slough, Welch Island, Whites Island, and Franz Lake compared to historic, long-term averages. Cunningham Lake total cover has continued to increase through 2022, beginning to rebound from the heavy cattle grazing observed in 2017-2020. Campbell Slough has exhibited a small increase in total cover levels in 2022, however the overall cover at Campbell is still low compared to non-grazed conditions; a new vegetation grid was established at Campbell Slough in 2021 to capture non-grazed conditions and continues to be used for comparisons. Cattle grazing has continued at Campbell Slough in the historic plant community study area since 2017, with fencing efforts failing to keep the cattle out of the wetland. The new non-grazed transects (out of reach from cattle on the other side of the slough) at Campbell clearly shows significantly more species cover and biomass accumilation than the historic transects.

Generally, native and non-native cover are more similar from year to year in the zone 1 and 2 sites (Ilwaco, Welch, Whites) compared to the zone 4 and 5 sites (Cunningham, Campbell, and Franz), this is likely due to the general hydrology of these sites, inundation patterns being much more stable from year to year in the tidally drive lower river, zone 1 and 2, sites compared to the fluvially dominated mid and upper river, zone 4 and 5, sites. These trends were generally observed in 2022, with Ilwaco Slough, Whites Island, Welch Island, and Franz Lake retaining similar native cover conditions as to previous years.

At Ilwaco Slough, in 2022, we continued to observed a general reduction in non-native *Agrostis stolonifera* cover and a corresponding increase in native *Carex lyngbyei* cover, in addition to increases in other natives such as *Argentina egedii ssp. Egedii*, *Deschampsia cespitosa*, *Lilaeopsis occidentalis*, and *Symphyotrichum subspicatum*. At Franz Lake, this shift was a result of a general mixed increase in native species cover including *Argentina egedii ssp. Egedii*, *Fraxinus latifolia*, *Salix lucida*, and *Helenium autumnale*. Comparatively, Campbell Slough continues to show a marginal increase in native relative cover. This shift can be accounted for by an increase in native herbs such as *Eleocharis ovata*, *Helenium autumnale*, *Lindernia dubia*, and *Ludwigia palustris* which were found growing in the plots heavily disturbed by grazing. This shift, caused by grazing, indicates that these native species are found in the seed bank but are normally (under no grazing) suppressed by more dominate non-native species such as *P. arundinacea* (Kidd 2015). Comparatively, Cunningham Lake, which has not experienced heavy grazing since 2017, had a decrease in native cover from a historic high of 65% in 2018 to a mere 46% in 2021. This decrease in native cover was accompanied by a general increase in non-native cover including at 47% increase in *P.arundinacea* cover between 2018 and 2021. This increase in *P.arundinacea* is to be expected both because of the reduced grazing pressure and because of the lower water conditions experienced during the 2021 growing season, which favors *P. arundinacea* growth (see more on this below).

Between 2012-2022 the six most common plant species identified throughout the tidal estuary (across the 6 trend sites) in order of overall abundance are *Phalaris arundinacea* (PHAR, non-native), reed canarygrass, *Carex lyngbyei* (CALY, native), lyngby sedge, *Eleocharis palustris* (ELPA, native), common spikerush, *Sagittaria latifolia* (SALA, native), wapato, *Leersia oryzoides* (LEOR, native), rice cut grass, and *Ludwigia palustris* (LUPA, native), water purslane. While these species are the most common and abundant across all sites over the years, they are not necessarily present at all sites every year. For example, *P. arundinacea* does not grow at Ilwaco, likely due to the saline conditions present at this wetland (Kidd 2017). However, it is found growing in abundance at all the other trend sites across the lower river.

Trends in P. arundinacea abundance
In 2022, *P. arundinacea* cover levels stayed relatively consistent to those observed in 2020 and previous years, however, at Cunningham, there was a significant increase in *P. arundinacea* levels from 21% in 2018 to 68% in 2021. Franz Lake also experienced an increase in *P. arundinacea*. *P. arundinacea* frequency (spread across the site) decreased at Cunningham, but only slightly from 74 % of plots in 2018 to 63 % of plots in 2021, and overall *P. arundinacea* frequency increased significantly at Franz Lake from 60 % of plots in 2018 to 75 % of plots in 2021. This shift in *P. arundinacea* levels observed at Cunningham and Franz Lake is likely a product of both very low freshet flooding conditions in 2021 and, at Cunningham Lake, a reduction of grazing pressure. The last several years cattle have heavily grazed Cunningham Lake wetlands; it is well known that cattle pressure can significantly reduce *P. arundinacea* abundance during the growing season (Kidd 2017). Generally, *P. arundinacea* abundance has been found to decrease in years of greater freshet discharge levels, especially in Cunningham Slough, Campbell Slough, and Franz Lake where wetland water levels are tightly correlated with Columbia River discharge conditions, higher water levels making growing conditions less favorable for *P. arundinacea*.

Water year conditions and impacts of plant community composition.
In 2022, data continued to support our findings that annual shifts in *P. arundinacea* cover are strongly correlated with Columbia River discharge levels and site water levels during the growing season, with lower water levels (and lower discharge levels) favoring *P. arundinacea* growth and observed abundance. These findings indicate that annual flooding conditions within sites (% daily inundation) and across the river (freshet accumulated discharge) are important mechanisms driving much of the observed annual variability in *P. arundinacea* dominance across the estuary. Additionally, these data support the hypothesis that annual flooding conditions in the Columbia can dramatically impact year to year shifts in plant community dynamics, especially the non-native species *P. arundinacea* in the upper river sites. *P. arundinacea* mean annual cover was also found to be tightly negatively correlated with native plant community cover across all river zones except the mouth (Ilwaco has no *P. arundinacea* due to high salinity levels), annual increases in *P. arundinacea* resulting in an overall decrease in native plant cover.

The long-term trends in the abundance of native species *C. lyngbeyi, S. latifolia, P. amphibium* have also been found to be strongly (and significantly) linked to annual river discharge conditions. Generally, *C. lyngbeyi* abundance has been found to increase in years of greater freshet discharge levels, especially in Ilwaco Slough, where salinity levels are reduced during large discharge years, making growing conditions more favorable for *C. lyngbeyi*. *S. latifolia* has been found to have a delayed reaction to freshet conditions, with lower freshet conditions resulting in an increase in *S. latifolia* abundance the following year. Additionally, *P. amphibium* levels at Franz Lake have also be found to follow a similar trend to *S. latifolia* with a one year delayed reaction to decreased freshet conditions, lower freshet conditions (lower water levels across the wetland site) resulting in an increase in *P. amphibium* cover the following growing year (Figure 43). For both species, this might be a result of increased rhizome stores from positive growing conditions (low water levels), providing for more robust growth in the following growing season.

Summarizing these findings, site level daily inundation patterns in addition to season freshet flooding conditions are important drivers of native and non-native plant communities across the estuary. Publication of these data and further investigations of these relationships will be explored in the FY23 report.

4.4 Food Web

4.4.1 Primary Production

4.4.1.1 *Emergent Wetland Vegetation*

Overall, 2022 resulted in a high production of standing stock and detritus biomass across all sites, with some of the largest values seen to date – likely a result of the longer growing seasons observed during the lower freshet conditions these years experienced. This was especially true for Franz lake, where the longer growing season was compounded with the removal of the beaver dam, proving a larger area for low marsh plant community establishment.

Net aboveground primary productivity (NAPP) is the rate of storage of organic matter in aboveground plant tissues exceeding the respiratory use by the plants during the period of measurement (Odum 1971). Many methods exist to estimate NAPP; however, for our ecosystems in which there is a clear seasonality, a good method is a single harvest at peak biomass (Sala and Austin 2000). Our analysis of the proportion of live versus dead material indicated that for most species the live proportion of the summer samples averaged greater than 90 percent; a confirmation that we indeed were sampling at or near the biomass peak. Starting in the summer of 2017 detritus sampling was included in the biomass sampling and analysis to evaluate detrital production and export. In the winter of 2018 (and all sampling events to follow), biomass sampling protocols changed slightly to accommodate detrital sampling and streamline data collection. This included shifting from "strata" mixed species designations to simple high and low marsh strata descriptions across all sites sampled. This change has also included species biomass weights to be recorded individually to assess species specific contributions to each high and low marsh stratum (in the past mixes of species were assessed together). In general, these changes will allow for a more detailed understanding of species-specific biomass contributions and still allow for long-term comparisons to overall site, high and low marsh contributions.

Generally, productivity in the high marsh strata has been very high and similar in quantity to the most productive North American marshes (Brinson et al. 1981; Bernard et al. 1988; Windham 2001). Average summer biomass of 1000 to 1500 g dry weight/m^2 in the high marsh strata is not an uncommon observation throughout the estuary (Kidd et al. 2018). Generally, the multi-year analysis of the summer biomass revealed high variability between years at Welch Island. Across sample sites, year to year variability in overall total biomass contribution was found to be negatively correlated with cumulative river discharge for August, indicating the importance of river conditions on annual wetland biomass production and export, even at the lower river wetland locations, Whites and Welch Island.

Overall proportion of biomass contribution from living, dead, and detritus varied across the seasons, living biomass contributing the most during the summer season, standing dead and detritus contributing the most during the winter, with biomass contributions being more evenly split between living, dead, and detritus in the spring, reflecting new spring plant growth across all sampled sites. This seasonal look at biomass composition shows the largest flux of standing biomass (living + dead) out of these wetlands is between the summer and winter time-period, some of this living and dead biomass shifting to detrital material and most being exported from the sampling areas altogether. The largest flux of detritus out of the wetland occurs during the spring-summer time-period, detrital material showing a gradual increase from summer to spring and then a sharp decline between the spring and summer sampling events. While the overall amount of biomass contributed is lower coming out of the low marsh compared to the high marsh strata, they were found to follow similar patterns of living, dead, and detritus biomass contribution over the seasonal shifts.

The EMP biomass sampling efforts continue to highlight the significant organic plant material contribution from these wetland sites to the estuary ecosystem annually; however, this contribution relative to the energy needs of the estuary food web is still unknown. Overall, across sites the high marsh strata dominated by a mix of native sedge *C. lyngbyei*, native herb *P. amphibium*, and the non-native grass *P. arundinacea* contributed the highest and most consistent amount of organic material, signifying the importance of the high marsh plant community complex to the estuary food web. The low marsh strata dominated by a mix of native *P. hydropiperoides, S. latifolia, and E. palustris* also contributes a consistent flux of organic material, while much lower in overall biomass weight, these low marsh contributions are generally less variable than the high marsh on a site to site and year to year basis. If organic material from marsh plants is indeed a limiting factor for the detrital based food web in the lower river, the restoration of additional marsh area dominated by native high and low marsh species could improve those conditions.

4.4.1.2 *Emergent Wetland Vegetation Nutrient Dynamics*

One factor in the EMP biomass analysis conducted in 2018 was the evaluation of the living above ground biomass, detritus, and soil nutrients Carbon (C), Nitrogen (N), and ADF lignin (L, lignin) composition. This research has continued through 2022, with the exception of the soil analyses. These data provide insight into the quality and nutrient dynamics of the biomass contributions and highlight the variability in nutrient composition between plant species and the high and low marsh strata. Species-specific functional plant traits such as C:N ratio and L:N ratio can also provide insight into the potential decomposition rates of species, with low C:N and L:N ratio species having greater decomposition potential than species with higher C:N and L:N ratios. The C:N ratio is commonly used to define the N immobilization-mineralization gradient, a greater C:N ratio promoting N up take by microbes (immobilization) and detrital accumulation, while a lower C:N ratio promotes N mineralization (release) by microbes and detrital decomposition (Reddy and Delaune 2008). The quality and rate of decomposition provides insight into the direct food web contributions provided by different species found in the high and low marsh stratas across wetlands.

Nutrient Conditions Observed Across Strata

Comparing C, N, and C:N ratios between the above ground living biomass, detritus, and soil across the elevation gradient can provide insight into plant species nutrient use efficiency and decomposition.

Trends in C, N, and C:N ratios across the elevation gradient within wetlands were particularly interesting with living above ground biomass and soil C content both increasing along the elevation gradient; low in the low marsh strata and high in the high marsh strata. Soil N followed a similar pattern being higher in the high marsh strata and lower in the low marsh strata. Living above ground biomass N content followed a reverse trend with lower N levels in the high marsh strata and higher levels in the lower marsh. These results generally translated into greater C:N ratios in the high marsh soil and living above ground biomass and lower C:N ratios in the low marsh soil and living above ground biomass. These results potentially reflect both a shift in plant species and plant species nutrient use efficiency along the high to low marsh gradient. The low marsh species having lower carbon content, and lower C:N ratios overall, indicating less decomposition time required for the plant species found in the low marsh zone, C:N Ratio under 25 indicating no N limitation to decomposition (Wang et al. 2016). The high to low marsh shift in C:N ratios also corresponds to the overall differences found in detritus accumulation between the high and low marsh zone across sites, less detritus accumulation occurring in the low marsh zone. L:N ratios across the wetlands were found to also correlate with elevation, following the N content trend, with smaller ratios in the lower marsh zones across sites. The above ground living biomass L:N ratio is also known as a good predictor of plant biomass decomposition rates, smaller ratios indicate more N and less lignin, and quicker decomposition (Taylor et al. 1989, Talbot et al. 2011).

Overall, mean summer lignin content was greatest in the detritus samples compared to the living plant biomass. This follows the expected trend of lignin concentrations increasing in the detritus as decomposition occurs, lignin and associated compounds resisting decomposition (Taylor et al. 1989, Talbot et al. 2011). Detrital lignin content was found to be positively correlated with detrital carbon content, greater carbon levels within the detritus corresponding with greater levels of lignin. Similarly, detritus L:N ratio was also positively correlated with detritus carbon content, higher levels of lignin and lower levels of N corresponding with greater levels of carbon. This result is expected, as others have found that as the biomass breaks down, the ratio of lignin and C will increase compared to N (Taylor et al. 1989, Talbot et al. 2011). This relationship is essentially showing N limitation in the long-term breakdown of organic matter with high C and Lignin content (Taylor et al. 1989, Talbot et al. 2011).

The mean soil N and C content showed a strong positive correlation, increases in soil C content corresponding to higher levels of N content. This relationship was also found in the detritus, with detrital C and N having a positive correlation across all sites. No relationship was found between mean living above ground biomass C and N content, indicating that this relationship becomes clearer once decomposition begins (detritus) and the decaying plant matter and associated microbial communities are incorporated into the soil within these sites.

Incorporating these nutrient dynamics into the long-term status and trends monitoring will provide additional insight and confidence in our understanding of the detrital and nutrient flux within these sites and their contributions to the greater estuary food web.

Species Specific Traits Observed

Specific species analysis of the above ground living biomass C, N, and lignin content showed a large range of variability in these traits from species to species, however, species specific trends were generally found consistent across all sites sampled. Species specific C:N and L:N ratio results have provided insight into the quality of biomass and detritus being produced by dominant species. It has long been hypothesized that non-native grass *P. arundinacea* produces lower quality biomass (higher L:N and C:N ratios) than the native sedge *C. lyngbyei,* preliminary results from summer biomass sampling in 2018 support this hypothesis (Hanson et al. 2016). The common high marsh non-native species, *P. arundinacea,* was found to have a higher mean L:N and C:N ratios than *C. lyngbyei.* These differences in L:N and C:N ratios mirror observations of decomposition in the field with more *P. arundinacea* being retained on the site as standing dead biomass than *C. lyngbyei* (Hanson et al. 2016).

Common native low marsh species *S. latifolia,* and *E. palustris,* were found to have much lower L:N and C:N ratios than the high marsh species, indicating these species have more N in their living above ground biomass than *P. arundinacea* and *C. lyngbyei,* aiding fast decomposition rates. *S. latifolia,* and *E. palustris,* are not generally found as standing dead due this faster decomposition and location in the low marsh which is exposed to more active hydrologic flushing (exporting the dead biomass) compared to the high marsh.

Other common species, *Polygonum amphibium* (Franz Lake, High Marsh) and *Polygonum hydropiperoides* (Whites and Welch Island, Low Marsh) were found to have the highest overall L:N ratios, this is not particularly surprising as these species have woody (high in lignin) perennial stems (especially when compared to the other common wetland grass and herb species) that persist throughout the winter months. *P. amphibium* and *P. hydropiperoides* are an interesting comparison to the other marsh species because they do lose their leaves annually without much dead leaf accumulation, but their stems tend to fall dormant (not actually standing dead), indicating that their L:N ratios may vary dramatically between the two plant structures (more in the perennial stems and less in the leaves). Further testing and distinction between leaves and stems of all species will help us better understand these functional plant traits and how they inform plant decomposition and detrital production within these sites moving forward.

4.4.1.3 *Pelagic*

Further discussion will be provided in the FY24 report, due to Covid related restrictions on time these data were still in process at the time of this report, for a partial update of these conditions see Section 3.4. In 2019, total algal biomass, as estimated by concentrations of chlorophyll *a*, was highest in March, prior to the spring freshet, at Welch Island and Whites Island; in contrast, the highest algal biomass at Campbell Slough and Franz Lake Slough was observed in August, with an exceptional peak in biomass at Franz Lake Slough in May. While there were a number of years between 2011 and 2019 where samples were not obtained in March, the values observed in March 2019 are relatively high for the early spring period. The low river flows in winter 2019 coincided with relatively high algal biomass, consistent with previous analyses that showed a negative correlation between river flow and algal biomass during the winter and spring months (Maier, 2014). The low levels of chlorophyll *a* observed after the freshet subsided and flows were reduced to some of the lowest rates in the 2011-2019 time series is also consistent with previous observations that in the summer months, river flow is positively associated with algal biomass (Maier, 2014).

The contrast in timing of maximum pelagic algal biomass between Welch and Whites Islands compared to Campbell Slough and Franz Lake Slough reflects the differences in species responsible for the bulk of the pelagic primary production. Whereas at Welch and Whites Islands the assemblages were dominated by diatoms, peak biomass at Campbell Slough and Franz Lake Slough was dominated by cyanobacteria and chlorophytes. This is an important distinction due to the differences in nutritional quality among the different groups of phytoplankton; studies have shown that feeding rates of zooplankton are very low on cyanobacteria (Schmidt and Jonasdottir, 1997). However, that same study showed that a supplementation of diatom diets by cyanobacteria can lead to an increase in feeding rates among copepods, as indicated by egg production rates; they observed that a 3:1 ratio of diatoms to small, unicellular cyanobacteria could result in an elevated feeding rate relative to diatoms alone (Schmidt and Jonasdottir, 1997). It is possible that the higher diversity in algal taxonomic classes observed at Campbell Slough and Franz Lake Slough contributes to the high densities of zooplankton there, in addition to slower presumed flushing rates that prevent dilution of standing stocks.

Over the last number of years, pelagic productivity has been high at Franz Lake Slough, which reached a peak >100 μg chl *a* L^{-1} in 2017. In 2019, cyanobacteria accounted for a large proportion of the phytoplankton assemblage in the summer; however, the cell densities (of cyanobacteria and other phytoplankton) were not as high as in 2017 or 2018 at most of the trends sites, with the exception of Campbell Slough, which had high abundances of cyanobacteria in August. There were also relatively high densities of cyanobacteria in 2019 at Ilwaco. Total phytoplankton biomass (as estimated by chlorophyll *a*) was highest in early spring at Ilwaco, Welch Island, and Whites Island (i.e., March, April); in contrast, peak biomass occurred after June at Campbell Slough. Phytoplankton biomass was high both before and after the freshet at Franz Lake Slough. At Franz Lake Slough the first peak coincided with high nitrate concentrations while the second peak (after the freshet) coincided with high phosphate concentrations. The species composition of the first peak was dominated by diatoms and chlorophytes, whereas the second peak was dominated by cyanobacteria, where the assemblage was dominated by *Anabaena* spp. and *Microcystis* spp. Anabaena was also abundant at Campbell Slough, in addition to Merismopedia spp., in August. *Microcystis* and *Pseudo-anabaena* were the most abundant cyanobacteria taxa at Whites Island, Welch Island, and Ilwaco.

The availability of phosphorus without available nitrate tends to stimulate the predominance of cyanobacteria (Andersson et al., 2015) since many of them are able to fix atmospheric nitrogen (Vahtera et al., 2007). The in situ fluorescence data showed a peak in phycocyanin, a pigment associated with cyanobacteria, in August, when phosphate concentrations were high. Although the proportional contributions by cyanobacteria to the phytoplankton assemblages was high, the cell densities were not as high as those observed in 2017 or 2018. Cyanobacteria blooms have been regularly observed in off-channel habitats during the mid to late summer months throughout the duration of the Ecosystem Monitoring Program (Sagar et al., 2016, Hansen et al., 2017), and each year of observations contributes to a better understanding of factors that control the initiation and development of blooms in these habitats. It is interesting to note that although cyanobacteria blooms tend to be associated with high temperatures (Paerl and Huisman, 2009, Paerl et al., 2013), the blooms observed during the warmest of recent years (2015) was associated with species that were not toxin-producing (i.e., *Merismopedia*, Tausz, 2015, Peterson et al., in prep.). In 2019, river flows and nutrient concentrations were not as high as in previous years; thus, while temperatures were favorable for the development of cyanobacteria blooms-and the proportional contributions to the total assemblage were high-the absolute densities were likely limited by low fluxes of nutrients to the system. This highlights the interplay between species composition and environmental conditions that influence the development of blooms, especially nutrient supply, temperature, and transport and colonization of organisms. Since nutrient supply to the lower Columbia River appear to come from different sources, including particulate matter (phosphorus), direct inputs from tributaries (nitrogen; especially from the Willamette), and the ocean (nitrogen or phosphorus, depending on the season; especially at Ilwaco), it is important to better understand how temporal patterns in nutrient supply influence the timing and magnitude of phytoplankton blooms, especially when they are dominated by noxious species such as toxin-producing cyanobacteria.

Outside of the warm summer months, the phytoplankton assemblage at Whites Island and Welch Island tends to be dominated by diatoms, with *Asterionella formosa* repeatedly being most abundant in the early part of the period of spring growth, while other diatoms, including *Skeletonema potamos* increased in abundance later in the year. *S. potamos* is a species typically associated with warmer waters; this species was present in high abundance in 2015, and was observed during the summer months during most years. In 2019, *S. potamos* was observed in relatively high abundance in May at Whites Island and in June at Welch Island and Campbell Slough, but was not observed at Franz Lake Slough, nor at Ilwaco. In each of the years between 2009 and 2019, *A. formosa* has constituted the early succession species that initiates the spring bloom in the river (Maier, 2014, Maier and Peterson, 2017, Maier et al., in review). This species is prone to heavy parasitism by flagellated chytrid fungi in the river mainstem (Maier and Peterson, 2014); the degree to which shallow water habitats with longer residence time influence rates and prevalence of parasitism upon primary producers that fuel aquatic food webs is currently being investigated (Cook and Peterson, unpubl. data). Since parasitism is often dependent on temperature (Ibelings et al., 2011), it is likely that periods of higher temperature would have a different prevalence of parasitism and thus influence carbon cycling and transfer through the lower food web.

Analysis of relationships between environmental variables and phytoplankton assemblages revealed that high relative proportions of diatoms are associated with high concentrations of dissolved oxygen and high dissolved oxygen saturation relative to the atmosphere. Diatom growth is also associated with a reduction in nutrient concentrations (accomplished through drawdown associated with growth). High dissolved oxygen saturation and low-to-moderate nutrient concentrations are indicative of good water quality. Diatoms tend to dominate in the spring months, where populations can get quite large; most of the annual growth of phytoplankton occurs in the spring and is accomplished by diatoms (Maier and Peterson, in prep.).

According to a Bayesian Inference stable isotope mixing model, phytoplankton carbon contributes to the juvenile salmonid food web as part of the diet of chironomid prey, based on stable isotope signatures of carbon; this carbon is incorporated as particulate organic matter and as periphyton (attached organisms). Models looking at how different sources of primary production contribution to additional prey sources are being investigated as more data are gathered, but analysis thus far suggests that periphyton constitutes an important source of organic matter for the preferred prey of juvenile salmonids (i.e., amphipods and chironomids). Estimates of dietary contributions from different prey items inferred from stable isotope mixing models suggest that juvenile salmonid growth is supported by amphipods, chironomids, and other crustacean prey, which is consistent with observations derived from stomach analysis.

4.4.2 Zooplankton

Zooplankton assemblages differ along the spatial gradient from Ilwaco Slough to Franz Lake Slough and over time from early spring to summer. Ilwaco Slough is consistently dominated by copepods, with inputs from rotifers, but very few cladoceran taxa. At the other sites, copepods generally dominated the zooplankton assemblages. At Welch Island and Whites Island, there was an increase in the proportional contribution by cladocerans from spring to summer in each of 2017, 2018, and 2019. At Campbell Slough and Franz Lake Slough, an increase in the proportional contribution of cladocerans was observed from March to June; however, by July, the relative proportions of cladocerans decreased at both sites in 2017 and 2018.

4.5 Macroinvertebrates

We examined trends in the availability of major juvenile Chinook salmon prey taxa, including amphipods, dipteran flies, cladocerans, and copepods. Amphipod abundance in benthic core samples was greatest at Ilwaco Slough. Relatively few amphipods were collected from Welch Island and Whites Island, although 2020 Welch Island benthic samples had the highest amphipod contribution to date. Amphipods were typically not present in the furthest upriver sites, Campbell Slough and Franz Lake. The distribution of benthic invertebrates in the environment is not uniform, and high variation has occurred among benthic samples. Regardless, the pattern of declining abundance in amphipods upriver is consistent over time and is also reflected in the diets of juvenile Chinook salmon.

Benthic dipteran larvae abundances have been variable, yet typically low across sites and years. In contrast, with the exception of 2020, dipterans have higher contributions to neuston tow samples, and greatest peaks, at higher reach sites. Campbell Slough and Franz Lake have lower connectivity to the mainstem, especially during low water periods, and aquatic insects, like chironomids and other dipterans, may be retained more within these sites than at more open sites like Ilwaco Slough and Welch Island. The extent of invertebrate export from tidal marsh systems is influenced by the size and geomorphology of wetland channels as well as the energy associated with oscillating water levels and velocities. Connectivity to the mainstem is likely a factor in the potential for fluvial export of wetland insects and may help explain the disconnect between our benthic and neuston sampling. Continued monitoring of patterns in benthic and neuston dipteran densities at the trend sites will help inform the complexity of prey availability in these tidal wetlands. There were no 2020 dipteran density peaks, which is likely due to the shortened sampling season.

In Pacific Northwest estuaries, including the Columbia River estuary, juvenile Chinook salmon diet composition is typically dominated by amphipods and dipterans (Simenstad et al. 1982, Lott 2004, David et al. 2016). The EMP study has consistently described a dietary transition from wetland insects to amphipods as juvenile Chinook salmon grow and move toward the estuary mouth. Beginning in 2017, however, Campbell Slough juvenile salmon diets have transitioned more to cladocerans relative to previous years, when they typically consumed Chironomidae and other dipteran taxa. A 2020 sampling peak that exceeded 1100 cladocerans per meter towed may be similar to a 2017 peak (1200 individuals per meter towed) that occurred after a spike in Chlorophyll a concentration caused substantial increases in zooplankton abundance (Kidd 2017).

2020 multivariate analyses corroborated previous annual reports of juvenile salmon diets consisting mostly of amphipods and dipterans, with higher contributions of cladocerans at Campbell Slough. Conditions affecting the growth potential of juvenile Chinook salmon, including prey availability, varies over both spatial and temporal scales in the estuary. For the fish, habitat opportunity metrics including site accessibility, temperature, water depth, and salinity interacts with habitat capacity metrics such as prey availability, competition, and predation to determine salmon feeding success, growth, and survival (D. Bottom et al. 2005). Examining average metabolic costs and energy assimilation may allow us to evaluate habitat quality across various time scales by informing us how habitat changes at the scale of a single juvenile Chinook migration season, or at the scale of years. The method may also be useful in comparing different sites to understand where salmon experience relatively good or poor growing conditions. For example, salmon sampled from a new restoration site could be plotted along with the long-term averages from the trend sites to provide an evaluation of the new habitat relative to other areas in the estuary.

4.6 Fish

In 2022, fish community composition was sampled at five trend sites—Ilwaco Slough, Welch Island, Whites Island, and Campbell Slough and Franz Lake. There is much overlap in overall species composition at all five trend sites with specific attributes that either separate or link sites in terms of similarity. Ilwaco stands apart with a greater influence of marine species while Welch and Whites Islands tend to resemble each other and overlap Ilwaco and the upriver sites at Campbell Slough and Franz Lake. The catches at Welch and Whites Islands are composed primarily of native species and most often are dominated by a single species (Threespine stickleback), however, Chinook salmon can also dominate numerically at Whites Island. Catches at Campbell Slough and Franz Lake most often have the highest values of species richness and diversity. The increased species diversity in the upper reaches of the estuary is primarily driven by non-native species, many of which have mature stages that could prey upon juvenile salmon. The greater proportion of non-natives species in this part of the estuary and river is likely due to several factors including reduced marine influence, summer water temperatures, and the predominance of back water sloughs connected to the mainstem through tide gates and water control structures. Studies have shown that these areas can be hotspots for non-native species and foster environmental conditions, such as high temperature and low dissolved oxygen, which many non-native species can tolerate (Scott et al. 2016, McNatt et al. 2017).

Patterns of salmon species composition vary by year and more strongly by site. While Chinook salmon are the most prevalent salmonid observed at four of the five sites, chum is the dominant salmonid observed at Ilwaco. Coho are observed at higher frequencies at Franz Lake than all other sites, but Chinook are still numerically dominant at Franz Lake. Chinook salmon are more abundant than any other salmonid species at Welch and Whites Islands, Campbell Slough, and Franz Lake. The majority of Chinook caught at all sites are unmarked fry and fingerlings except at Campbell Slough where the proportion of unmarked and marked fish varies. Highest densities of unmarked Chinook salmon are observed at Welch Island except in 2021 when highest densities were observed at Whites Island. Abundance and density of Chinook increases seasonally from February and peaks in April-May for unmarked Chinook, and May for marked Chinook. These findings support the results of other studies of juvenile salmon use in the lower river and estuary (Bottom et al. 2011, McNatt et al. 2016, Roegner et al. 2012, Sather et al. 2016). The lack of Chinook at Ilwaco Slough is consistent across years yet difficult to explain. It is possible that prevailing currents cause smolts to bypass the area or that the site's location adjacent to a vast mud flat limits juvenile salmon access to later stages of incoming tides. One noteworthy exception to this pattern is February of 2020 when 29 Chinook were captured at Ilwaco. This "anamoly" serves as a reminder that our samples are merely snapshots of fish abundance and distribution at specific points in time and variability is high. For example, in 2021 no salmonids were observed at Ilwaco despite three completed beach seine sets each sampling date. Coho abundance at Franz Lake is variable. Most coho are unmarked fingerling or yearling-sized fish, with execptions in 2008-2009 when large numbers of marked coho were observed in May. Unmarked coho at Franz Lake are observed throughout the season with a noteable peak in December of 2011.

Site-specific trends in the stock composition are evident. Unmarked West Cascade fall are the predominant stock of Chinook observed at Welch and Whites Islands. These sites are located downstream of tributaries such as the Lewis, Kalama, and Cowlitz Rivers which produce large numbers of West Cascade fall stock. Franz Lake is located upstream of West Cascade fall tributaries, and this is reflected in the higher percentage of interior and Spring Creek Group stocks observed there. The greatest diversity of stocks is located at Campbell Slough in Reach F, where salmon from interior Columbia Basin, Willamette River, and lower river stocks converge. Results from this study support the findings of Teel et al. (2014) who sampled hydrogeomorphic reaches throughout the estuary and found the greatest diversity of stocks in Reaches E and F.

Spring Creek group stock dominates catches of marked Chinook at Campbell Slough and Franz Lake in the upper portions of the estuary. This is likely due to the close proximity to and a large number of hatchery fish of this stock released from hatcheries just above and below Bonneville Dam. Spring Creek Group stock comprise a larger percentage of marked than unmarked Chinook at Welch and Whites Islands, but West Cascade fall stocks remain the predominant stock of both unmarked and marked fish at these sites.

The seasonal distribution of stocks is similar to what has been found in previous studies (Roegner et al. 2012, Teel et al. 2014). West Cascade fall stock are present throughout the year. Spring Creek group stock tend to increase in proportion during April–May, concurrent with large hatchery releases, and interior stocks tend to show up beginning in April and through summer. Seasonal trends for February-March of 2020 were not dissimilar to previous years except for the presence of an interior stock (mid and upper Columbia River spring) in February.

The temporal distributions of Chinook and chum salmon indicate separation in the timing of estuary use. Chum salmon densities peak in March or early April, whereas Chinook salmon densities increase through April, peak in May, and then start to decline. This pattern of estuary use is similar to patterns of abundance found by Roegner et al. (2012). The consistency with which juvenile salmon are captured at EMP trend sites demonstrates the importance of tidal wetlands to juvenile Chinook salmon. Chinook are rearing in these areas during times of low and high flows. The predominance of Chinook salmon in tidal wetland habitats is consistent with findings of other studies within the Columbia River estuary and elsewhere (Levy and Northcote 1982, Healey 1991, Bottom et al. 2011, Hanson et al. 2017).

The abundance of food resources in tidal wetlands is a likely attractant of juvenile Chinook. This study and others have demonstrated that prey items originating from tidal wetlands are an important part of Chinook diet (Lott 2004, Maier and Simenstad 2009, Hanson et al. 2017, Weitkamp et al. 2018) and Chinook have been observed entering wetland channels against water flow during times of peak diel prey abundance (McNatt et al. 2016). Condition factors at EMP trend sites are consistent, with little variability over the years. Measures of percent lipids and triglycerides are variable over time and across sites. The value ranges of lipid content for juvenile Chinook within the Columbia River estuary (1.4–2.3%) are consistent with values observed in Chinook salmon shortly after ocean entry. Daly et al. (2010) measured percent lipid of juvenile Chinook salmon in May and June off the coast of the Columbia River and southern Washington and found average (SD) values of 1.3% (0.7), whereas other marine fishes tended to have much higher values, e.g., Liparidae = 5.8% (0.5) and Cottidae = 6.8% (1.5).

Somatic growth analyses from otoliths indicate that fish collected in this study (2005-2018, over a range of mainstem and off-channel sites, historically sampled) are growing at rates similar to or greater than what other studies in the Columbia River estuary have observed (this study: 0.54 mm/d, Chittaro et al. 2018; 0.41 mm/d, Campbell 2010; 0.23 mm/d, Goertler et al. 2016; 0.53 mm/d, McNatt et al. 2016). At off-channel sites, fish length correlated with growth rates, as larger fish grew faster than smaller fish. Chittaro et al. (2018) also found that fish collected in the upper reaches of the estuary grew at faster rates than those collected at lower reaches of the estuary. This pattern seems contrary to conventional thinking—that growth rates increase as the salmon move from colder tributary waters to warmer estuarine habitats with large capacities of prey production. A number of factors could contribute to this observation. The transition from freshwater to saltwater environments and maintaining position in an increasingly tidal habitat may require additional energetic resources. At off-channel sites, growth rates have been consistent from 2007–2018, implying that differences in flow regimes from year-to-year have little impact on the growth rates of juvenile Chinook that utilize tidal wetlands. Of note is that otoliths sampled from 2015, which was an extreme low flow and high temperature year, were lost and not processed, so any impacts from such extreme conditions cannot be ascertained.

Additionally, as juvenile salmon pass through lower reaches of the river, the input of highly estuary-dependent stocks such as West Cascade falls increases. This could lead to density-dependent impacts on fish utilizing tidal wetlands. Given that 70% of vegetated tidal wetlands in the Columbia River estuary have been lost (Marcoe and Pilson 2017) the reduced capacity of the estuary to produce adequate prey resources may exacerbate increased competition for food.

Data from off-channel PIT detection arrays indicate that off-channel habitat is used by a wide variety of stocks and species including Chinook and coho salmon, as well as steelhead. The extent of use varies among stock. Fall Chinook typically are the most abundant in these areas and reside longer than other stocks. However, at Horsetail Creek individual steelhead have been shown to reside for several months. One caveat to off-channel use is that northern pikeminnow, a known predator of juvenile Chinook salmon have also been detected in these habitats and tend to reside for weeks to months. Thus, extended use of these habitats could increase juvenile salmon vulnerability to predation.

The ecological trade-off between predation risk and foraging opportunity in tidal wetlands, as in tributaries and the ocean, is the mechanistic driver of survival. Increases in foraging opportunities through habitat restoration and efforts to decrease predators (especially non-native predators) may help tilt the scale towards improved salmon survival.

5 Adaptive Management & Lessons Learned

Habitat restoration practitioners look to the best available science to inform restoration design. Despite the number of research studies completed in the Columbia River Estuary that provided valuable habitat data (focused mainly in Reaches A and B), the Ecosystem Monitoring Program is currently the only long-term monitoring program that consistently collects long-term habitat data in the lower river from the mouth to the upper, freshwater reaches. Information provided under the EMP provides context for action effectiveness monitoring results and EMP sites often act as reference sites to which habitat restoration sites are compared. Long-term observations are essential for capturing the range of and potential drivers of annual variability in environmental conditions, and the longer a monitoring program is implemented, the more descriptive the dataset becomes.

The lower river and estuary provide rearing and refugia habitat for juvenile salmonid stocks originating from across the Columbia River basin. Long-term monitoring of the various stocks that use lower river habitats, migration timing through the lower river, and the extent to which salmonids use these habitats is valuable information for resource managers. Tracking fish habitat use in conjunction with abiotic variables at reference sites provides information about conditions necessary for juvenile salmon survival and, in turn, can inform habitat restoration design. In addition, EMP data track annual patterns in fish presence, size, condition, growth, and diet of juvenile salmon during their migration period. These patterns vary according to genetic stock, life history type, and whether the fish is marked or unmarked (e.g., marked fish catches correspond to the timing of hatchery releases). Such monitoring data can be used to track how fish from these different groups utilize lower river habitats during this critical time of their life cycle. However, new data suggest that the current sampling methods (specifically the timing of fish collection with respect to the tidal cycle) may not be fully inclusive of all life history types, with yearlings potentially being underrepresented in catches. The lack of new sampling methods also results in low to no catches in Franz Lake, which is a unique EMP site based on its abiotic conditions and plankton assemblages. Efforts to conduct additional sampling across the tidal range and at high tide may produce results that differ from those derived using traditional methods, and provide additional information to further explore the influence of tidal ranges.

Non-native fish species are consistently caught throughout all reaches of the lower river and estuary. It is unclear to what degree non-natives compete with juvenile salmon for resources such as food and space. Juvenile Chinook salmon consume a wide range of prey functional groups from benthic to pelagic to terrestrial-derived. As such, there is a high likelihood that prey items consumed by juvenile Chinook salmon overlap with prey items consumed by non-native species. A comprehensive examination of diet contents of non-native fish that overlap spatially and temporally with juvenile Chinook salmon would help illuminate some of these interactions that may have a substantial impact of juvenile salmon foraging success. Additionally, some non-native fish species, such as smallmouth bass and yellow perch, are predators of juvenile salmon in their adult form. Management options for controlling the numbers of these predators need to be explored.

Non-native species can pose risks to native species (e.g., increasing competition for resources, predation, the introduction of disease, reducing biodiversity, altering ecosystem function). For example, reed canarygrass (*Phalaris arundinacea*) is known to out-compete native wetland plants, and above-ground biomass data indicate that this species does not contribute the same quantity and quality of macrodetritus to the system as native species (Cordell et al. 2023). Wetland plant distribution is highly dependent on elevation and hydrology, thus vegetation community structure and % cover can vary from year-to-year based on river discharge patterns. Long-term vegetation monitoring in emergent wetlands offers valuable information to managers seeking to control non-native plant species by helping them predict how vegetation at a recently restored site will respond to annually fluctuating river flows. These data are especially critical when trying to evaluate if restoration actions used to control *P. arudinacea* have been successful or if *P. arudinacea* abundances are changing due to natural variability.

Physical, biogeochemical, and ecological habitat characteristics across varied hydrologic years may offer insight into how environmental factors (e.g., water temperature, dissolved oxygen levels) play into the survival success of juvenile salmon. Unsuitable conditions in off-channel habitats can have negative implications for rearing juvenile salmon. Water temperatures in 2019 were higher than 2018 during late spring and summer; so were the average number of days where water temperatures exceeded relevant thresholds for salmon survival. Similar observations were made in 2015 and 2016, which were dry years, with low discharge freshets. River discharge for 2019 were generally low, similar to 2015, except for high freshet flows observed in April. These conditions, in combination with patterns observed over the past decade indicate a shift in climate patterns, which needs to be explored further.

Water quality can vary within a watershed based on season and location. Even though the EMP sites are considered to be relatively undisturbed, our results indicate that water quality values sometimes exceed water quality standards and could pose a risk to aquatic organisms. In addition, connectivity between off-channel areas and the mainstem river is important for flushing and exchange of biotic and abiotic material. In poorly flushed sites, water chemistry characteristics such as very low dissolved oxygen and high chlorophyll concentrations may cause hypoxic conditions that are harmful to aquatic life, as well as nutrient inputs that can trigger further algae growth, including the proliferation of cyanobacteria.

Based on EMP data collected over the last several years, there are a number of potential threats to the survival and growth of salmonids associated with poor water quality. For example, over the last several years, the tidal intrusion of ocean waters in Baker Bay at Ilwaco Slough in the summer months has led to increasing poor water quality in terms of dissolved oxygen saturation and pH; 2018-2021 had the greatest number of observations of hours with low dissolved oxygen over the last several years. In 2019-2021, while pH at Ilwaco slough were largely in the range of good water quality, in contrast, Campbell slough exceeded standard in June, and remained high through September. In some years, pH fluctuations have been outside of the range for good water quality, and chlorophyll concentrations have exceeded water quality standards, particularly at Franz Lake Slough (e.g., in 2017). High abundances of cyanobacteria have been consistently observed at both Campbell Slough and Franz Lake Slough during the summer months, with high abundances occurring occasionally in the spring as well. In general, these threats to water quality mainly occur in the summer months when water temperatures are highest.

To some extent, the threats can be mitigated through increase water volume and flushing; however, as atmospheric temperatures increase and snowpack declines with global climate change, high flows do not necessarily provide as strong a temperature buffer as they have in the past. Flows in 2017 were high relative to the long-term average; yet, there was a higher number of days with temperatures exceeding recommended values for salmonid growth and survival compared to all years but 2015, which had both low flows and high atmospheric temperatures. When water temperatures are high despite relatively high flows, cold water refugia become extremely important for salmonids. Monitoring the water quality in the lower river provides contextual information that identifies critical times periods and locations that should be targeted for management.

Water volume and quality (temperature, dissolved oxygen, pH, nutrients, chlorophyll) are driven by river flows under the influence of climatic factors that include atmospheric temperature and precipitation patterns. Biological production at the base of aquatic food webs depends directly on some these features (e.g., water residence time, temperature, nutrients) and also influences some of these features (e.g., pH, dissolved oxygen). The growth and survival of salmonids depend on food availability—which is directly tied to primary and secondary production—and to water quality parameters that influence growth and physiology (e.g., dissolved oxygen, pH, and temperature). We are developing models to infer the diet of juvenile salmon so that we can relate hydrologic characteristics to components of the food web to improve our ability to predict how hydrology will influence salmon production and survival. In particular, habitat restoration efforts should consider how interventions influence water retention time and volume; EMP data show that when waters have long retention times during warm periods, they are vulnerable to the proliferation of noxious phytoplankton blooms, which impairs water quality in terms of dissolved oxygen, temperature, and pH. Additionally, it is important for managers to consider future fluctuations predicted to be associated with climate change and the consequences of rising water temperatures when planning habitat projects.

There are a number of questions that emerge based on several years of observations in the lower Columbia. Some of these have been presented below. Based on the long-term dataset available, we recommend an EMP Synthesis study addressing some of these questions:

- ***How important are biogeochemical processes upstream of Bonneville Dam for the tidal freshwater estuary?*** It is unclear how conditions above Bonneville Dam influence water chemistry and plankton stocks observed downstream. Measurements of water quality and food web components from above the dam would help to determine the degree to which advection is important versus in situ processes such as growth and gas equilibration with the atmosphere.
- ***What is the importance of decomposition of organic matter by microbial organisms in determining its quality for salmon prey?*** Microbial decomposition often results in "trophic upgrading", whereby less labile compounds are transformed through microbial metabolism to compounds that are more easily assimilated. How are these processes influenced by water chemistry, temperature, and nature of the organic matter (e.g., non-native vs. native plant species)?
- ***What factors contribute to cyanobacteria blooms in Franz Lake Slough? Do these blooms pose a problem for wildlife, and if so, what is the extent of the problem?*** Over the last few years, elevated phosphorus concentrations have been observed at Franz Lake Slough in advance of cyanobacteria blooms, although the source is unknown.
- ***How do pulses in primary production from different sources vary in space and time, and how does this influence secondary production and salmon food webs?*** The timing of availability of different sources of organic matter produced through primary production varies between pelagic phytoplankton and marsh vegetation. It would be helpful to compare the magnitude of these stocks to identify patterns that could inform food web models. In addition, pulse events, such as the production and deposition of pollen, could produce reservoirs of organic matter originating from vascular plants in the water column that is independent of detritus transport.
- ***How does prey quality and quantity vary spatially and temporally across the estuary?*** While studies have shown that emergent wetlands are important for prey production and export, accurate assessments of information on prey source in the mainstem and floodplain habitats are yet to be made in the lower Columbia river. The spatial and temporal variation of energy densities of chironomids and amphipods in these undisturbed sites of the lower Columbia river would provide an important functional tool for restoration design. Maintenance metabolism and energy ration calculations from juvenile salmon diet data, or future calculations of modeled growth, may address questions about habitat quality for juvenile Chinook salmon. High prey quality and quantity may help mitigate effects of suboptimal temperatures and hydrological conditions.
- ***How does mainstem cumulative discharge affect prey availability and juvenile salmon health and habitat use?*** Additional information is needed to explore the effect of different mainstem hydrologic conditions on the food web and habitat structure for the EMP. Since many EMP sites

serve as reference sites for restoration projects, additional information about changes in habitat use and structure under various freshet conditions would help determine crucial actions in restoration design, and mitigate effects of climate change.

- ***How much do specific environmental factors impact growth, fish condition, residence time, age at maturation and survival of anadromous salmonids in the estuary?*** Habitat use in the lower Columbia depends on a myriad of abiotic conditions, and a closer look into specific characteristics such as temperature, DO, discharge, etc. would provide critical information about juvenile salmonid behavior which can be used to inform landscape principles in restoration planning. Bioenergetics analysis of subyearling Chinook could be a useful tool for determining impacts of temperature, flow-based variation in food availability, and habitat availability on subyearling growth and presumed survival. (links with topic above on discharge and prey availability).
- ***How does sediment carbon interact with Greenhouse gases in EMP Trend Sites?*** In order to understand the effects of climate change on the EMP sites, another aspect that needs to be explored further are the exchanges between carbon and greenhouse gases in emergent wetlands. While some data is available from sediment analysis, further exploration is required in terms of accretion and nutrients and carbon sequestration.
- ***How does discharge and river flow impact availability of off-channel habitat including restored areas?*** Availability of alternate migration pathways and rearing opportunities is important for building population resiliency. Impacts of climate change may limit access to rearing habitat as flows decrease. Applying habitat connectivity models used in Puget Sound to the lower Columbia River could help identify under what flows habitat connectivity is constrained or maximized throughout the entire lower river or specific reaches.

The Estuary Partnership shares results from the monitoring program with other resource managers in the region and results from this multi-faceted program are applied to resource management decisions. Results from the EMP are presented and discussed at an annual Science Work Group meeting. The Science Work Group is composed of over 60 individuals from the lower Columbia River basin representing multiple regional entities (i.e., government agencies, tribal groups, academia, and private sector scientists) with scientific and technical expertise who provide support and guidance to the Estuary Partnership. In addition, EMP results will also be shared with regional partners at various conferences throughout the year. Data are often provided to restoration practitioners for use in restoration project design and project review templates (e.g., ERTG templates). Finally, data from the EMP are used to compare and contextualize results from the Action Effectiveness Monitoring Program (see 2022 AEMR report, link). Furthermore, the Estuary Partnership is working on shifting all EMP and AEMR data into a regional database to store, share, and conduct additional, largescale synthesis analyses of these data by utilizing Tableau.

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7 Appendices

Appendix A.

For archival purposes and to ensure long-term accessibility, we have provided a static snapshot of the Tableau dashboards here in this appendix. In the digital realm, Tableau provides a dynamic and interactive experience, enabling users not only to engage directly with the data for deeper analysis and insights but also to access written explanations and further details with a simple click on specific sections of the analysis. The PDF version captures a snapshot of the Tableau dashboards but cannot convey these interactive elements. While this static representation offers a valuable overview, we strongly recommend engaging with the online version to fully benefit from the additional context and detailed explanations embedded within the interactive platform. For the full hybrid report please see this link.

Lower Columbia River Estuary Ecosystem Monitoring Program Overview Dashboard by Ecosystem Monitoring Program

Welcome to the Ecosystem Monitoring Program Overview Dashboard

Click on the beautiful sneezeweed below to see the written report.

Lower Columbia Estuary Partnership

BONNEVILLE POWER ADMINISTRATION

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Lower Columbia River Ecosystem Monitoring Program
Hybrid Tableau Report

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This Dashboard Provides all the Overview and Results Links. Click any of the buttons below to access more data.

Ecosystem Monitoring Program Overviews Can Be Found Below
(Click on Overview of Interest)

Navigate to Executive Summary

Navigate to Program Background

Navigate to Site Descriptions

Ecosystem Monitoring Program Focal Research Topic Overviews Can Be Found Below
(Click on Metric of Interest)

Lower Columbia River Ecosystem Monitoring Program
Annual Report for Year 17

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Technical Contacts: Sarah Kidd & Ian Edgar
Lower Columbia Estuary Partnership
skidd@estuarypartnership.org, iedgar@estuarypartnership.org

BPA Project Manager: Anne M. Creason
Fish & Wildlife Project Manager
Bonneville Power Administration
amcreason@bpa.gov

Editors:
Sarah A. Kidd[1]
Ian Edgar[1]
Sneha Rao[1]

Active Authors (alphabetical by last name):
Kerry Accola[5]
Jeff Cordell[5]
Paul M. Chittaro[3]

Navigate to Mainstem and Abiotic site conditions

Navigate to Habitat Structure

Navigate to Food Web analysis

Navigate to Macroinvertebrate Analysis

Navigate to Fish Communities

Navigate to Data Inventory - coming soon

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Paul M. Chittaro[3]
Jeffery Grote[7]
Susan A. Hinton[3]
Sarah A. Kidd[1]
Joseph A. Needoba[4]
Tawnya D. Peterson[4]
Sneha Rao[1]
Curtis Roegner[3]
Ian Edgar[1]
Jason D. Toft[5]

Past Contributors/Authors (alphabetical by last name):
Amy B. Borde[6],[8], Catherine A. Corbett[1], Lyle P. Cook[4],Valerie I. Cullinan[6], Roger N. Fuller[2], Amanda C. Hanson[1], David Kuligowski[3], Daniel Lomax[3], Lyndal L. Johnson[3], Regan A. McNatt[3], Katrina Poppe[2], Shon A. Zimmerman[6], Gina M. Ylitalo[3]

[1]Lower Columbia Estuary Partnership
[2]Estuary Technical Group, Institute for Applied Ecology
[3]Northwest Fisheries Science Center, NOAA-National Marine Fisheries Service
[4]Oregon Health & Science University
[5]University of Washington
[6]Pacific Northwest National Laboratory
[7]Ocean Associates, Inc
[8]Columbia Land Trust

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LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

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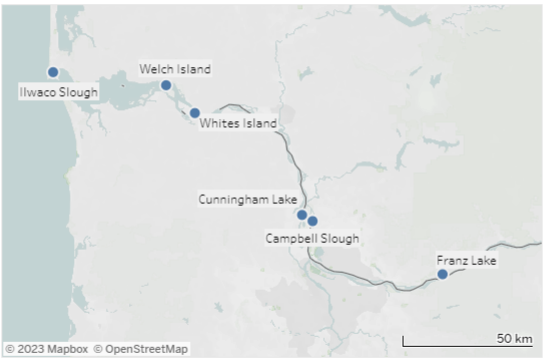
Ecosystem Monitoring Program Executive Summary

Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact skidd@estuarypartnership.org

Overview Map
Click on a site within the map below to view each site's description



This Dashboard Provides a Brief Overview of the Ecosystem Monitoring Program. Please click any of the buttons below to view the associated, metric specific dashboard.

Navigate to Mainstem and Abiotic site conditions

Navigate to Habitat Structure

Navigate to Food Web analysis

Lower Columbia Estuary Partnership

OHSU

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Navigate to Title Page

Navigate to Program Background and Study Area

Navigate to Site Descriptions

Navigate to Data Inventory - coming soon

Executive Summary

The Ecosystem Monitoring Program (EMP) is managed by the Lower Columbia Estuary Partnership and is an integrated status and trends program for the lower Columbia River. Under the EMP, researchers collect key information on ecological conditions for a range of habitats throughout the lower river characteristic of those used by migrating juvenile salmon and provide information to aid the recovery of threatened and endangered salmonids. The program inventories the different types of habitats within the lower river, tracks trends in the overall condition of these habitats over time, provides a suite of reference sites for use as end points in regional habitat restoration actions, and places findings from management actions into context with the larger ecosystem. The EMP is implemented through a multi-agency collaboration, focusing sampling efforts on examining temporal trends within a study area that extends from the mouth of the river to Bonneville Dam. The goal of this executive summary is to provide a brief synopsis of the ecological conditions observed in the trend sites in 2022. The full report linked throughout this report should be consulted for detailed scientific methods and findings.

In 2022, data were collected on fish and fish prey, habitat, hydrology, food web, abiotic site conditions, and mainstem river conditions at Ilwaco Slough (river kilometer; rkm 6), Welch Island (rkm 53), Whites Island (rkm 72), Campbell Slough (rkm 149), and Franz Lake (rkm 221). Habitat and hydrology data were also collected at Cunningham Lake (rkm 145) along with with primary production and hydrology data collected at Steamboat Slough (rkm 57, a restoration site included in our long-term biomass study). The trends sampling sites are minimally disturbed, tidally influenced freshwater emergent wetlands with backwater sloughs that represent a subset of the eight hydrogeomorphic reaches across the lower river. In addition to tracking ecological changes in the Lower Columbia River, this year a collaborative effort has been made to study the effect of varying flow regimes over the monitoring period, of the mainstem on site-specific biotic and abiotic conditions as well as answering specific longterm questions about the lower Columbia river. The primary research questions we have attempted to answer with this report are "What are the longterm status and trend conditions we see across the estuary and how can we use these data to address the uncertainties brought forth by the ERTG and others about restoring sustainable habitat conditions in the estuary?" We believe that exploring this question provides crucial information to restorative planning in the face of rising water levels and shifting climate patterns.

Navigate to Macroinvertebrate Analysis

Navigate to Fish Communities

LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

Ilwaco Island - Summer

In a significant advancement this year, the EMP report has adopted a hybrid format leveraging the capabilities of Tableau, an interactive data visualization platform. This ensures that the data and analyses presented in the report are not just static but can be interacted with online, providing a more immersive experience for readers and stakeholders. The integration of Tableau allows for dynamic engagement, facilitating deeper exploration of the data and insights, thereby enriching the understanding and interpretation of our findings.

This report is a collaborative effort by many researchers. Habitat structure research leads from Lower Columbia Estuary Partnership are Dr. Sarah Kidd, Ian Edgar, and Sneha Rao. Water Quality and Food Web dynamics research leads from Oregon Health and Science University are Dr. Joseph A. Needoba and Dr. Tawnya D. Peterson. Salmon Prey and Diet research leads from University of Washington are Dr. Jeff Cordell, Dr. Jason Toft, and Kerry Accola. Fish community and genetic composition research leads from NOAA – Fisheries are Curtis Roegner and Susan A Hinton. Dr. Sarah Kidd, Ian Edgar, and Sneha Rao, are the lead report Editors.

Mainstem Conditions of the Columbia River
River Discharge

The 2022 water year in the Columbia River was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average flows in the early spring, and higher-than-average flows associated with the spring freshet, which peaked in mid-June.

Columbia River discharge at Bonneville Dam was close to the 2009-2022 average during the winter months; after mid-March flows were lower than average and reached minimum values for the time period in mid-April. Flows increased from early and peaked in mid-June at volumes close to the long-term maximum, observed in 2017. The decline in river discharge following peak flows was steeper than in 2017, but flow remained above average through the end of August after which they were close the long-term average. River discharge associated with the Willamette was higher than average during a few peaks in winter and spring (early January, early March, early May and early June) and was otherwise close to or below average values observed between 2009-2022.

Water Quality

The average daily water temperature in 2022 was average in the winter, slightly below average in the spring leading up to the freshet, average during the freshet, and higher than average after the freshet. There were 50 days having temperatures exceeding 19oC, similar to the long-term average. At the off-channel EMP sites, temperatures were highest after July at Campbell Slough and Franz Lake Slough.

Water quality was generally good at the off-channel EMP sites in 2022, with pH being in the acceptable range except at Campbell Slough after early August where values exceeded 8.5 units, alongside peaks in dissolved oxygen saturation and chlorophyll, indicating that environmental conditions were dominated by biological activity.

Tidal Wetland Habitat Conditions of the Columbia River
Native and non-native Plant Communities

Overall, 2022 total plant cover was relatively stable across Ilwaco Slough, Welch Island, Whites Island, and Franz Lake compared to historic, long-term averages. Cunningham Lake total cover has continued to increase through 2022, beginning to rebound from the heavy cattle grazing observed in 2017. Campbell Slough has exhibited a small increase in total cover levels in 2022, however the overall cover at Campbell is still low compared to non-grazed conditions; cattle grazing has continued at Campbell Slough since 2017, with fencing efforts failing to keep the cattle out of the wetland.

Between 2012-2022 the six most common plant species identified throughout the tidal estuary (across the 6 trend sites) in order of overall abundance are *Phalaris arundinacea* (PHAR, non-native), reed canarygrass, *Carex lyngbyei* (CALY, native), lyngby sedge, *Eleocharis palustris* (ELPA, native), common spikerush, *Sagittaria latifolia* (SALA, native), wapato, *Leersia oryzoides* (LEOR, native), rice cut grass, and *Ludwigia palustris* (LUPA, native), water purslane. While these species are the most common and abundant across all sites over the years, they are not necessarily present at all sites every year.

Ilwaco Island - Summer

Whites Island - Summer

Welch Island - Summer

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In 2022, *P. arundinacea* cover levels stayed relatively consistent to those observed in 2021 and previous years, however, at Cunningham, there was a significant increase in *P. arundinacea* levels. Franz Lake also experienced a small increase. This shift in *P. arundinacea* levels observed at Cunningham and Franz Lake is likely a product of both very low freshet flooding conditions in 2022 and, at Cunningham Lake, a break from grazing pressure. In 2022, data continued to support our findings that annual shifts in *P. arundinacea* cover are strongly correlated with Columbia River discharge levels and site water levels during the growing season, with lower water levels (and lower discharge levels) favoring *P. arundinacea* growth and observed abundance. These findings indicate that annual flooding conditions within sites and across the river (freshet accumulated discharge) are important mechanisms driving much of the observed annual variability in *P. arundinacea* dominance across the estuary. The long-term trends in the abundance of native species *Carex lyngbyei, Sagittaria latifolia, Polygonum amphibium* have also been found to be strongly (and significantly) linked to annual river discharge conditions. Generally, *C. lyngbeyi* abundance has been found to increase in years of greater freshet and discharge levels, especially in Ilwaco Slough, where salinity levels are reduced during large discharge years, making growing conditions more favorable for *C. lyngbeyi*. *S. latifolia* has been found to have a delayed reaction to freshet and river discharge conditions, with lower discharge years resulting in an increase in *S. latifolia* abundance the following year. Additionally, *P. amphibium* levels at Franz Lake have also be found to follow a similar trend to *S. latifolia* with a one-year delayed reaction (increase in abundance) to decreased river discharge conditions. For both species, this might be a result of increased rhizome stores from positive growing conditions (low water levels), providing for more robust growth in the following growing season.

Macroinvertebrates

Juvenile salmon diets in the Lower Columbia estuary consist mostly of **amphipods**, **dipterans**, and **cladocerans**. Young salmon consume primarily wetland insects (dipterans) at Franz Lake, the uppermost site, incorporate cladocerans at Campbell Slough, transition to dipterans and amphipods at Welch Island and Whites Island, and consume primarily amphipods near the estuary mouth at Ilwaco Slough. Diets are **most metabolically beneficial** to small salmon (30 - 59 mm). Larger salmon have higher metabolic costs that are directly influenced by larger body mass and higher water temperatures. Top salmon prey sources have small yet consistent contributions from the benthic core and neuston tow samples.

Fish

Examinations of fish communities for all years of sampling show that all five trend sites are different from each other. The one exception is that Welch and Whites, when compared directly to each other, are similar. Thirteen major families of fish have been consistently present at the trend sites. Within those families, the fish species range from native marine species at Ilwaco Slough, to freshwater native and non-native species at the remaining EMP trend sites sampled through 2022. Chinook salmon are captured at all five trend sites and are often the numerically dominant salmonid species. Chum salmon (primarily at Ilwaco Slough) and coho salmon (primarily at Franz Lake) have also been captured at the five sites in low numbers.

Franz Lake - Summer

Campbell Slough - Summer

Closing Summary

The Ecosystem Monitoring Program is the only study in the lower Columbia river that collects long-term habitat data from relatively undisturbed tidal freshwater marshes to upper freshwater reaches to allow researchers and restoration practitioners to differentiate between variability associated with natural conditions and variability resulting from human influence, and enhance our understanding of the degree to which these wetlands aid in supporting life-cycle and recovery of endangered and threatened salmonids. We continue to monitored water quality, habitat structure, food web dynamics, and fish use at five trend sites from the mouth of the Columbia River to the Bonneville dam to assess habitat function at these sites. We also began a focused effort to evaluate the influence of river discharge on wetland habitat conditions. Results from our collective analyses indicate that differences in annual Columbia River discharge and climate conditions are correlated with significant shifts in wetland food web and habitat conditions including plant community, plankton, and zooplankton abundance; as well as composition, food web nitrogen, and carbon dynamics. These findings are critical for evaluating how future environmental fluctuations predicted to be associated with climate change may impact salmonid habitat and food web dynamics. Future EMP research will focus on synthesizing these environmental observations and identifying how shifting climatic, and habitat conditions will impact the salmonid food web.

Management Implications

There are a number of questions that emerge based on several years of observations in the lower Columbia. Some of these include:

- How important are biogeochemical processes upstream of Bonneville Dam for the tidal freshwater estuary? It is unclear how conditions above Bonneville Dam influence water chemistry and plankton stocks observed downstream. Measurements of water quality and food web components from above the dam would help to determine the degree to which advection is important versus in situ processes such as growth and gas equilibration with the atmosphere.

- What is the importance of decomposition of organic matter by microbial organisms in determining its quality for salmon prey? Microbial decomposition often results in "trophic upgrading", whereby less labile compounds are transformed through microbial metabolism to compounds that are more easily assimilated. How are these processes influenced by water chemistry, temperature, and nature of the organic matter (e.g., non-native vs. native plant species)?

- What factors contribute to cyanobacteria blooms in Franz Lake Slough? Do these blooms pose a problem for wildlife, and if so, what is the extent of the problem? Over the last few years, elevated phosphorus concentrations have been observed at Franz Lake Slough in advance of cyanobacteria blooms, although the source is unknown.

- How do pulses in primary production from different sources vary in space and time, and how does this influence secondary production and salmon food webs? The timing of availability of different sources of organic matter produced through primary production varies between pelagic phytoplankton and marsh vegetation. It would be helpful to compare the magnitude of these stocks to identify patterns that could inform food web models. In addition, pulse events, such as the production and deposition of pollen, could produce reservoirs of organic matter originating from vascular plants in the water column that is independent of detritus transport.

- How does prey quality and quantity vary spatially and temporally across the estuary? While studies have shown that emergent wetlands are important for prey production and export, accurate assessments of information on prey source in the mainstem and floodplain habitats are yet to be made in the lower Columbia river. The spatial and temporal variation of energy densities of chironomids and amphipods in these undisturbed sites of the lower Columbia river would provide an important functional tool for restoration design. Maintenance metabolism and energy ration calculations from juvenile salmon diet data, or future calculations of modeled growth, may address questions about habitat quality for juvenile Chinook salmon. High prey quality and quantity may help mitigate effects of suboptimal temperatures and hydrological conditions.

- How does mainstem cumulative discharge affect prey availability and juvenile salmon health and habitat use? Additional information is needed to explore the effect of different mainstem hydrologic conditions on the food web and habitat structure for the EMP. Since many EMP sites serve as reference sites for restoration projects, additional information about changes in habitat use and structure under various freshet conditions would help determine crucial actions in restoration design, and mitigate effects of climate change.

- How much do specific environmental factors impact growth, fish condition, residence time, age at maturation and survival of anadromous salmonids in the estuary? Habitat use in the lower Columbia depends on a myriad of abiotic conditions, and a closer look into specific characteristics such as temperature, DO, discharge, etc. would provide critical information about juvenile salmonid behavior which can be used to inform landscape principles in restoration planning. Bioenergetics analysis of subyearling Chinook could be a useful tool for determining impacts of temperature, flow-based variation in food availability, and habitat availability on subyearling growth and presumed survival. (links with topic above on discharge and prey availability).

- How does sediment carbon interact with Greenhouse gases in EMP Trend Sites? In order to understand the effects of climate change on the EMP sites, another aspect that needs to be explored further are the exchanges between carbon and greenhouse gases in emergent wetlands. While some data is available from sediment analysis, further exploration is required in terms of accretion and nutrients and carbon sequestration.

- How does discharge and river flow impact availability of off-channel habitat including restored areas? Availability of alternate migration pathways and rearing opportunities is important for building population resiliency. Impacts of climate change may limit access to rearing habitat as flows decrease. Applying habitat connectivity models used in Puget Sound to the lower Columbia River could help identify under what flows habitat connectivity is constrained or maximized throughout the entire lower river or specific reaches.

The Estuary Partnership shares results from the monitoring program with other resource managers in the region and results from this multi-faceted program are applied to resource management decisions. Results from the EMP are presented and discussed at an annual Science Work Group meeting. The Science Work Group is composed of over 60 individuals from the lower Columbia River basin representing multiple regional entities (i.e., government agencies, tribal groups, academia, and private sector scientists) with scientific and technical expertise who provide support and guidance to the Estuary Partnership. In addition, EMP results will also be shared with regional partners at various conferences throughout the year. Data are often provided to restoration practitioners for use in restoration project design and project review templates (e.g., ERTG templates). Finally, data from the EMP are used to compare and contextualize results from the Action Effectiveness Monitoring Program (see 2023 AEMR report, link). Furthermore, the Estuary Partnership is working on shifting all EMP and AEMR data into a regional database to store, share, and conduct additional largescale synthesis analyses of these data by utilizing Tableau.

Lower Columbia River Estuary Ecosystem Monitoring Program Overview Dashboard by Ecosystem Monitoring Program

Ecosystem Monitoring Program Background and Study Area

Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact skidd@estuarypartnership.org

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Overview Map

Click on a site within the map below to view each site's description

This Dashboard Provides a Brief Methods Overview and Links to all the Results Summaries: Click any of the buttons below to access more data.

Navigate to Mainstem and Abiotic site conditions

Navigate to Habitat Structure

Navigate to Food Web analysis

Ecosystem Monitoring Program Background and Study Area

1.1 Background

The Columbia River supported diverse and abundant populations of fish and wildlife and is thought to have been one of the largest producers of Pacific salmonids in the world (Netboy 1980). Anthropogenic changes since the 1860s encompassing dike construction, land use conversion, and the construction of the hydropower system on the Columbia River basin have resulted in alterations to the hydrograph (i.e., timing, magnitude, duration, frequency, and rate of change in river flows); degraded water quality and increased presence of toxic contaminants; introduction of invasive species; and altered food web dynamics. These changes have subsequently significantly reduced the quantity and quality of habitat available for fish and wildlife species. The availability of suitable habitats affects the diversity, productivity, and persistence of salmon populations (Fresh et al. 2005). Degradation and loss of suitable estuarine habitats can threaten salmon population viability, thus highlighting the importance of identifying limiting factors to salmon survival and filling key knowledge gaps across the habitat gradient of the lower Columbia River to promote salmon recovery.

Threatened and endangered salmonids utilize the shallow water wetland habitats of the lower Columbia River for rearing and refugia, with some stocks utilizing these habitats for long time periods before completing their migratory journey to the ocean (Bottom et al. 2005, Fresh et al. 2005, 2006, Roegner et al. 2008, McNatt et al. 2016). Traditionally, fish and fish habitat research and monitoring efforts have been concentrated in the lower reaches of the estuary, particularly near the mouth of the river, leaving knowledge gaps in the basic understanding of fish habitat use and benefits within the upper, freshwater-dominated reaches of the Columbia River.

Tidal emergent wetland vegetation provides rearing and refuge habitat for juvenile fish and a source of organic matter to the

Navigate to Food Web analysis

Navigate to Macroinvertebrate Analysis

Navigate to Fish Communities

Click on any titles below for the pdf report.

LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

Cunningham Lake - 2022

Tidal emergent wetland vegetation provides rearing and refuge habitat for juvenile fish and a source of organic matter to the mainstem and downstream habitats, while tidal channels provide access to wetlands and to foraging opportunities. Most emergent wetlands in the lower river cover a narrow elevation range of 0.8 to 2.6 m, relative to the Columbia River Datum (CRD). The annual fluctuations in hydrology drive the spatial and temporal variability of wetland vegetation, specifically the cover and species composition, and affect overall wetland inundation (Sagar et al. 2013). The vegetation species composition in the lower river is spatially variable, with the middle reaches generally showing the greatest species diversity; although some areas are dominated by non-native species such as reed canarygrass (*Phalaris arundinacea*), particularly in the river-dominated upper reaches (Sagar et al. 2013). Identification and quantification of vital habitat metrics allow for a greater predictability in biotic responses to changing environmental conditions and improves our overall understanding of the ecological functions in the lower river.

Salmonids occupy the upper trophic levels in the Columbia River system. They spend portions of their life cycle in fresh, estuarine, and oceanic waters. Threats to their survival could arise from a variety of sources or stressors occurring at any one of several life stages or habitat types. Large-scale changes to the ecological characteristics of the lower Columbia River food web as a consequence of wetland habitat loss have resulted in a significant reduction of icrodetritus inputs to the system that historically formed the basis of the aquatic food web (Sherwood et al. 1990). Organic matter derived from fluvial phytoplankton (rather than icrodetritus) may be a seasonal driver of the salmon food web (Maier and Simenstad 2009). The consequences of the apparent shift in the type of organic matter fueling food web dynamics are uncertain, and the understanding of shifts in the food web requires a detailed examination of the interactions between multiple trophic levels and environmental conditions. Studying the abundance and assemblage of phytoplankton and zooplankton over space and time provides crucial information on the diets of preferred salmon prey, such aschironomids and benthic amphipods. In turn, characterizing the abiotic conditions within emergent wetlands, and in the river mainstem is essential for elucidating spatial and temporal patterns in the primary and secondary productivity in the lower river.

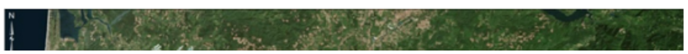
The Lower Columbia Estuary Partnership (Estuary Partnership), as part of the Environmental Protection Agency (EPA) National Estuary Program, is required to develop and implement a Comprehensive Conservation and Management Plan. This Management Plan specifically calls for sustained long-term monitoring to understand the ecological conditions and functions, to evaluate the impact of management actions over time (e.g., habitat restoration), and to protect the biological integrity in the lower Columbia River. The Estuary Partnership implements long-term monitoring through the Ecosystem Monitoring Program (EMP). Ultimately, the goal of the EMP is to track ecosystem conditions over time and allow researchers and managers the ability to distinguish between the variability associated with natural conditions and variability resulting from human influence. The EMP partnership collects on-the-ground data from relatively undisturbed emergent wetlands to provide crucial information about habitat structure, fish use, abiotic site conditions, salmon food web dynamics, and river mainstem river conditions to assess the biological integrity of the lower river, enhance our understanding of the estuary functions, and ultimately support recovery of threatened and endangered salmonids. The creation and maintenance of long-term datasets are vital for documenting the history of change within important resource populations. Therefore, through the EMP, we aim to assess the status (i.e., spatial variation) and track the trends (i.e., temporal variation) in the overall conditions of the lower Columbia River, to provide a better basic understanding of ecosystem functions, to provide a suite of reference sites for use as end points in regional habitat restoration actions, and to place findings from other research and monitoring efforts, such as the Action Effectiveness Monitoring into context within the larger ecosystem.

Ecosystem-based monitoring of the fish habitat conditions in the lower river is a regional priority intended to aid in the recovery of historical productivity and diversity of fish and wildlife. In addition to tracking ecological changes in the lower Columbia River, we also measure and study the effect of varying flow regimes over the monitoring period, of the mainstem on site-specific biotic and abiotic conditions. This year, we are specifically addressing uncertainties brought forward by the Expert Regional Technical Group (ERTG). The hydrology of the mainstem Columbia is strongly influenced by winter snow melt and precipitation between the months of October

Welch Island - 2022

Franz Lake - 2022

Campbell Slough - 2022



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The EMP is funded by the Northwest Power and Conservation Council/Bonneville Power Administration (NPCC/BPA) and a primary goal for the action agencies (i.e., the BPA and US Army Corps of Engineers) is to collect key information on ecological conditions for a range of habitats and whether the habitats in the lower river are meeting the needs of outmigrating juvenile salmonids for growth and survival. Such data provide information toward implementation of the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008). Specifically, NPCC/BPA funding for this program focuses on addressing BPA's Columbia Estuary Ecosystem Restoration Program (CEERP) goal of improving habitat opportunity, capacity and realized function for aquatic organisms, specifically salmonids.

The EMP addresses Action 28 of the Estuary Partnership Comprehensive Conservation and Management Plan; Reasonable and Prudent Alternatives (RPAs) 161, 163, and 198 of the 2000 Biological Opinion for the Federal Columbia River Power System; and RPAs 58, 59, 60, and 61 of the 2008 Biological Opinion. The Estuary Partnership implements the EMP by engaging regional experts at Battelle-Pacific Northwest National Laboratory (PNNL), National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA-Fisheries), Estuary Technical Group (ETG), University of Washington (UW), and Oregon Health & Science University

1.2 Study Area

The lower Columbia River and estuary is designated as an "Estuary of National Significance" by the Environmental Protection Agency (EPA) and as such, it is part of the National Estuary Program (NEP) established in Section 320 of the Clean Water Act. The EMP study area encompasses that of the NEP (a.k.a., the Estuary Partnership), including all tidally influenced waters, extending from the mouth of the Columbia River at river kilometer (rkm) 0 to Bonneville Dam at rkm 235 (tidal influence is defined as historical tidal influence, relative to dam construction in the 1930s). The Estuary Partnership and monitoring partners collect data for the EMP from habitats supporting juvenile salmonids, in tidally influenced shallow water emergent wetlands connected to the Columbia River.

The Estuary Partnership and monitoring partners use a multi-scaled stratification sampling design for sampling the emergent wetland component of the EMP based on the Columbia River Estuary Ecosystem Classification (Classification). The Classification, a GIS-based data set, is a six-tier hierarchical framework that delineates the diverse ecosystems and component habitats across different scales in the lower river. The primary purpose of the Classification is to enable management planning and systematic monitoring of diverse ecosystem attributes. The Classification also provides a utilitarian framework for understanding the underlying ecosystem processes that create the dynamic structure of the lower river. As such, it aims to provide the broader community of scientists and managers with a larger scale perspective in order to better study, manage, and restore lower river ecosystems. The EMP sampling design has been organized according to Level 3 of the Classification, which divides the lower river into eight major hydrogeomorphic reaches (Figure 1).

Campbell Slough - 2022

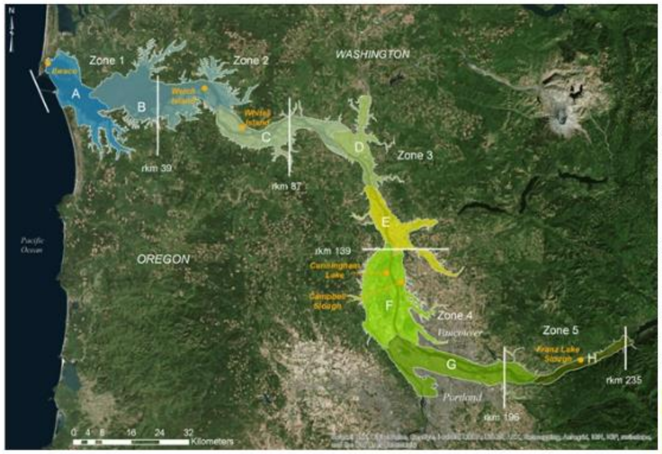

Figure 1. Lower Columbia River and estuary with hydrogeomorphic reaches (A-H) specified by color (Simenstad et al. 2011) and wetland zones (1-5) delineated by white lines (Jay et al. 2016). The 2022 EMP trends sites are shown in orange.

Battelle-Pacific Northwest National Laboratory (PNNL), National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA-Fisheries), Estuary Technical Group (ETG), University of Washington (UW), and Oregon Health & Science University

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More recently, subsequent to the development of the sampling design, data collected as part of the EMP and other studies (Borde et al. 2011; Borde et al. 2012) have been used to define five emergent marsh (EM) zones based on spatial variation of the hydrologic regime and vegetation patterns observed in the lower river (Jay et al. 2016). Vegetation species assemblages vary temporally and spatially and are broadly grouped into categories, or EM zones, based on vegetation cover and species richness. EM zones are used here to evaluate vegetation patterns within the tidal wetlands of the lower river because they are more representative of vegetation patterns than hydrogeomorphic reach. The zone boundaries are meant to be broad, and variation of the zone boundaries is observed between years. The following river kilometers are currently used to delineate the zones:

EM Zone	River Kilometer (rkm)
1	0 – 39
2	39 – 88
3	89 – 136
4	137 – 181
5	182 – 235

Site Descriptions

Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact skidd@estuarypartnership.org

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Overview Map

Click on a site within the map below to view each site's description

Ilwaco Slough:

This site is located in Reach A, EM Zone 1 at river kilometer (rkm) 6, southwest of the entrance of Ilwaco harbor, in Baker Bay, WA. The property is currently owned by Washington Department of Natural Resources. The site has developed in the past century as the bay filled in, likely due to changes in circulation from the construction of the jetties at the mouth of the Columbia River, the placement of dredge material islands at the mouth of the bay, and changes in river flows. Ilwaco Slough marsh is dominated by lush fields of Lyngby's sedge (Carex lyngbyei) with higher portions occupied by tufted hairgrass (Deschampsia cespitosa) and cattail (Typha angustifolia). Being so close to the mouth of the Columbia River, the tidal channel is regularly inundated with brackish water (average salinity < 10 Practical Salinity Units (PSU), however salinity up to 20 PSU occur in the late summer). Selected as a long-term monitoring site in 2011, Ilwaco Slough was sampled for all EMP metrics every year except 2014 when only habitat and hydrology were monitored.

View the drone flight in high res here: https://www.youtube.com/embed/LsLZmglP0mw

Ilwaco Slough:

This site is located in Reach A, EM Zone 1 at river kilometer (rkm) 6, southwest of the entrance of Ilwaco harbor, in Baker Bay, WA. The property is currently owned by Washington Department of Natural Resources. The site has developed in the past century as the bay filled in, likely due to changes in circulation from the construction of the jetties at the mouth of the Columbia River, the placement of dredge material islands at the mouth of the bay, and changes in river flows. Ilwaco Slough marsh is dominated by lush fields of Lyngby's sedge (Carex lyngbyei) with higher portions occupied by tufted hairgrass (Deschampsia cespitosa) and cattail (Typha angustifolia). Being so close to the mouth of the Columbia River, the tidal channel is regularly inundated with brackish water (average salinity < 10 Practical Salinity Units (PSU), however salinity up to 20 PSU occur in the late summer). Selected as a long-term monitoring site in 2011, Ilwaco Slough was sampled for all EMP metrics every year except 2014 when only habitat and hydrology were monitored.

View the drone flight in high res here: https://www.youtube.com/embed/LsLZmgIP0mw

Figure 2 - Ilwaco Slough, Flight performed by Sneha Rao

Mainstem and Abiotic Site Conditions by Ecosystem Monitoring Program

Welcome to the Mainstem and Abiotic Site Conditions Ecosystem Monitoring Dashboard

Developed for Bonneville Power Administration
Authors (OHSU): Joseph A Needoba, Tawnya D. Peterson
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact skidd@estuarypartnership.org

Lower Columbia Estuary Partnership

OHSU

BONNEVILLE POWER ADMINISTRATION

Overview Map

This Dashboard Provides a Brief Methods Overview and Links to all the Results Summaries: Click any of the buttons below to access more data.

Navigate to Overview Dashboard

Navigate to Habitat Structure

Navigate to Macroinvertebrate Analysis

Navigate to Food Web analysis

Navigate to Section 1 - Sampling Effort and Data Inventory

Navigate to Section 2 - Mainstem Conditions

Navigate to Section 3 - Abiotic Site Conditions

Executive Summary of Results

The 2022 water year in the Columbia River was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average flows in the early spring, and higher-than-average flows associated with the spring freshet, which peaked in mid-June.

Columbia River discharge at Bonneville Dam was close to the 2009-2022 average during the winter months; after mid-March flows were lower than average and reached minimum values for the time period in mid-April. Flows increased from early and peaked in mid-June at volumes close to the long-term maximum, observed in 2017. The decline in river discharge following peak flows was steeper than in 2017, but flow remained above average through the end of August after which they were close the long-term average. River discharge associated with the Willamette was higher than average during a few peaks in winter and spring (early January, early March, early May and early June) and was otherwise close to or below average values observed between 2009-2022.

The average daily water temperature in 2022 was average in the winter, slightly below average in the spring leading up to the freshet, average during the freshet, and higher than average after the freshet. There were 50 days having temperatures exceeding 19oC, similar to the long-term average. At the off-channel EMP sites, temperatures were highest after July at Campbell Slough and Franz Lake Slough.

Water quality was generally good at the off-channel EMP sites in 2022, with pH being in the acceptable range except at Campbell Slough after early August where values exceeded 8.5 units, alongside peaks in dissolved oxygen saturation and chlorophyll, indicating that environmental conditions were dominated by biological activity.

Management Implications:

Environmental characteristics of the shallow, EMP sites are dictated by mainstem conditions, discharge volumes, and water elevation.

- Periods of lower flows lead to evolution in habitat characteristics that sometimes result in poor water quality, including high pH, high chlorophyll, low dissolved oxygen, and pH that is outside of the acceptable range. *If poor water quality develops, elevated discharge can mitigate these conditions.*

Navigate to Food Web analysis

Navigate to Fish Communities

Citation: Kidd, S.A., Edgar, I., Rao, S., Accola, K., Cordell, J., Chittaro, P.M., Grote, J., Hinton, S.A., Needoba, J.A., Peterson, T.D., Roegner, C., Toft, J.D., Borde, A.B., Corbett, C.A., Cook, L.P., Cullinan, V.I., Fuller, R.N., Hanson, A.C., Kuligowski, D., Lomax, D., Johnson, L.L., McNatt, R., Poppe, K., Zimmerman, S.A., Ylitalo, G.M, et al. 2023. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 17 (October 1, 2021 to September 30, 2022). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

For pdf versions of these reports please click the links below:

LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

can mitigate these conditions.

- Water quality is affected by the release of water from impoundments behind the major dams; for example, discharge of large voluemes of water from Grand Coolee Dam results in transport of that water downstream and is detectable in water quality sensors. *The timing of release of water from reservoirs influences water quality downstream of the dams.*

Uncertainties:

Habitat mainstem

How might operational decisions and other mainstem habitat actions maintain and improve focal populations of anadromous fish, resident fish, and wildlife?
With several years of data exploring inter-annual and intra-annual differences in river discharge, water elevation, and water quality, the EMP is poised to begin addressing this question. Salmonid survivial and growth depends on adequate availability of food resources as well as water temperatures, flow velocities, pH, and dissolved oxygen levels. Dam operations affect the timing and magnitude of Columbia River flows, which in turn influence water elevation, exchange, and chemistry/biology. For example, in this report we link discharge associated with Roosevelt Lake behind Grand Coolee Dam to changes in river discharge, chlorophyll a concentration at EMP sites downstream of Bonneville Dam and the Willamette-Columbia confluence.

What role do changes to the historical mainstem habitat (prior to dam construction) have in changing the density-dependent responses of salmon, sturgeon, and other species (anadromous and resident)?
The multi-organizational partnership among research groups that form the EMP can help answer this uncertainty by integrating information about habitat characteristics and fish densities. Changes in Columbia River flow related to dam construction and operations have resulted in a decrease in spring flows and an increase in summer flows relative to historic values. We can address the importance of changes in discharge dynamic range and variability by examining multiple years of data and comparing salmonid stocks in the mainstem river and its off-channel habitats.

Mainstem and Abiotic Site Conditions by Ecosystem Monitoring Program

1. Sampling Effort and Data Inventory

Return to Welcome Page

Navigate to Section 2 - Mainstem Conditions

Navigate to Section 3 - Abiotic Site Conditions

The tables below (1.1 - 1.5) show the periods that YSI Water Quality sondes were deployed at EMP sites. Specifically, instruments were deployed during the following time periods in 2022:

Ilwaco: 5/8/22 - 9/28/22
Welch Island: 4/8/22 - 9/21/22
Whites Island: 4/8/22 - 9/21/22
Campbell Slough: 4/1/22 - 9/28/22
Franz Lake Slough: 4/1/22 - 8/23/22

3.2.1_Availabillity_temp_data

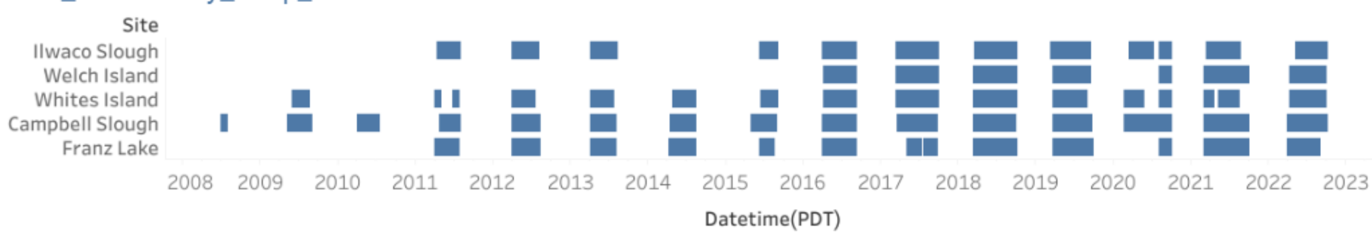


Figure 3.1 Periods of deployment of YSI water quality sondes that include temperature sensor measurements.

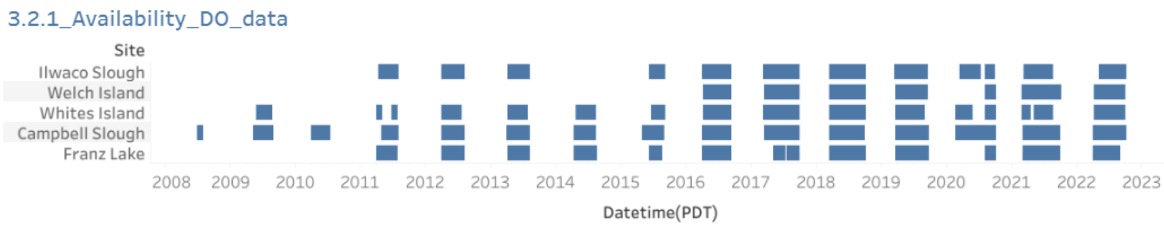


Figure 3.2. Periods of deployment of YSI water quality sondes that include dissolved oxygen (percent saturation relative to air; DO % saturation) sensor measurements.

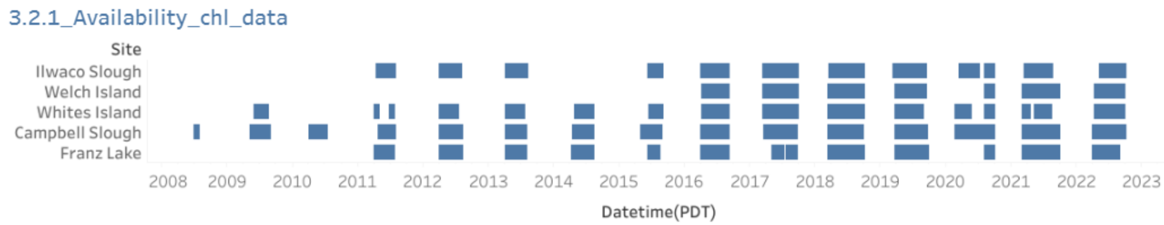


Figure 3.3 Periods of deployment of YSI water quality sondes that include chlorophyll fluorescence measurements.

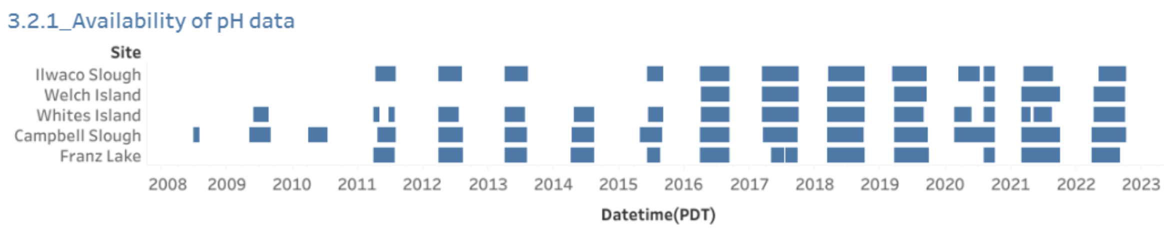


Figure 3.5 Periods of deployment of YSI water quality sondes that include pH measurements.

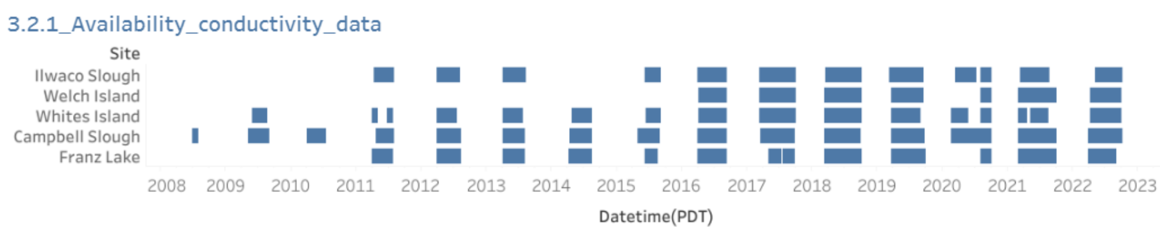


Figure 3.6 Periods of deployment of YSI water quality sondes that include conductivity measurements.

2. Mainstem Conditions

Return to Welcome Page

Navigate to Section 1 - Sampling Effort

Navigate to Section 3 - Abiotic Site Conditions

SUMMARY: 2022

River Discharge

- spring freshet was large, peaking in mid-June
- winter flows were average
- spring flow prior to the freshet were below average
- summer flows were average

River Temperature

-The number of days with average temperatures exceeding 19oC (n=55) was similar to the long-term average

River Discharge Results

The graphs below show daily averaged river discharge at Bonneville Dam, Beaver Army Terminal (River Mile 53), and the difference between the two (i.e., river discharge associated with the Willamette River, the largest tributary on the Columbia). iver discharge volumes observed in 2022 are shown in red. For comparison to other years, click on the boxes in the legends to the right of the figures.

At Bonneville Dam (i.e., Columbia River flow without contributions from the Willamette River or other tributaries downstream of the dam), river discharge was close to the 2009-2022 average during the winter months; after mid-March flows were lower than average and reached minimum values for the time period in mid-April. Flows increased from early and peaked in mid-June at volumes close to the long-term maximum observed in 2017. The decline in river discharge following peak flows was steeper than in 2017, but flow remained above average through the end of August after which they were close the long-term average.

At Beaver Army Terminal (BAT) winter flows were higher than average in January 2022, but declined to average and then below-average values from mid-January to the end of February. Aside from a peak in early March, flows were below average until early-mid May at the onset of the spring freshet. Peak flows at BAT were observed in mid-June, similar to observations at Bonneville Dam. Similar to discharge volumes at Bonneville, flows at BAT were approximately average through September.

The difference between observations at Bonneville Dam and at BAT approximates flow associated with the Willamette River. River discharge associated with the Willamette was higher than average during a few peaks in winter and spring (early January, early March, early May and early June) and was otherwise close to or below average values observed between 2009-2022.

Discussion

The 2022 water year was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average flows in the early spring, and higher-than-average flows associated with the spring freshet, which peaked in mid-June.

-The number of days with average temperatures exceeding 19oC (n=55) was similar to the long-term average

Discussion

The 2022 water year was characterized by periods of high pluvial flow associated with the Willamette River in the winter, below average flows in the early spring, and higher-than-average flows associated with the spring freshet, which peaked in mid-June.

River discharge at Bonneville Dam

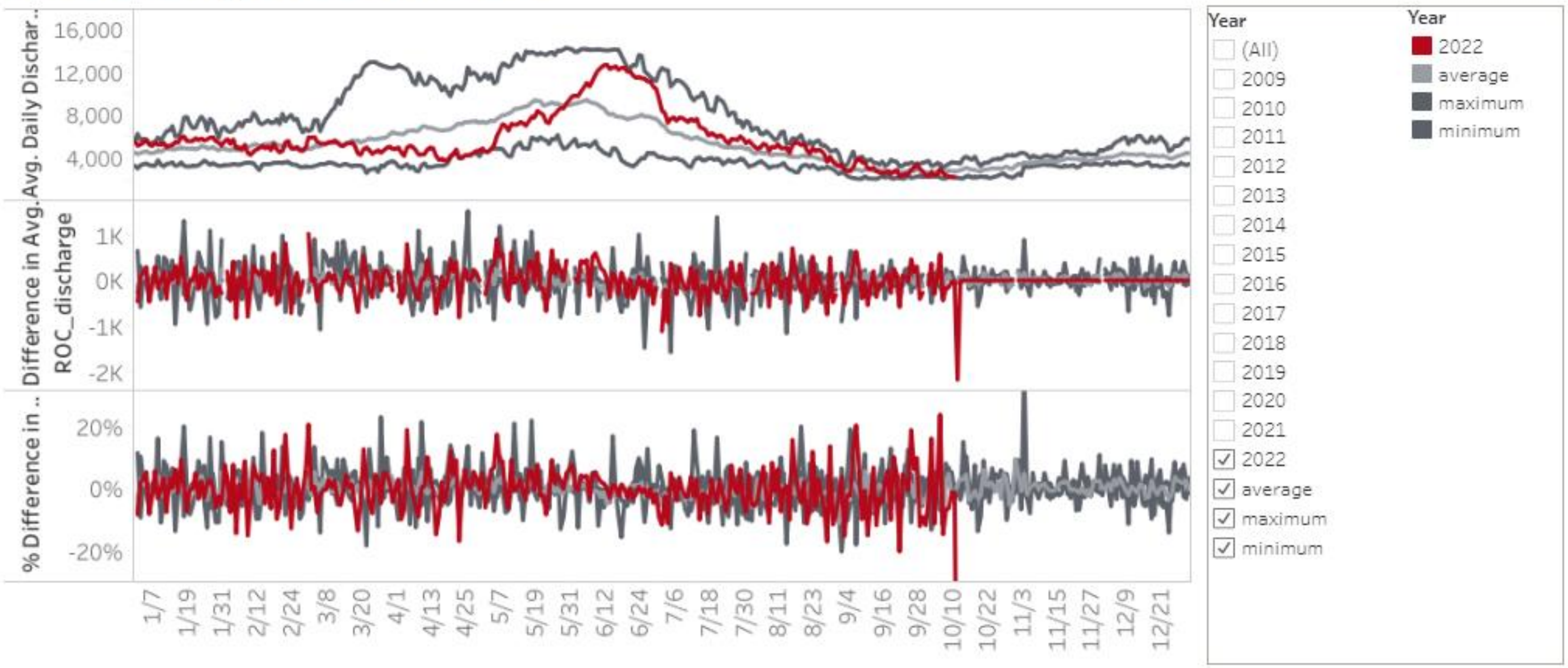


Figure 3-7. Day-to-day difference in average river discharge (m3/s) as a percentage at in 2022.

Figure 3-8. Comparison of flows (top panel) and flow variability (day-to-day change in discharge (middle panel), and percent difference from day-to-day for 2022 (red) and 2018 (teal).

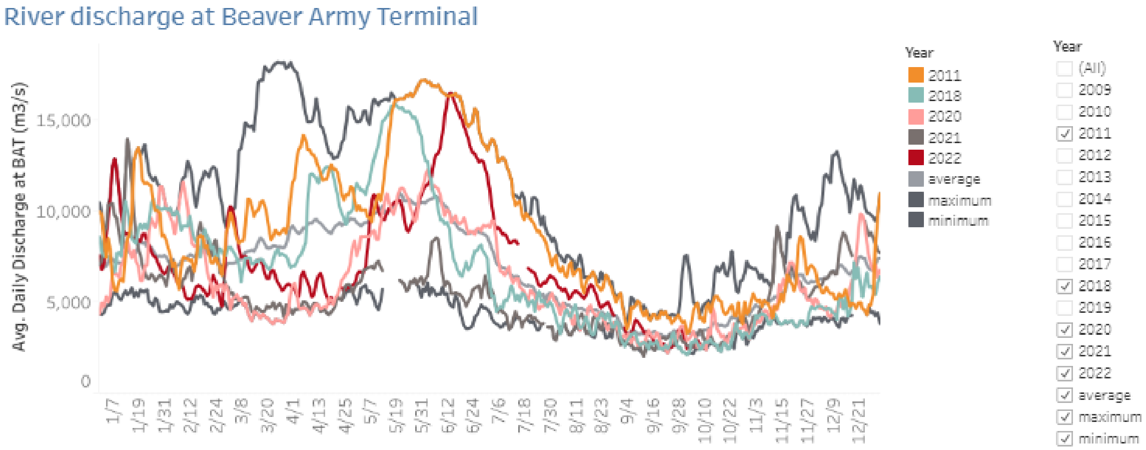


Figure 3-9. Daily average river discharge (m3 s-1) at Beaver Army Terminal (RM-53). Select year(s) to show a given year of interest. Average, Maximum, and Minimum flows can also be selected for comparison. These values were computed by calculating the average, maximum, and minimum river discharge values for a given calendar day.

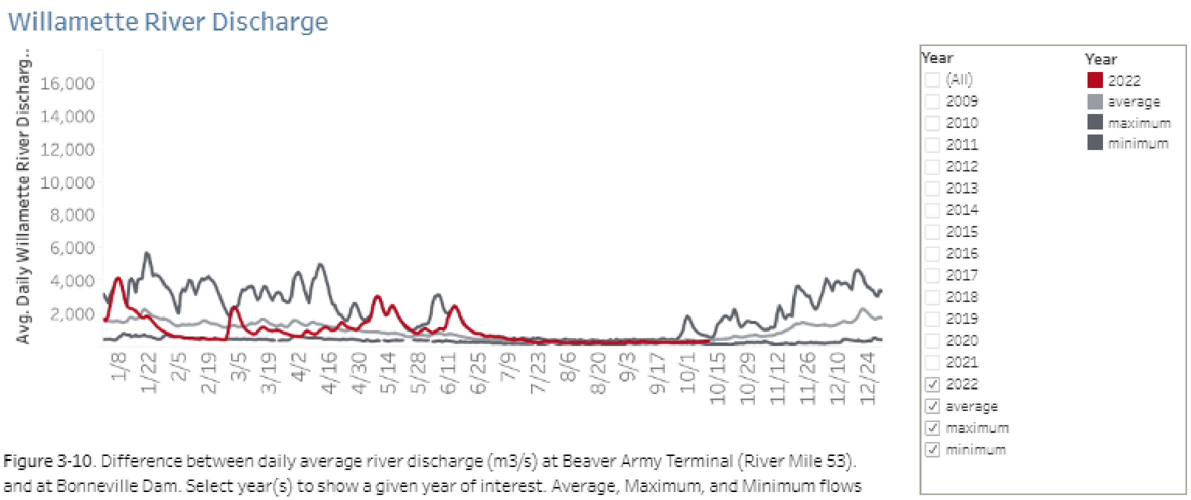


Figure 3-10. Difference between daily average river discharge (m3/s) at Beaver Army Terminal (River Mile 53). and at Bonneville Dam. Select year(s) to show a given year of interest. Average, Maximum, and Minimum flows can also be selected for comparison. These values were computed by calculating the average, maximum, and minimum river discharge values for a given calendar day.

2.2 RIVER TEMPERATURE

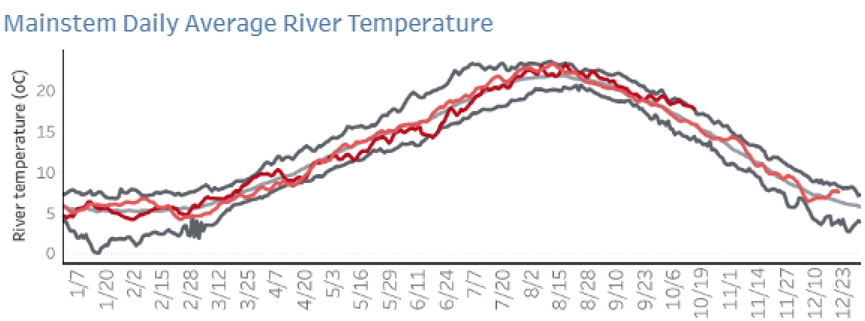
Results

Water temperatures in the mainstem Columbia River as measured by in situ sensors were close ot the long-term average (2009-2022). After early September, river temperatures exceeded the long-term average and were similar to maximum temperatures observed over the data set.

The number of days having an average temperature exceeding 19oC (n = 55) was similar to the long-term average in 2022, with a z-score of -0.18 indicating that the number of warm days was slightly below average.

Discussion

In the last several years, there have been a few years where river temperatures have exceeded 19oC, the optimum temperature for juvenile salmonid survival; these include 2015 and 2021 (Fig. 2.2.2). Aside from 2020, where river temperatures were cooler than average, years between 2015 and 2021 were generally slightly above average.



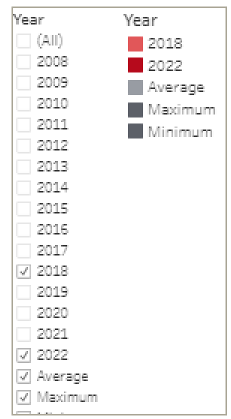
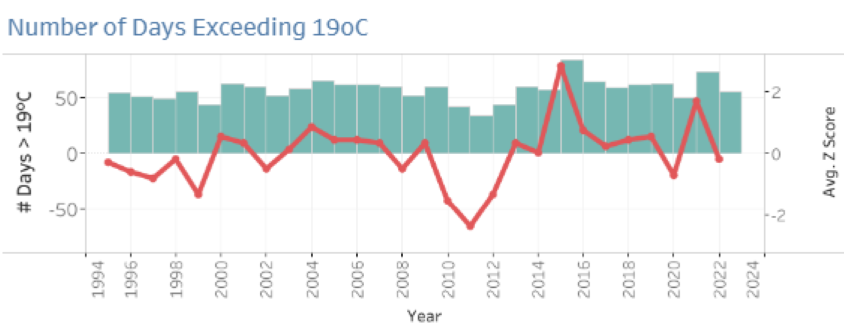


Figure 3-11. Daily average Columbia River temperature (oC). Temperature was determined from in situ sensor measurements made at Camas, WA, Beaver Army Terminal (RM-53), and SATURN observatory stations. In the Tableau Dashboard, you can toggle the year of interest to put it into context with the long-term average, maximum, and minimum daily river discharge values. Shown in this figure is the year 2022 in red.



The Z score shows the deviation from the long-term average; larger values indicate higher temperatures than normal, while negative values indicate lower temperatures than the long-term average.

Figure 3-12. Histogram showing the number of days having an average temperature of 19oC for each year between 1995 and 2022 in the Columbia River mainstem. The red line indicates the z-score for each year relative to the average over the whole time period.

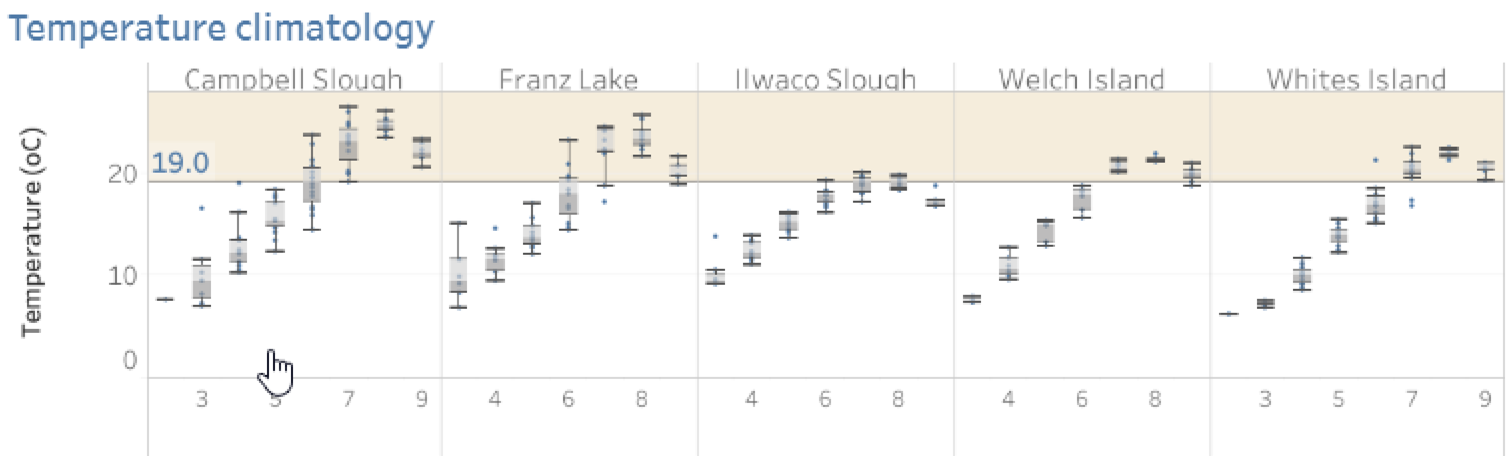


Figure 3-15. Box-and-Whisker plots showing variability in temperature by month at the EMP sites over the period of 2008-2022. The shaded area indicates temperatures above a threshold of 19oC. The data show that at Campbell Slough, Franz Lake Slough, Welch Island and Whites Island, the median monthly temperature is above 19oC for the months of July, August, and September.

Mainstem and Abiotic Site Conditions by Ecosystem Monitoring Program

3. Abiotic Conditions at EMP Sites

Overview Map

Return to Welcome Page

Navigate to Section 1 - Sampling Effort

Navigate to Section 2 - Mainstem Conditions

WATER QUALITY METRICS

Current Site Selected: **Franz Lake**

Overall Results: Water temperature at Franz Lake Slough approached 28 oC in late July-early August. Temperatures increased from the end of the spring freshet in mid-June to the maximum in late July-early August. Conductivity peaked in mid-July, early than at the other EMP sites, with minimum values observed in late May. pH values never exceeded the range of acceptable water quality standards; however, there were a number of observations where values were lower than 7.0: lower-than-acceptable values were observed in mid-June, early and late July, and early and late August. Chlorophyll a concentrations were generally acceptable, with a peak exceeding 15 ug/L on May 19th.

Action Guide: Click on a site within the map to toggle between sites. Click on a site in the legend to highlight it across the page.

3.3.2_Temperature_sites

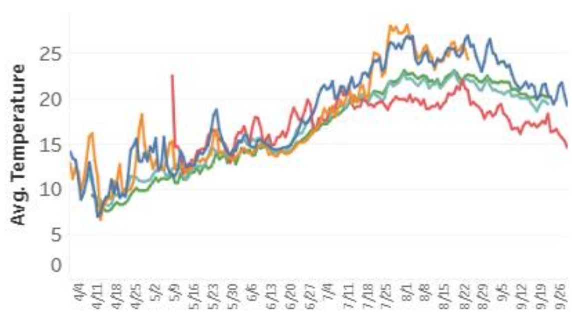


Figure 3-13. Daily average Columbia River temperature (oC) at the five EMP sites (Ilwaco, Welch Island, Whites Island, Campbell Slough, and Franz Lake Slough).

3.3.2_Conductivity

Figure 3-21. Daily average specific conductivity at EMP sites in the Lower Columbia River in 2022.

3.3.2_pH

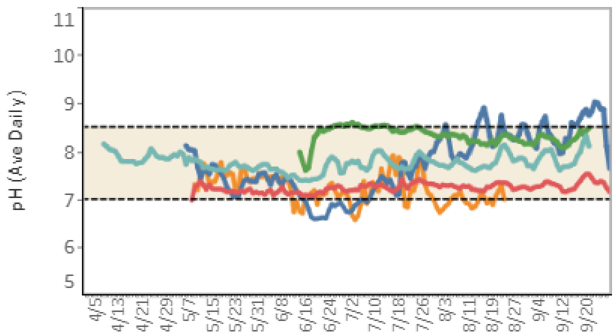


Figure 3-17. Time series of daily averaged pH values measured by in situ sensors at five EMP trend sites: Ilwaco Slough, Welch Island, Whites Island, Campbell Slough, and Franz Lake Slough. Water quality is considered acceptable when pH values are between 7.0 and 8.5 units (Washington Department of Ecology). The range of acceptable pH values is indicated in the shaded area.The current plot shows pH values at the five EMP sites in 2022; in Tableau, the user can select different years of study for comparison among sites, or else choose one site to compare multiple years.

3.3.2_Chlorophyll ug/L

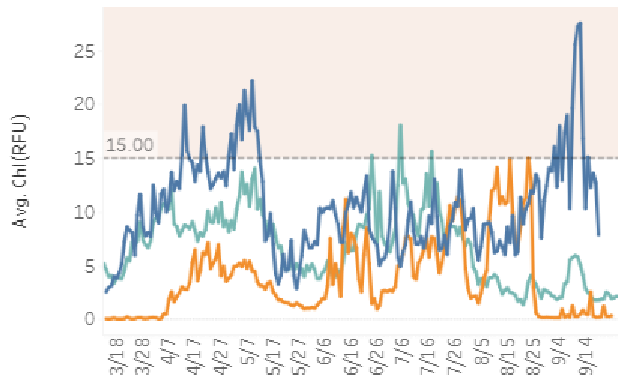


Figure 3-20. Time series of chlorophyll a data measured using in situ fluorometers at EMP sites in 2021. RFU = Relative Fluorescence Units. Consecutive monthly measurements above 15 µg L-1 are indicative of poor water quality; this benchmark is indicated by a dashed line.

3.3.2_DO Percent Saturation

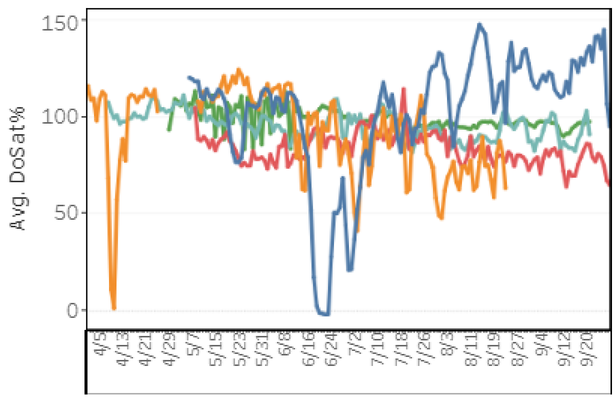


Figure 3-19. Time series of daily average dissolved oxygen percent saturation (DO Sat%) at five EMP sites in 2022: Ilwaco Slough, Welch Island, Whites Island, Campbell Slough, and Franz Lake Slough.

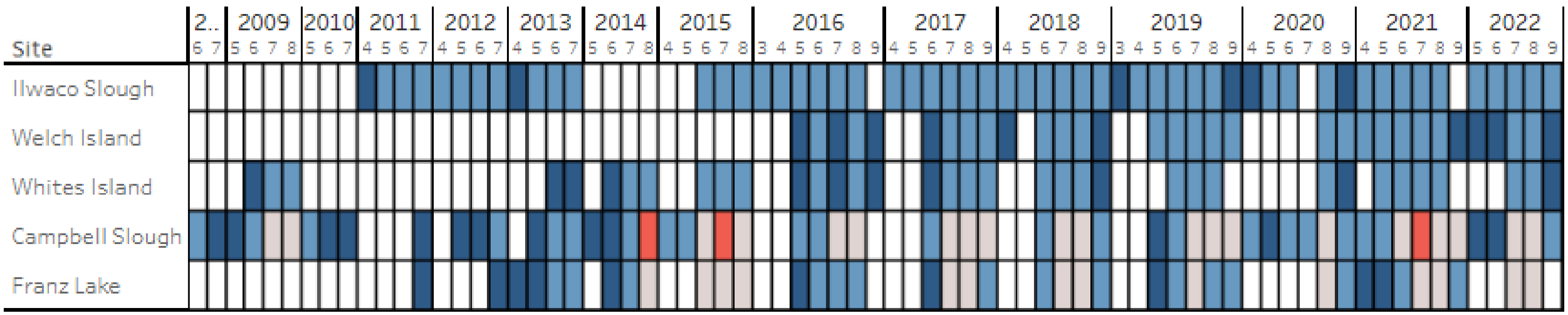
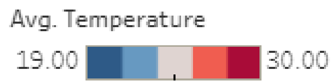


Figure 3-14. Heat map showing the mean daily temperatures averaged by month at each of the EMP sites from 2008 to 2022. Warmer colors indicate higher average temperatures; cooler colors indicate average monthly temperatures at or below 19oC.



Welcome to the Habitat Metrics Ecosystem Monitoring Dashboard

Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information, please contact skidd@estuarypartnership.org

Lower Columbia Estuary Partnership

BONNEVILLE POWER ADMINISTRATION

Overview Map

This Dashboard Provides a Brief Methods Overview and Links to all the Results Summaries: Click any of the buttons below to access more data.

Navigate to Overview Dashboard

Navigate through the Habitat Dashboard by Clicking on the Sections Below

Navigate to Section 1 - Sampling Effort and Data Inventory

Navigate to Section 2.0 - Hydrology

Navigate to Section 2.1 - Sediment Accretion and Erosion

Navigate to Section 2.2 - Soil Development

Navigate to Section 2.3 - Vegetation Development

Navigate to Section 2.4 - Biomass Analysis

Executive Summary

In 2022, habitat conditions remained relatively stable compared to long-term average conditions, with plant cover maintaining consistent abundances across key areas, including Ilwaco Slough, Welch Island, Whites Island, and Franz Lake, adhering to historical, long-term averages. Yet, Cunningham Lake saw an ongoing increase in plant cover, indicating a likely recovery from heavy cattle grazing documented in 2017. Meanwhile, Campbell Slough presented a minor increase in total cover levels this year. Despite this, overall cover at Campbell remains low compared to non-grazed conditions due to persistent cattle grazing since 2017. Previous fencing efforts aimed at mitigating this issue have proven unsuccessful. To aid future analysis and generate data less affected by grazing, we introduced new transects at Campbell Slough in 2021.

In the last decade, the six most common plant species identified throughout the tidal estuary (across the trend sites) are *Phalaris arundinacea* (non-native), reed canarygrass, *Carex lyngbyei* (native), lyngby sedge, *Eleocharis palustris* (native), common spikerush, *Sagittaria latifolia* (native), wapato, *Leersia oryzoides* (native), rice cut grass, and *Ludwigia palustris* (native), water purslane. It's important to note that while these species have been frequently found, they're not necessarily present at all sites each year. Recently, *P. arundinacea* cover has stayed more or less steady when compared to prior years, yet Cunningham and Franz Lake have witnessed a noticeable rise. This could be a result of relatively low flooding conditions in recent times, and in the case of Cunningham Lake, a decrease in grazing pressure. Findings suggest that variations in *P. arundinacea* cover levels are closely associated with river discharge levels and site water levels during the growing season. Lower water levels tend to encourage *P. arundinacea* growth and abundance, indicating that annual flooding conditions play a crucial role in determining the annual variability in this species' dominance.

The long-term abundance trends of native species such as *Carex lyngbyei, Sagittaria latifolia, and Polygonum amphibium* are similarly tied to annual river discharge conditions. Generally, *C. lyngbyei* abundance increases in years with greater freshet and discharge levels, particularly in areas like Ilwaco Slough. *S. latifolia* and *P. amphibium* have shown a lagged response to freshet and river discharge conditions, with a decrease in discharge leading to an increase in these species' abundance in the following year. This could be due to the improved growing conditions (low water levels) leading to increased stores for future growth.

Navigate to Mainstem and Abiotic site conditions

Navigate to Food Web analysis

Navigate to Macroinvertebrate Analysis

Navigate to Fish Communities

Citation: Kidd, S.A., Edgar, I., Rao, S., Accola, K., Cordell, J., Chittaro, P.M., Grote, J., Hinton, S.A., Needoba, J.A., Peterson, T.D., Roegner, C., Toft, J.D., Borde, A.B., Corbett, C.A., Cook, L.P., Cullinan, V.I., Fuller, R.N., Hanson, A.C., Kuligowski, D., Lomax, D., Johnson, L.L., McNatt, R., Poppe, K., Zimmerman, S.A., Ylitalo, G.M, et al. 2023. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 17 (October 1, 2021 to September 30, 2022). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

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LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM
ANNUAL REPORT

Methods for all data collection can be found here: Kidd, S., I. Edgar, S. Rao, and A. Silva (Eds.). 2023. Protocols for Monitoring Juvenile Salmonid Habitats in the Lower Columbia River Estuary. Portland, Oregon: Lower Columbia Estuary Partnership. Click link below:

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS
IN THE LOWER COLUMBIA RIVER ESTUARY

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH
ANNUAL REPORT

Management Implications

Non-native species can pose risks to native species (e.g., increasing competition for resources, predation, the introduction of disease, reducing biodiversity, altering ecosystem function). For example, reed canarygrass (*Phalaris arundinacea*) is known to out-compete native wetland plants, and above-ground biomass data indicate that this species does not contribute the same quantity and quality of macrodetritus to the system as native species (Cordell et al. 2023). Wetland plant distribution is highly dependent on elevation and hydrology, thus vegetation community structure and % cover can vary from year-to-year based on river discharge patterns. Long-term vegetation monitoring in emergent wetlands offers valuable information to managers seeking to control non-native plant species by helping them predict how vegetation at a recently restored site will respond to annually fluctuating river flows. These data are especially critical when trying to evaluate if restoration actions used to control *P. arudinacea* have been successful or if *P. arudinacea* abundances are changing due to natural variability.

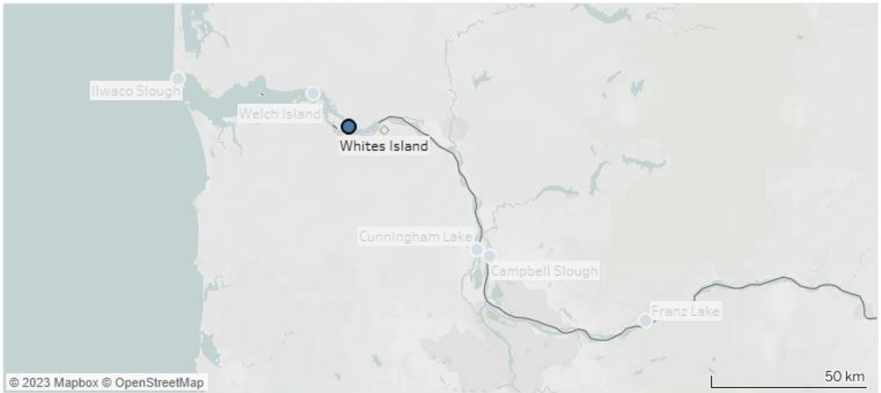
Uncertainties

What is the importance of decomposition of organic matter by microbial organisms in determining its quality for salmon prey? Microbial decomposition often results in "trophic upgrading", whereby less labile compounds are transformed through microbial metabolism to compounds that are more easily assimilated. How are these processes influenced by water chemistry, temperature, and nature of the organic matter (e.g., non-native vs. native plant species)?

How do pulses in primary production from different sources vary in space and time, and how does this influence secondary production and salmon food webs? The timing of availability of different sources of organic matter produced through primary production varies between pelagic phytoplankton and marsh vegetation. It would be helpful to compare the magnitude of these stocks to identify patterns that could inform food web models. In addition, pulse events, such as the production and deposition of pollen, could produce reservoirs of organic matter originating from vascular plants in the water column that is independent of detritus transport.

Water Surface Elevation and Temperature

Overview Map



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Navigate to Section 1 - Sampling Effort and Data Inventory

Navigate to Section 2.1 - Sediment Accretion and Erosion

Navigate to Section 2.2 - Soil Development

Navigate to Section 2.3 - Vegetation Development

Navigate to Section 2.4 - Biomass Analysis

Summary: Water surface elevation (WSE), water depth, and water temperature data were collected in 1 hour intervals at Whites Island.

The hydrology of Whites Island (rkm 72) is influenced by tidal action as well as periods of prolonged freshets. Annual maximum WSE measurements for 2021 were observed in January with smaller peaks occurring in May and June. These elevations coincide with king tide duration for that month, as well as, peak flow durations of the Columbia in 2021.

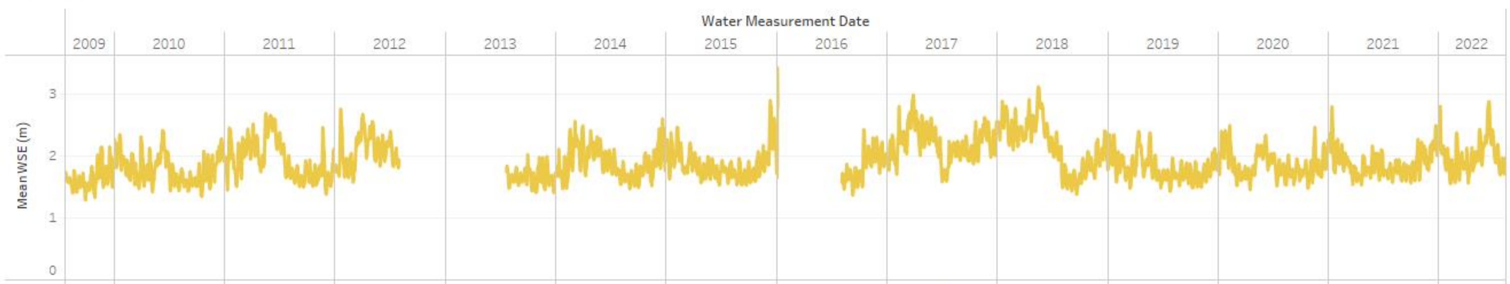
Interactive Data: Click on a site within the map to adjust the content on this page (use ctrl+click to select multiple sites). Toggle monitoring years on/and off (check the box) to see how any one specific monitoring location shifted through the years. Keep scrolling to the bottom of this dashboard to see a summary of habitat opporunity results for the same time period.

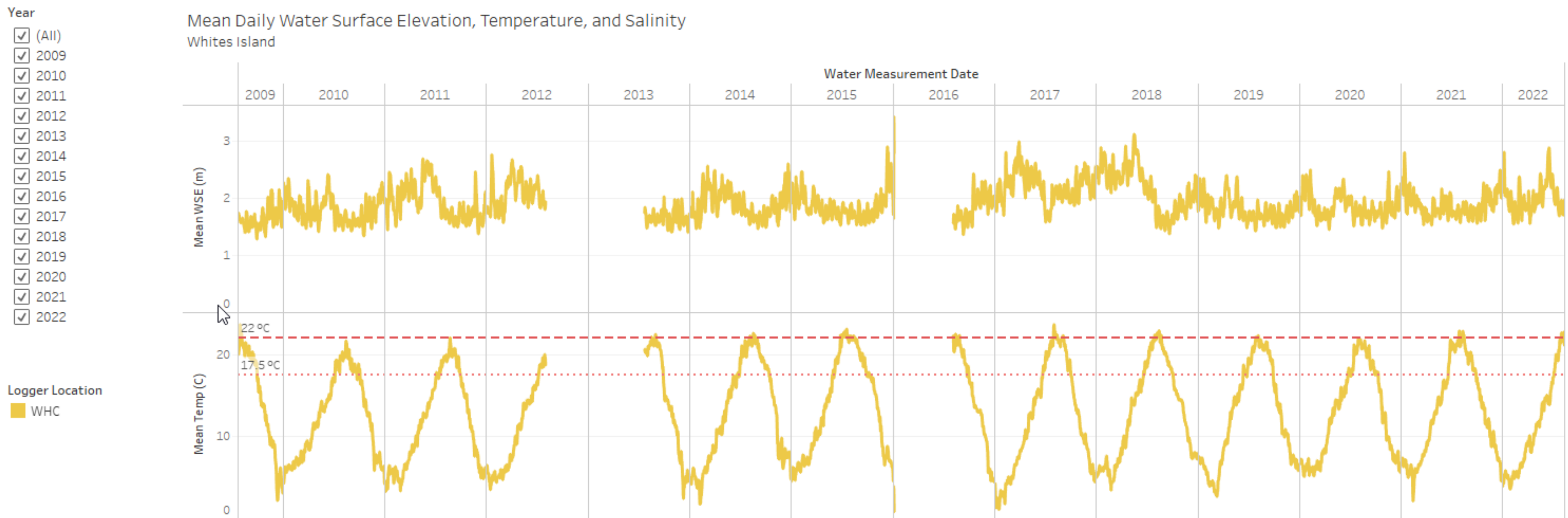
Year

- ☑ (All)
- ☑ 2009
- ☑ 2010
- ☑ 2011
- ☑ 2012
- ☑ 2013
- ☑ 2014
- ☑ 2015
- ☑ 2016
- ☑ 2017
- ☑ 2018
- ☑ 2019
- ☑ 2020
- ☑ 2021
- ☑ 2022

Mean Daily Water Surface Elevation, Temperature, and Salinity

Whites Island

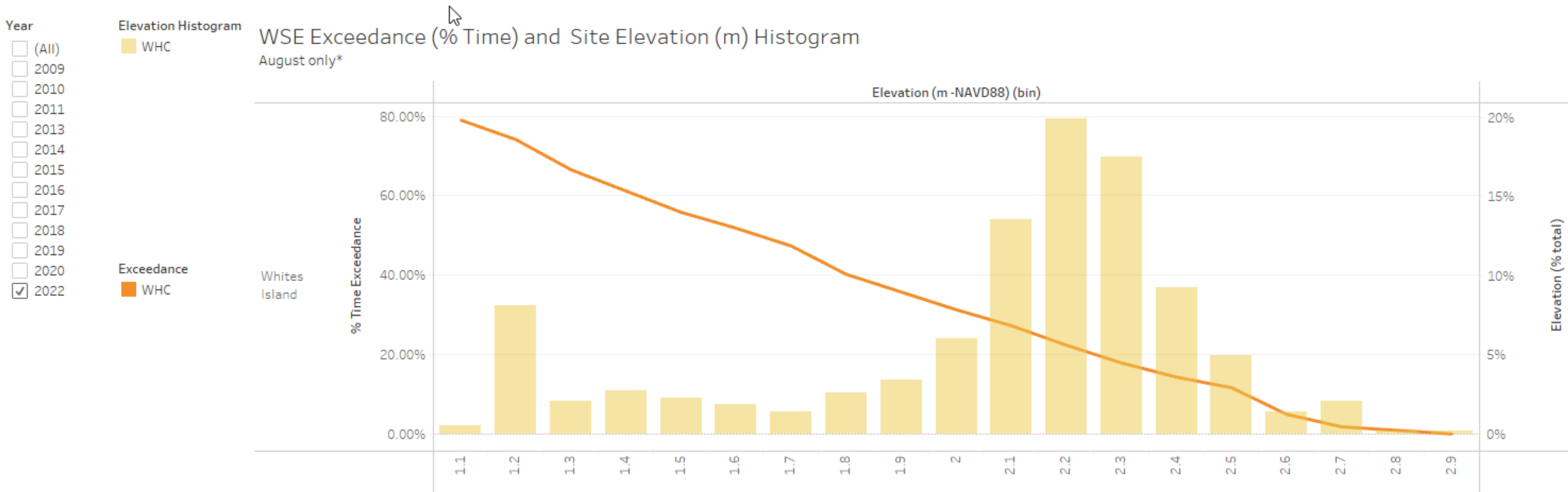




Year
(All)
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Logger Location
WHC
Mean Daily Water Surface Elevation, Temperature, and Salinity
Whites Island
Water Measurement Date
Mean WSE (m)
Mean Temp (C)
22 ºC
17.5 ºC

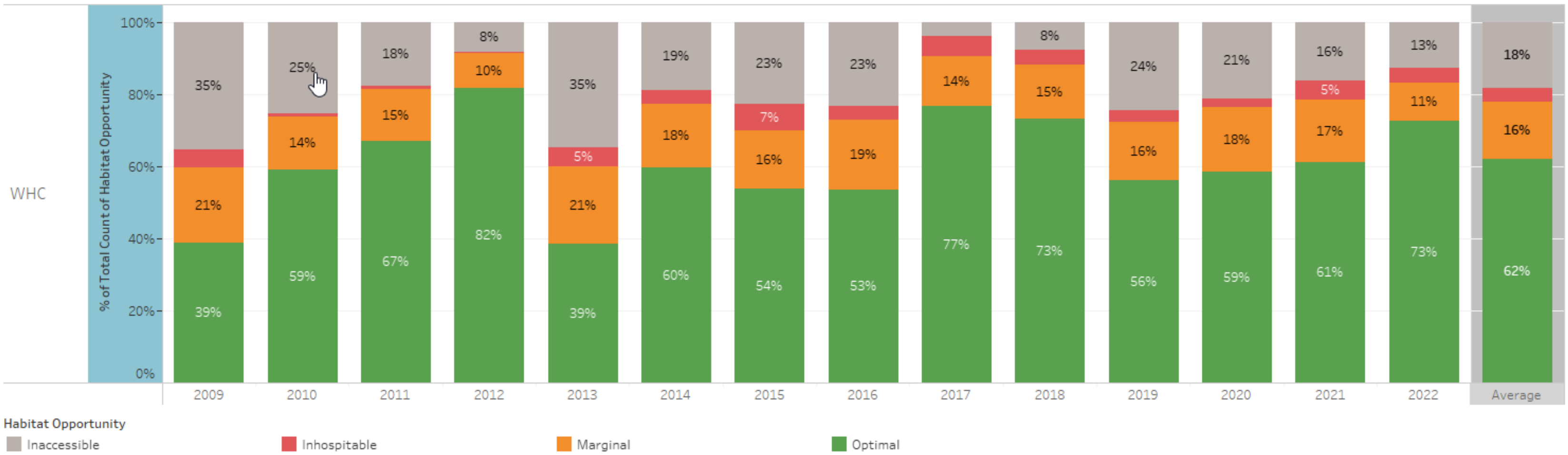
Exploring the Data:
To assess the flood exposure of specific site elevations, utilize the filters provided below. These allow you to modify the time period considered in the "% time exceedance analysis". This analysis represents the percentage of time when recorded water levels spanned the site's elevation range. Included is a histogram depicting the distribution of site elevations. This visual aid provides a clear representation of where along the elevation gradient our vegetation data was collected. To focus on specific data categories, simply click an item in the legend.

Why This Matters:
The flooding exposure across varying site elevations isn't just an interesting hydrological phenomenon; it carries profound ecological implications. The frequency and duration of flooding at different elevations can greatly influence soil composition, nutrient availability, and vegetation growth. Some plant species are more tolerant of prolonged inundation, while others thrive in areas less frequently submerged. Moreover, we've observed that the seasonality in the Columbia River's flow patterns corresponds with these flood exposures. The river's flow, in tandem with shifts in dominant species like reed canarygrass and wapato, further shapes the wetland's ecological composition and functioning. These site elevation ranges and associated flooding frequencies (% Exceedance) thus serve as key determinants for both soil quality and vegetation development across the wetland ecosystem.



Annual Habitat Opportunity (% of time, hourly data)

Toggle years above to see how conditions change overtime. Hover over a bar graph to view the number of days of data for that year. The furthest right column is the overall average habitat opportunity over the extent of the timeseries.



Salmonid Habitat Opportunity

Analysis: Habitat Opportunity was adapted from previously established analyses and is defined by the depth and temperature of water that is considered ideal for salmonid access and utilization (Bottom et al. 2011, Schwartz and Kidd et al. 2018). Juvenile Salmonids require ≥0.5 m of water depth above the channel or wetland surface for habitat access and we have defined depths of < 0.5 m of depth inaccessible to fish passage/use. In addition to the required water depths, water temperature ranges were used to define optimal, marginal, and inhospitable habitat conditions as follows; optimal conditions require a water temperature of less than 17.5 °C, marginal conditions were defined by water temperatures greater than 17.5 °C but less than 22 °C, and water temperatures greater than 22 °C were defined as inhospitable to salmonids (Schwartz and Kidd et al. 2018). For this analysis, we used the hourly mean water depth and temperature data to calculate the % of each year that these habitats were both accessible to salmonids and the water temperatures were in the ideal, marginal or inhospitable ranges, at the location of monitoring.

Developed for Bonneville Power Administration

Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

Major Contributors (Columbia River Estuary Study Taskforce): April Silva, Narayan Elsmar

Lower Columbia Estuary Partnership

Sediment Accretion and Erosion

Overview Map

Campbell Slough

Marsh Location
- High Marsh
- Low Marsh

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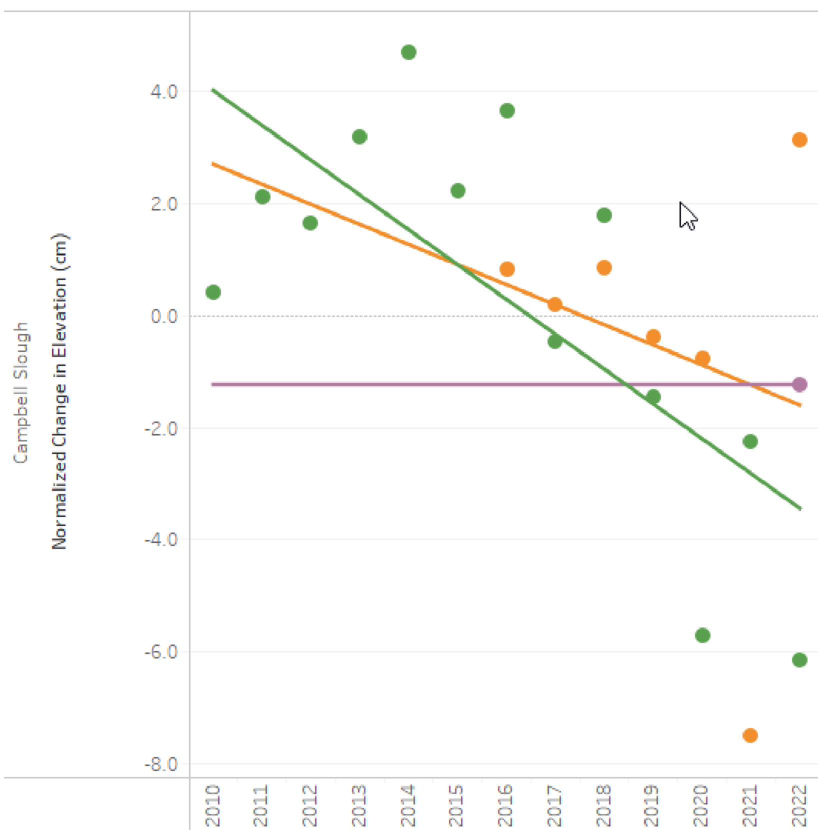
Click the image below to see learn more about our large-scale Sediment Accretion and Erosion Monitoring effort for the Estuary.

Summary: Normalized change in elevation is the amount of elevation gained (accretion) or loss (erosion) from the first year of the survey period. Average Net Accretion is the rate at rate at which this change takes place in cm/yr. See all the data below.

Interactive Data: Click on a site within the map to adjust the content on this page (use ctrl+click to select multiple sites).

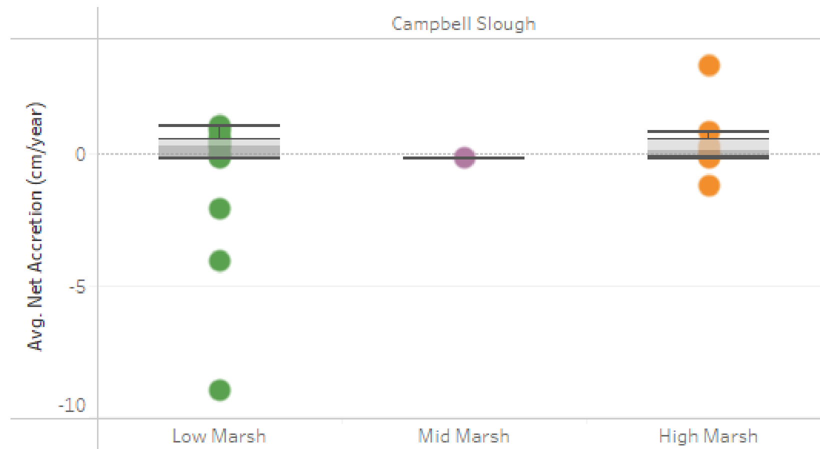
Marsh Location
High Marsh
Low Marsh

Campbell Slough
Marsh Location - Site Accretion and Erosion- Trends Over-time



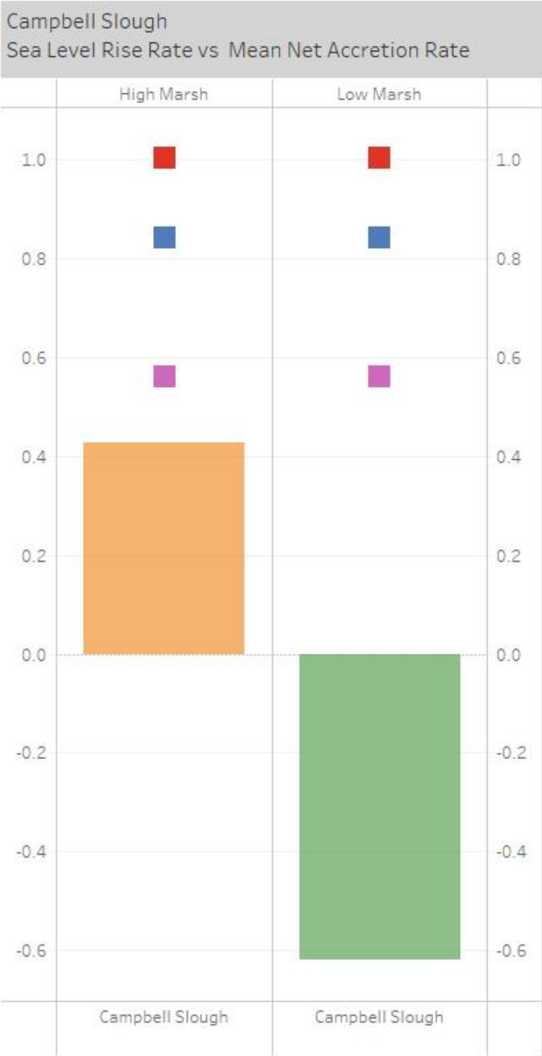
Interactive Data: Click on a site within the map to adjust the content on this page (use ctrl+click to select multiple sites).

Campbell Slough
Marsh Location - Site Accretion and Erosion - Accretion Rate (cm/yr)



High vs. Low Marsh Sediment Accretion and Erosion

Results: Average sediment accretion or erosion rates at the five trend sites generally ranges from –6 to 6 cm per year. Note that Campbell Slough and Cunningham Lake both have large bovine populations, causing largely increased erosion and variability year to year. Of sites without cattle grazing, Franz Lake high marsh stakes had the highest rate of average erosion, with greatest variability (FLM-2: -0.47±1.32 cm), which has been a consistent trend since installation of these stakes in 2015. Campbell slough showed large rates of erosion, likely this is attributed to cattle grazing and repeated trampling of the site. Sedimentation stakes installed in Whites Island low marsh displayed the maximum accretion rate (1.86 ± 1.28 cm). It should be noted that accretion and erosion rates in the long-term dataset are accompanied by high degree of variability.



Keeping Pace with Sea Level Rise

Understanding how our tidal wetlands and floodplains are keeping track with Sea Level Rise (SLR) is critical for considering how future restoration and management actions can address further potential wetland loss. For this preliminary analysis, we have used the USACE's 2020 Lower Columbia River Adaptive Hydraulics (AdH) Model Scenarios (Link to USACE model report here: https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/36295/1/ERDC-CHL%20TR-20-6.pdf).

These Scenarios (50, 75, and 100 yr) are slightly more aggressive (greater rates of change) than the Miller et al. 2018 model (https://wacoastalnetwork.com/research-and-tools/slr-visualization/) which focuses on the Oregon and Washington Coast. However, they do provide a glimpse into how well our reference and restoration sites may be keeping up with increases in Water Surface Elevation across each reach of the Lower Columbia. **Further refinement of this analysis is forth coming.** Note that it has been well established in the literature that sediment accretion rates can be greater during the first few years of restoration – and then stabilize long-term (e.g., Roman & Burdick 2012).

For more analysis of SLR impacts to wetland across the LCR using the same model scenarios see our online report here: https://lcep.maps.arcgis.com/apps/webappviewer/index.html?id=90de906767444d3b97cebf7491c1d74d

Burdick, David M., and Charles T. Roman. 2012. "Salt Marsh Responses to Tidal Restriction and Restoration." The Science and Practice of Ecological Restoration. Island Press/Center for Resource Economics. http://www.springerlink.com.proxy.lib.pdx.edu/content/p70568084lmv5463/abstract/.

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Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao
Major Contributors (Columbia River Estuary Study Taskforce): April Silva, Narayan Elsmar

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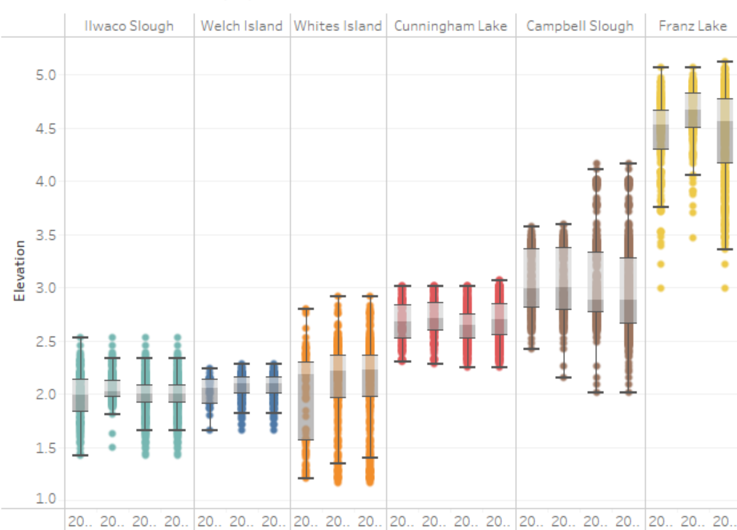
Soil Development

Overview Map

Site
Campbell Slough, Franz Lake, Welch Island, Cunningham La.., Ilwaco Slough, Whites Island

Sampling Elevation (m)



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Navigate to Section 2.4 - Biomass Analysis

Research Overview and Significance: Our research is focused on unraveling the intricate ecological processes that determine plant community dynamics in tidally restored wetlands and in reference sites like the EMP sites. Before restoration, many agricultural sites had soils that were well-drained and oxygen-rich. By reintroducing tidal actions, these soils are saturated, transitioning them into an anaerobic or oxygen-deprived wetland environment. In areas of the estuary with higher salinity, this change is also marked by altered salt levels. Such transitions induce a series of interconnected biogeochemical and microbial changes in the soil, shaping the way plant communities form and grow.

Using specialized tools, like soil ORP (oxygen reduction potential), pH, and salinity/conductivity probes, we observe these biogeochemical alterations across different sites, both restored and reference sites, such as those under the EMP, within the Lower Columbia River Estuary. Our observations reveal crucial details, such as the conditions that foster the spread of Reed canarygrass (Phalaris arundinacea), a plant that predominantly thrives in soils with specific pH, salinity, and ORP levels.

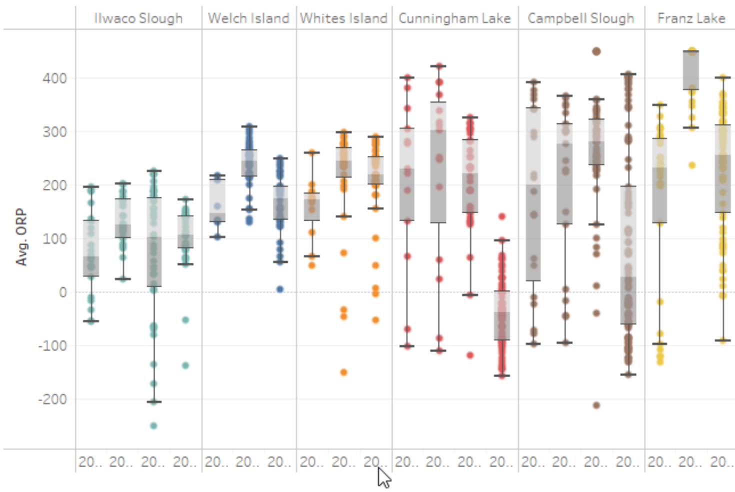
The Value of Reference Data: Reference sites, like those under EMP, hold immense value for our understanding. These sites present a benchmark, showcasing the natural mechanisms at play within undisturbed wetlands. By monitoring soil conditions here, we can gain insights into the inherent drivers of plant community and habitat changes. This baseline knowledge not only deepens our comprehension of tidal wetland ecosystems but also enhances our capability to evaluate the outcomes of tidal wetland restoration projects. Through this, we are better positioned to design restoration initiatives that are more effective and harmonious with the natural balance of these ecosystems.

Data Collection Insights: It's worth noting that while we strive for consistency, the amount of data we gather from different sites varies based on factors like environmental conditions and the reliability of our equipment. Our dedication to soil sampling sometimes faces challenges due to time constraints or equipment hitches in the field, especially during intensive habitat monitoring sessions.

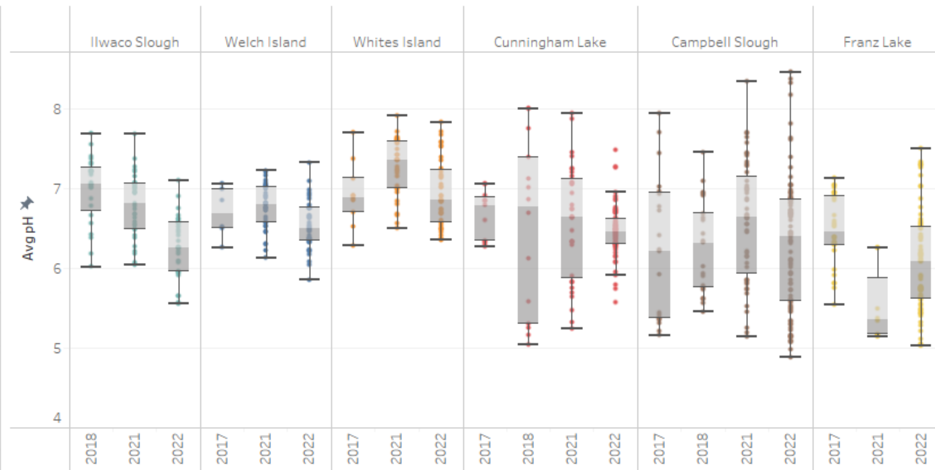
Why Should We Care About Soil? Soil is the canvas upon which wetland habitats are painted. Restoring natural tidal actions to previously modified agricultural lands brings significant shifts in soil properties, paving the way for wetland plant communities to flourish. As we navigate through our research journey, our keen interest is to understand these dynamic soil changes over time. For those keen to delve deeper, references like Kidd 2017 provide a scholarly yet accessible perspective on the importance of soil monitoring in tidal wetland restoration. Additionally, a visual summary of our findings can be found in our recently produced poster – click on the blue title below.

Tracking Soil Dynamics to Understand Plant Community Development in Restored Tidal Wetlands

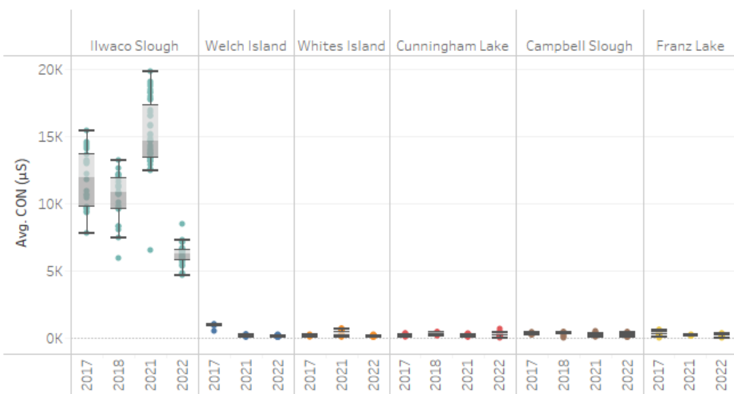
ORP



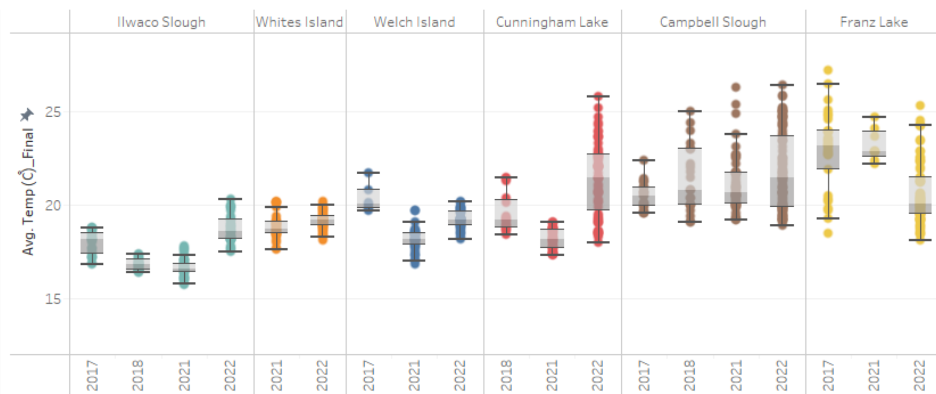
pH



Conductivity



Tempurature



Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao
Major Contributors (Columbia River Estuary Study Taskforce): April Silva, Narayan Elsmar

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Plant Community Development

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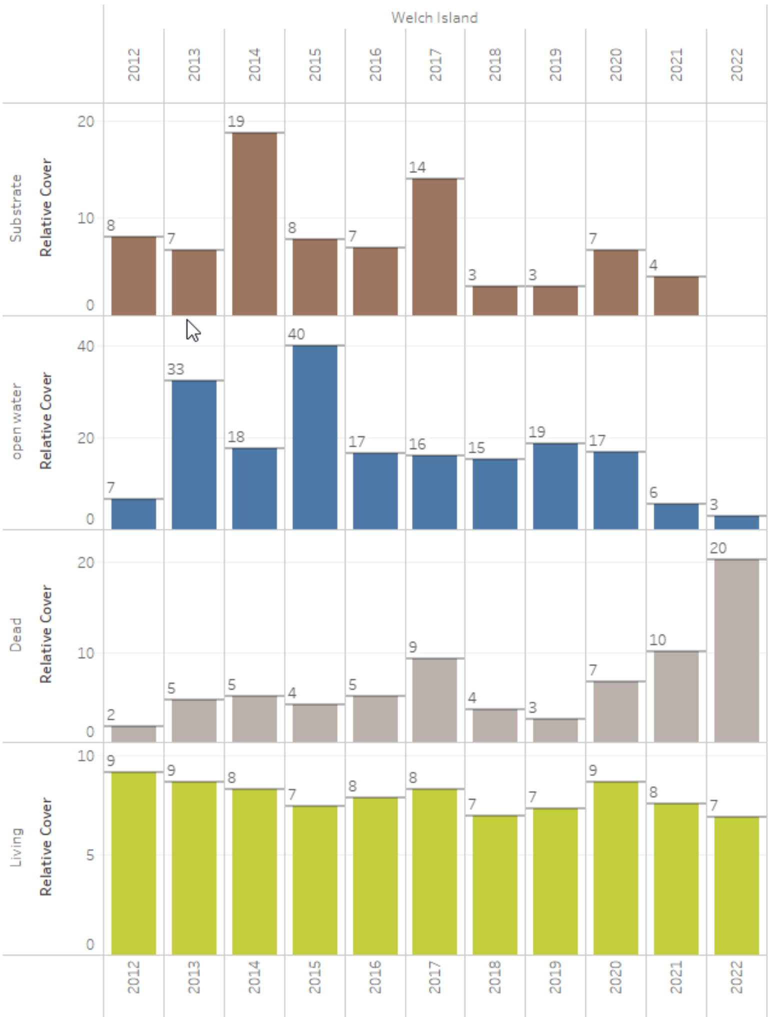
Summary: At each site, we surveyed vegetation cover and composition. This assesses changes to habitat structure related to restoration actions. Vegetation cover and composition is an indicator of the production of organic matter and the detritus produced by decaying vegetation forms the base of the food web for many species in the lower Columbia River and estuary (Borde et al. 2010, Maier and Simenstad 2009). Vegetation plot elevation was recorded to track the influence of marsh elevation on invasive vegetation abundance, local hydrology and native plant species growth.

Vegetation surveys across the estuary sites reveal stable plant cover in most locations, though Cunningham Lake shows recovery from past cattle grazing. Over a decade, six primary species, including the non-native *Phalaris arundinacea* and natives like *Carex lyngbyei*, dominate the estuary. Growth patterns for these plants correlate with the Columbia River's discharge levels, affecting their dominance. For instance, *C. lyngbyei* thrives in high discharge years at Ilwaco Slough due to lower salinity. In contrast, *S. latifolia* and *P. amphibium* display delayed growth responses. **Further analysis comparing hydrology, biomass, soil conditions, and plant cover dynamics across sites is underway.**

Welch Island Relative Cover by Habitat Type



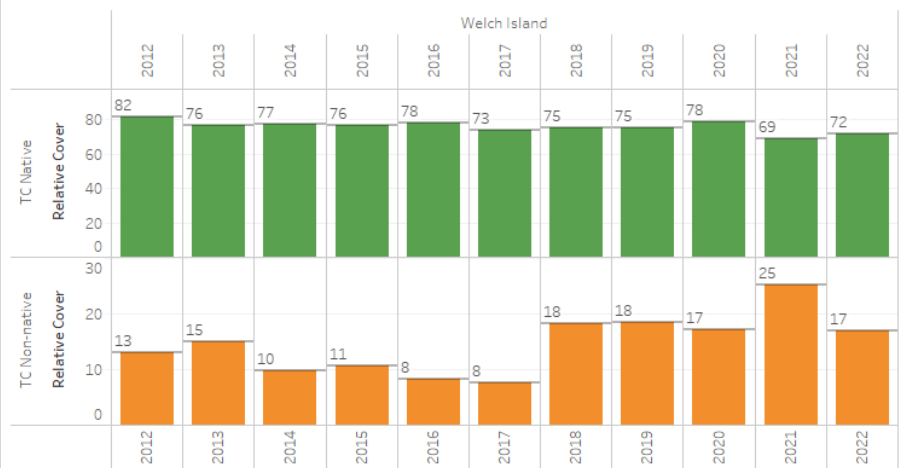
Welch Island Relative Cover by Species and Status

Cover of species and substrate common across EMP sites

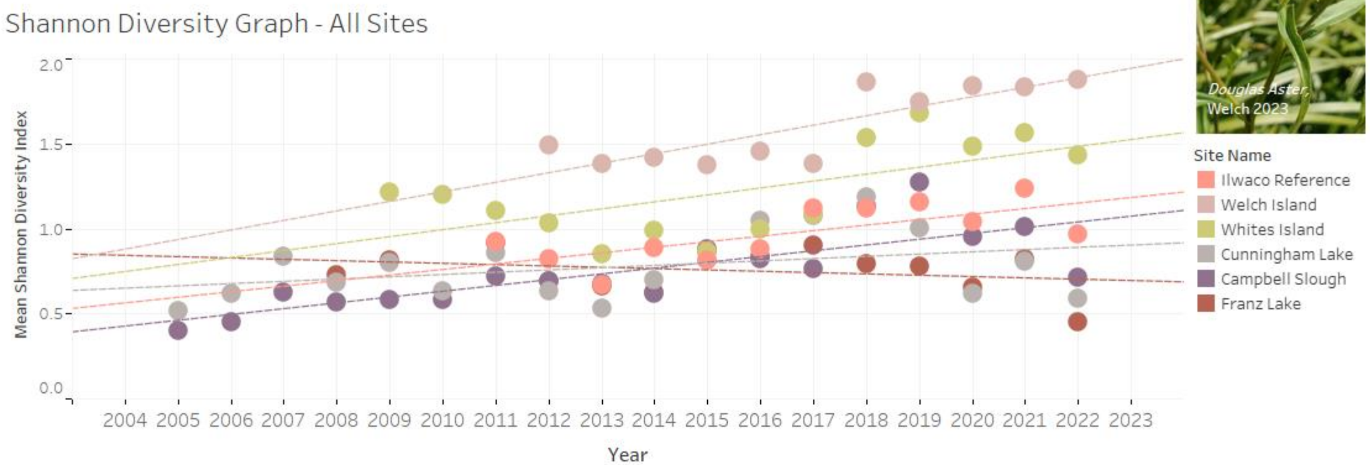
	Longterm Avg	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Carex lyngbyei	38	28	28	29	32	35	48	46	41	40	48	48
open water	21	3	6	17	19	15	16	17	40	18	33	7
Phalaris arundinacea	19	8	14	31	14	11	17	31	22	20	65	33
bare ground	10		4	7	3	3	14	7	8	19	7	8
Eleocharis palustris	7	9	7	6	9	6	9	8	7	7	4	7
Sagittaria latifolia	7	7	7	9	6	5	5	8	9	7	7	7
Ludwigia palustris	6											6
Agrostis stolonifera L.	3	1	3	2	4	3						
Leersia oryzoides	2	2	2	2	2	3	2	2	2	2	2	3
Deschampsia cespitosa	2	1	2	2	2	3	3	1	2	1	1	

Status: Native, Non-native, Substrate

Welch Island Relative Cover By Native Status



In general, species diversity has been increasing yearly with the greatest diversity at Welch Island and the least diversity at Cunningham Lake. Additionally, species diversity is impacted by episodic heavy grazing at Campbell Slough and Cunningham Lake. The most notable shift in diversity was observed at Franz Lake, where dramatic increases in *Polygonum amphibium* and bare ground were observed in 2022, as well as a long-term increase in *Phalaris arundinacea*. These conditions have shift from the influence of not only the Columbia shifting flows but also local beaver dam influences on the site's hydrology and have led to a reduced number of species observed in 2022. (Click on the map at the top of the dashboard to see shifts in plant community conditions across each site)



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Biomass Dashboard

Overview Map

Welch Island Biomass Plot Locations

Dominant Species (Codes)

CALY ELPA PHAR

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Summary:
Our comprehensive above-ground biomass sampling, stratified by season and year, offers a detailed representation of dominant plant species in both the high and low marsh zones. Since 2017, we've expanded our scope to include detritus sampling, aiming to assess detrital production and its ecological implications. From 2018-2022, we've augmented this with rigorous testing, capturing nutrient content from living biomass and decomposing detritus. This covers vital components such as nitrogen, carbon, ADF lignin, and a plethora of essential minerals from calcium to zinc.
These rich datasets serve a dual purpose:

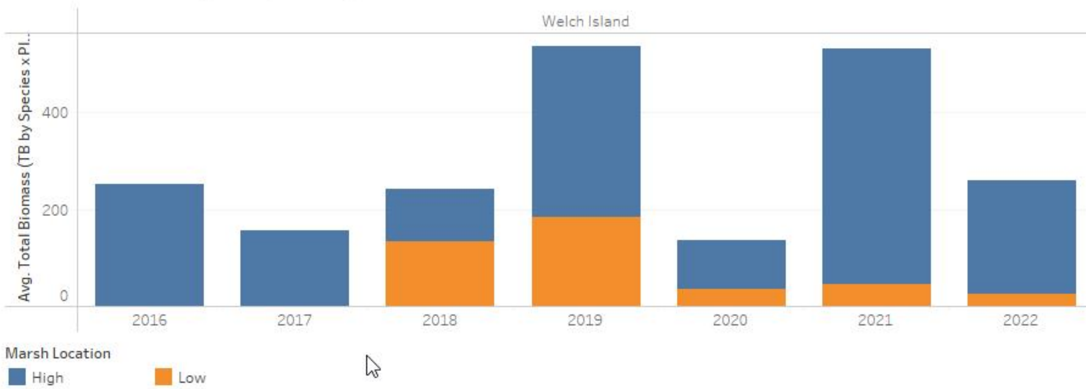
Insight into Food Web Dynamics: By gauging the nutrient composition and availability in vegetation, we can infer the potential energy and nourishment available for macroinvertebrates. This becomes particularly relevant when we consider the variation in nutrient composition across different plant species and their states (living, dead, or detritus). For instance, certain species may provide more energy-rich detritus, benefiting specific macroinvertebrates, and influencing their abundance and role in the broader food web.

Role of Dominant Plant Species & Environmental Drivers: Recognizing the nutritional value and productivity patterns of dominant species allows us to predict their impact on local ecosystems. The consistency observed in high marsh productivity juxtaposed against the more dynamic low marsh, which is sensitive to river hydrology, reveals the nuanced responses of these ecosystems to environmental drivers. Factors like Beaver dam flooding at Franz Lake exemplify how external drivers can markedly influence both marsh zones, affecting not just plant productivity but also the consequent energy flow through the food web.

These insights are instrumental in deepening our understanding of the intricate ecological interplays and helping formulate strategies to protect and restore these vital habitats. As we continually refine our data set, more in-depth analyses will soon be shared.

Interactive Data: Click on a site within the upper map to dive deeper into the details of each plot sampled in 2022. Biomass is a story of not just quantity, but also quality, and the multifaceted roles it plays in underpinning and driving diverse ecological networks.

Welch Island - Dry Weights High Low



Welch Island - Dry Weights Species

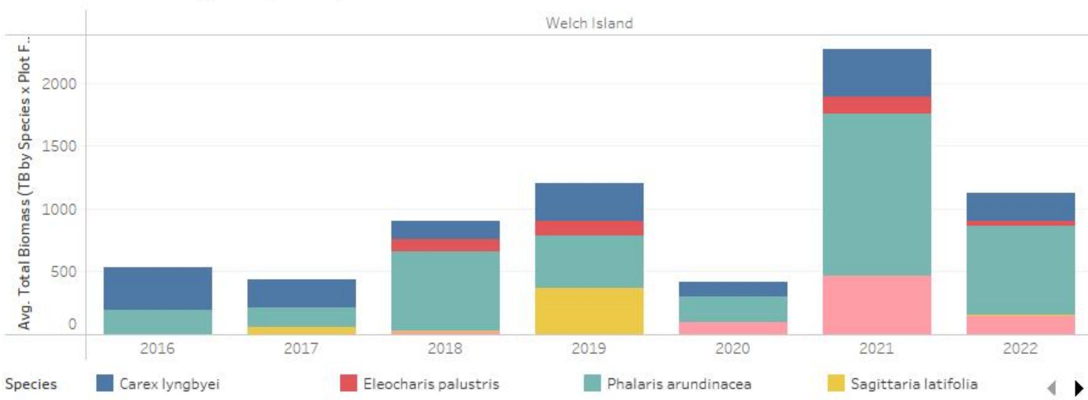
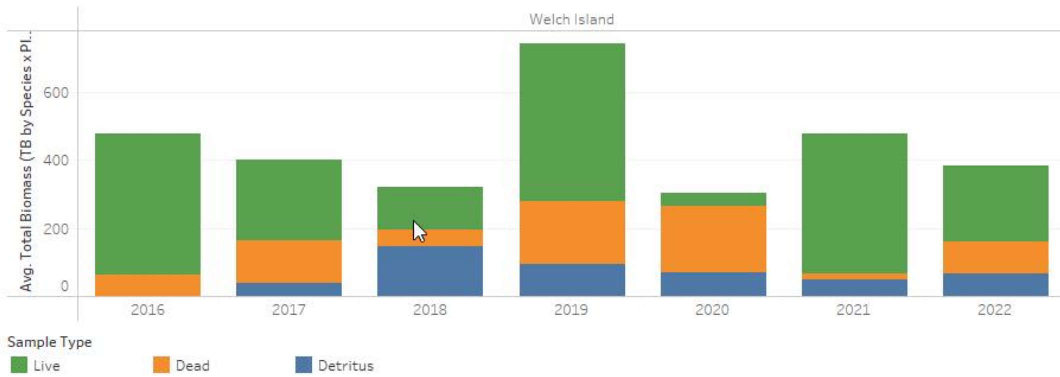


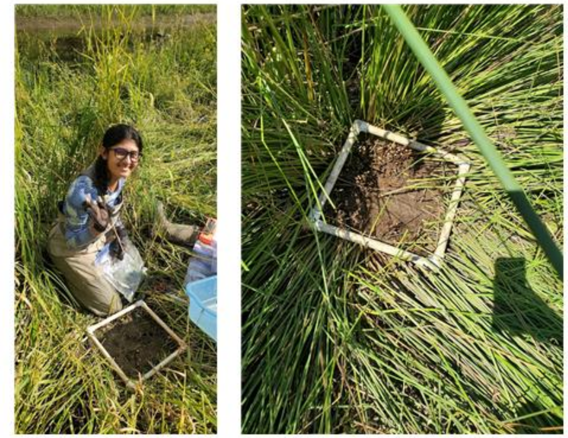
Image above of biomass monitoring in *Polygonum amphibium* at Franz Lake (2022)

Plant Community Summary: At Welch Island, the high marsh biomass species stratification remained similar to the long-term abundances, dominated by *Carex lyngbyei*, native, and *Phalaris arundinacea*, non-native; however, the low marsh biomass samples at Welch Island shifted to being dominated completely by *Eleocharis palustris*, native. At Steamboat Slough, the high marsh samples remain fairly consistent to previous years, being dominated by both *Juncus effuses*, non-native, and *P. arundinacea*. Conversely, the low marsh biomass samples at Steamboat Slough has shifted to being dominated by *Sagittaria latifolia*, native. Whites Island biomass sampling has seen a large increase in *Myosotis sp.* and an increase in *C. lyngbyei*, native. The low marsh biomass samples at Whites Island are dominated by E. palustris and C. lyngbyei. The Franz Lake high marsh biomass sampling also remained similar to long-term averages of *P. arundinacea* and *Polygonum amphibium*, native. The low marsh biomass sampling at Franz Lake is focused on *S. latifolia* dominated areas.

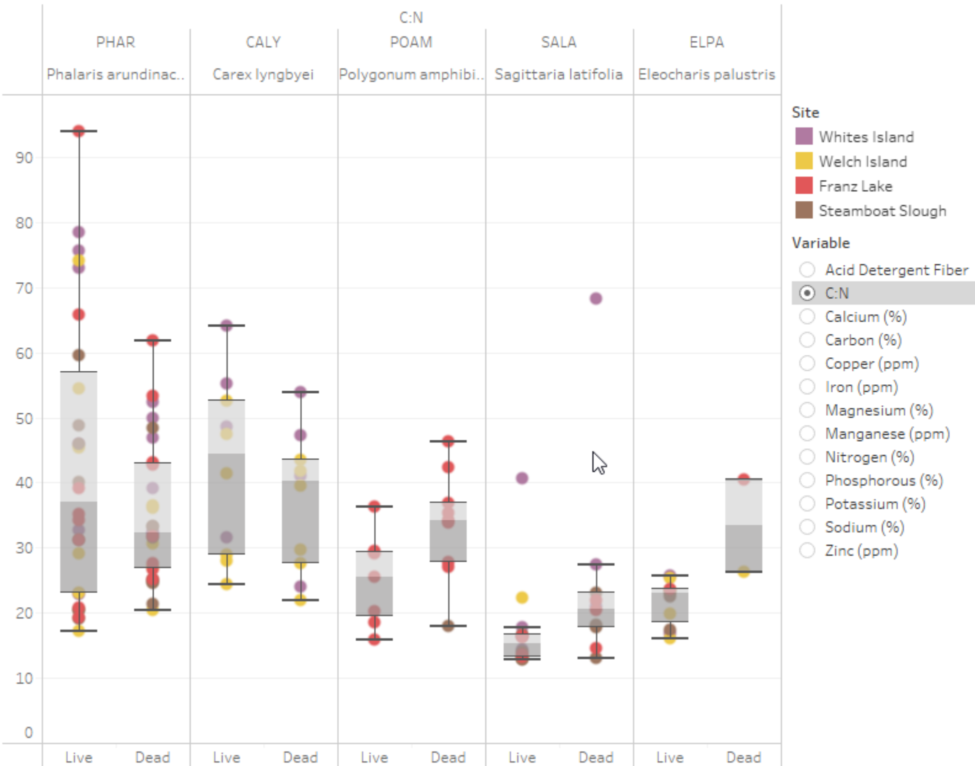
Welch Island - Dry Weights Living Dead



Images below Biomass sampling at Whites (left) with Sneha Rao sampling in *Carex lyngbyei*, native, and Steamboat Slough (right) in *Juncus effusus*, non-native



Above Ground Living vs. Dead Biomass Chemical Analysis
C:N By Dominant Species Across Sites



Exploring Nutrient Dynamics in Wetland Vegetation:
Wetland vegetation plays a pivotal role in ecosystem function, not just through its presence, but also through its nutrient content. Beginning in 2018, we took a deep dive into this, examining both living biomass and detritus samples. Our analysis captures a wide spectrum of nutrients: from primary elements like nitrogen and carbon, which are crucial for plant growth and energy storage, to ADF lignin, which affects plant decomposition rates. Furthermore, we've also assessed a range of essential minerals, including Calcium, Copper, Iron, Magnesium, Manganese, Phosphorus, Potassium, Sodium, and Zinc. Each of these elements plays a unique role in plant health, ecosystem dynamics, and the broader food web.

If you're new to nutrient content in plants, here's a brief primer:

Nitrogen & Carbon: Fundamental building blocks for plants, crucial for growth and energy. Their ratio can influence herbivore feeding patterns and decomposition rates.

ADF Lignin: A measure of plant's structural components that are less easily decomposed. Higher lignin often implies slower decomposition and lesser immediate nutrient release into the ecosystem.

Essential Minerals: These influence plant health, resistance to diseases, and can also dictate the nutritional value of the plant for consumers in the food chain.

The data presented integrates our leaf and stem sample outcomes for each species. As further investigations unfold, we will segregate these insights, unveiling significant distinctions amongst these species and between the high and low marsh zones of the examined wetlands. In particular, *Phalaris arundinacea* and *Carex lyngbyei* display contrasting leaf chemistries. Carex lyngbyei leaves, endowed with a richer nutrient profile and reduced carbon and lignin content, decompose more rapidly than those of *Phalaris arundinacea*. Similarly, species like *Sagittaria latifolia* possess a notably high nutrient concentration, leading to swift decay and minimal residual detritus. Understanding these differences in decomposition rates and nutrient content is crucial, as they directly influence wetland food web dynamics, shaping the availability of resources for various trophic levels and ultimately determining ecosystem health and functionality.

Developed for Bonneville Power Administration
Authors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact skidd@estuarypartnership.org

Lower Columbia Estuary Partnership

Welcome to the Plankton Ecology and Juvenile Salmonid Food Web Monitoring Dashboard

Developed for Bonneville Power Administration

Authors (OHSU): Tawnya D. Peterson, Joseph A. Needoba
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

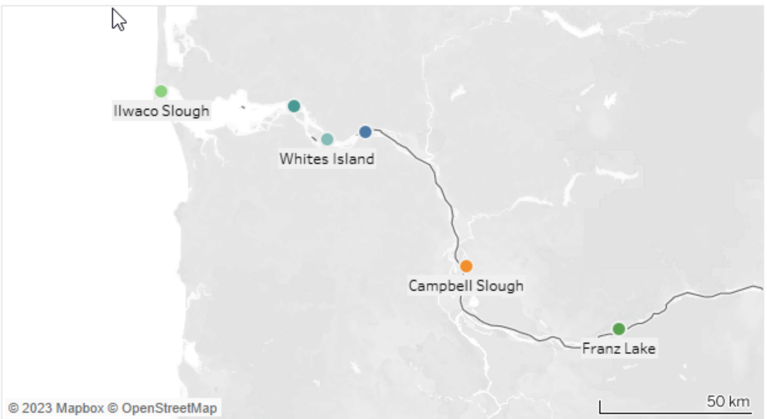
For more information, please contact skidd@estuarypartnership.org

Lower Columbia Estuary Partnership

OHSU

BONNEVILLE POWER ADMINISTRATION

Site Map



This Dashboard Provides a Brief Methods Overview and Links to all the Results Summaries: Click any of the buttons below to access more data.

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Navigate to Habitat Structure

Navigate to Macroinvertebrate Analysis

Navigate to Fish Communities

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Navigate to Section 2 - Nutrients & Chlorophyll

Navigate to Section 3 - Phytoplankton

Navigate to Section 4 - Zooplankton

Navigate to Section 5 - Stable Isotopes

Executive Summary of Plankton Results

Nutrient concentrations in 2021 were highest between February and April, particularly in the Columbia River mainstem, Whites Island, and Franz Lake Slough, where nitrate approached 30 µM, similar to most years. Algal biomass in terms of chlorophyll a was within an acceptable range (i.e., either <15 µg L^{-1} or 25 µg L^{-1}, depending on the water quality criterion used) for most EMP sites during the spring and summer in 2021 and 2022; however, values were greater than or close to 30 µg L^{-1} on two occasions at Franz Lake Slough in 2021. Since a body of water is only considered impaired when the threshold is exceeded in observations from three consecutive months, no site met this criterion. Total algal biomass, as estimated by concentrations of chlorophyll *a*, tends to be highest in March or April, prior to the spring freshet, at Welch Island and Whites Island; in contrast, the highest algal biomass at Campbell Slough and Franz Lake Slough is usually observed in July-August. Campbell Slough and Franz Lake Slough are prone to the development of algal blooms in the summer months, which often discolor the water.

In general, the relative proportion of diatoms at the EMP trends sites is higher in the spring compared to summer, when chlorophytes and cyanobacteria made significant contributions to the total assemblages. High relative proportions of diatoms are associated with high concentrations of dissolved oxygen at the EMP sites. In addition, diatom growth is associated with nutrient drawdown and are indicative of good water quality. Diatoms tend to dominate in the spring months, where populations can get quite large; most of the annual growth of phytoplankton occurs in the spring and is accomplished by diatoms.

Zooplankton assemblages differ along the spatial gradient from Ilwaco Slough to Franz Lake Slough and over time from early spring to summer. Ilwaco Slough is consistently dominated by copepods, with inputs from rotifers, but very few cladoceran taxa. At the other sites, copepods generally dominated the zooplankton assemblages. At Welch Island and Whites Island, there is an increase in the proportional contribution by cladocerans from spring to summer, while densities are more variable over seasons at Franz Lake Slough and Campbell Slough.

Stable isotope signatures of carbon and nitrogen were determined for juvenile salmon tissues, primary producers, and prey items. The data set is growing for salmon tissue, organic matter sources, and prey, which is necessary for building food web models in a highly variable ecosystem. According to a Bayesian Inference stable isotope mixing model, phytoplankton carbon contributes to the juvenile salmonid food web as part of the diet of chironomid prey, based on stable isotope signatures of carbon; this carbon is incorporated as particulate organic matter and as periphyton. Models looking at how different sources of primary production contribution to additional prey sources are being investigated as more data are gathered, but analysis thus far suggests that periphyton constitutes an important source of organic matter for the preferred prey of juvenile salmonids (i.e., amphipods and chironomids). Estimates of dietary contributions from different prey items inferred from stable isotope mixing models suggest that juvenile salmonid growth is supported by amphipods, chironomids, and other crustacean prey, which is consistent with observations derived from stomach analysis.

Isotopic values of carbon in particulate organic matter (δ13C-POM) collected onto filters revealed δ13C signatures in the typical range of freshwater phytoplankton most of the time, with values closer to terrestrial vascular plants in May and June at Campbell Slough and Franz Lake Slough. δ13C-POM at Ilwaco was closer to marine values. When the samples from EMP trend sites were grouped according to whether they came from years with low, moderate, or high cumulative discharge (very dry, dry, moderate, wet), there were significant differences in average δ13C, but not in δ15N.

Citation: Kidd, S.A., Edgar, I., Rao, S., Accola, K., Cordell, J., Chittaro, P.M., Grote, J., Hinton, S.A., Needoba, J.A., Peterson, T.D., Roegner, C., Toft, J.D., Borde, A.B., Corbett, C.A., Cook, L.P., Cullinan, V.I., Fuller, R.N., Hanson, A.C., Kuligowski, D., Lomax, D., Johnson, L.L., McNatt, R., Poppe, K., Ylitalo, G.M, Zimmerman, S.A., et al. 2023. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 17 (October 1, 2021 to September 30, 2022). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

For pdf versions of the reports please click on the links below:

LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH ANNUAL REPORT

Uncertainties:

Uncertainty: ***How will climate change affect the LCRE ecosystem, and restoration strategy and what actions could be taken to mitigate for adverse effects?***

The long-term data collected as part of the EMP allows us to relate differences in hydrologic conditions, temperature, and nutrient cycling with juvenile salmon distributions and condition. Climate change affects ecosystem attributes, including the volume and timing of discharge, atmospheric (and therefore water) temperatures, and patterns of precipitation, all of which influence primary productivity. Over the years we have documented the development of algal blooms in shallow habitats during the summer months, as well as the relationship between algal biomass and phytoplankton and zooplankton composition on discharge patterns and temperature.

Uncertainty: ***How does water management in the Columbia River basin influence habitat-forming processes, habitat conditions, and connectivity between the mainstem and floodplain wetlands in the LCRE and, thereby, the accessibility and capacity of these habitats to support juvenile salmon? What actions could be taken to mitigate adverse effects?***

The EMP data can be used to show how water level and river discharge influence conditions in the shallow, off-channel sites used by juvenile salmonids. During analysis of recent data, we showed that release of reservoir water from Lake Roosevelt in the spring results in a discernible difference in water quality in the lower Columbia River EMP sites (for example, a dilution of algal biomass observed as a decline in chlorophyll concentration).

1 Sampling Effort and Data Inventory

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Navigate to Section 3a - Phytoplankton

Navigate to Section 3b - Site Specific Look

Navigate to Section 4 - Zooplankton

Navigate to Section 5 - Food web modeling

Overview of Sampling Effort and Data Inventory

Nutrients are determined in discrete samples collected at EMP sites (Ilwaco, Welch Island, Whites Island, Campbell Slough, Franz Lake Slough) and at sites in the mainstem river, including Beaver Army Terminal (BAT, RM-53), Camas (at the Port of Camas-Washougal, WA), and between Welch and Whites Islands in the Columbia River. Nitrate, phosphate, nitrite, silicic acid, and ammonium are measured colorimetrically and reported in micromol/liter.

Phytoplankton abundance is estimated in two ways: (1) from pigment concentrations (i.e., chlorophyll *a*), and (2) by direct counts using inverted light microscopy. Phytoplankton abundance can be estimated by measuring the concentration of chlorophyll *a*, a photosynthetic pigment that is common to all types of phytoplankton. Surface water samples were collected into two 1 L brown HDPE bottles and sub-sampled prior to processing. A subsample of water (typically between 60–300 mL) was filtered onto a 25 mL glass-fiber filter (GF/F) for chlorophyll *a* and kept frozen (-80ºC) pending analysis. Chlorophyll *a* was determined fluorometrically using a Turner Designs Trilogy fluorometer using to the non-acidification method, which is highly selective for chlorophyll *a* even in the presence of chlorophyll b (Welschmeyer 1994).

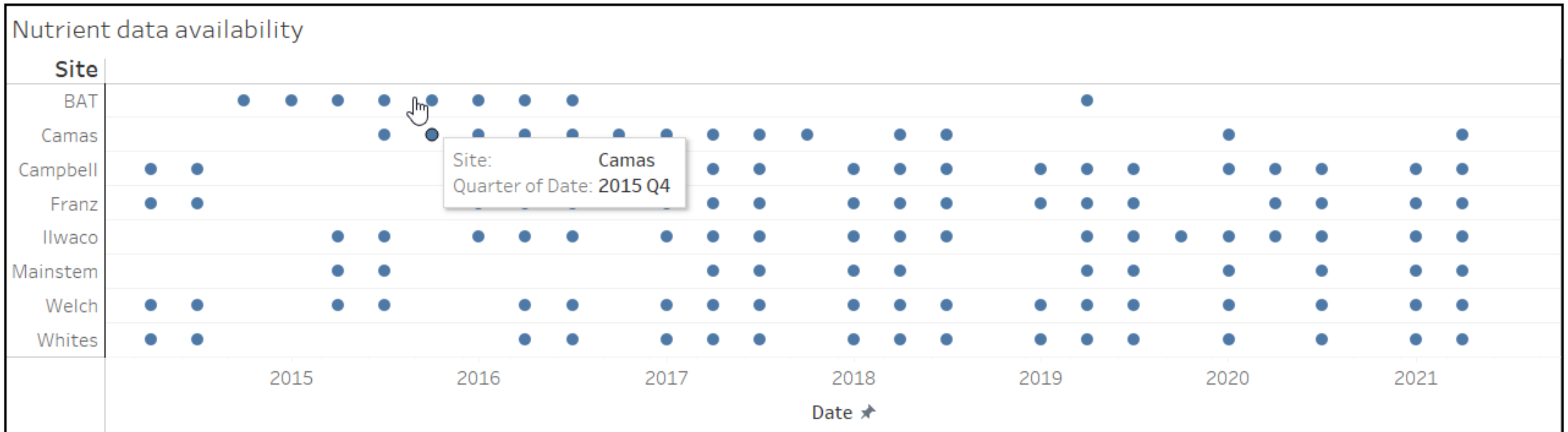


Table 3-1. Availability of nutrient data at Ecosystem Monitoring Program sites in the lower Columbia River. Nutrient include nitrate, phosphate, silicic acid, nitrite, and ammonium.

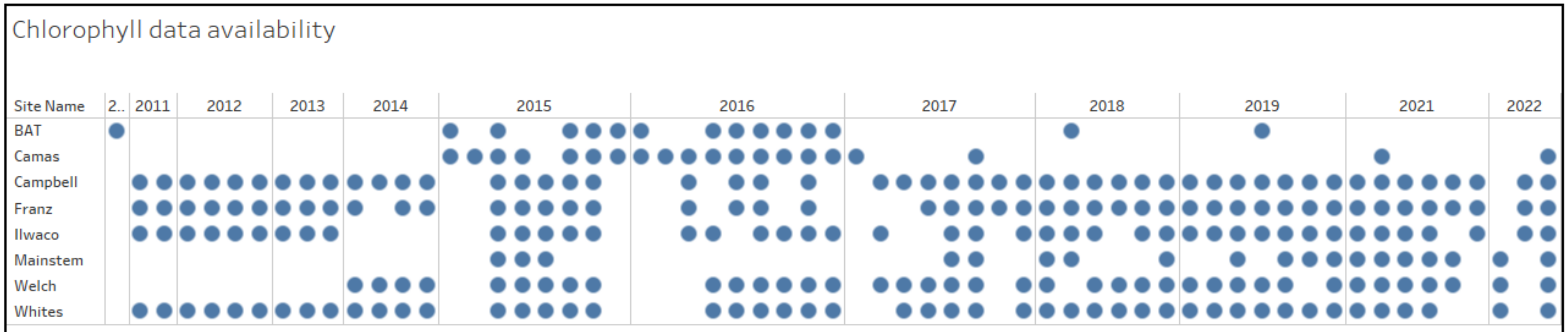


Table 3-2. Availability of chlorophyll data at Ecosystem Monitoring Program sites in the lower Columbia River.

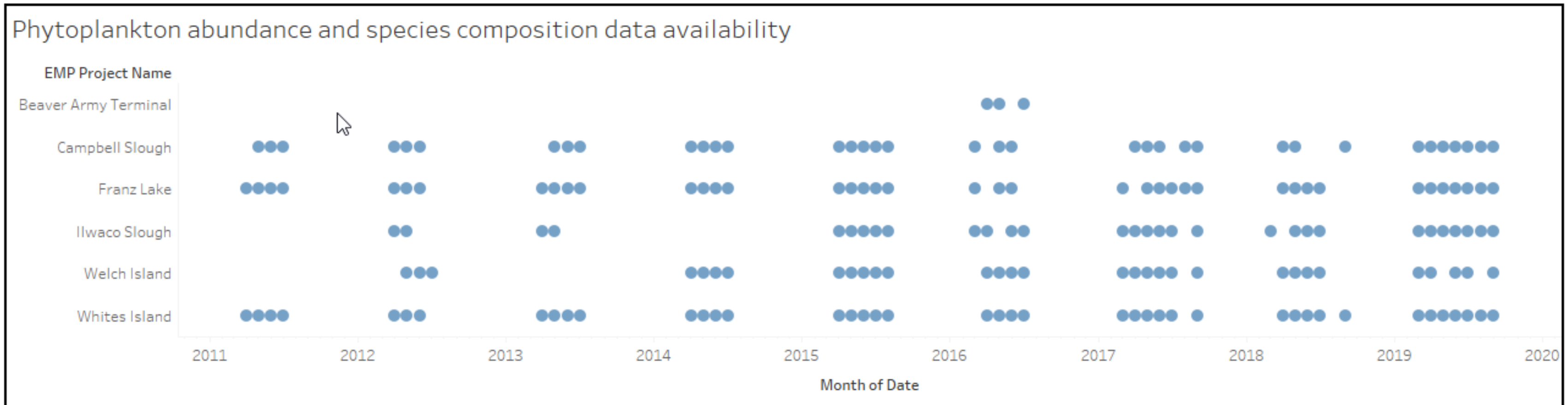
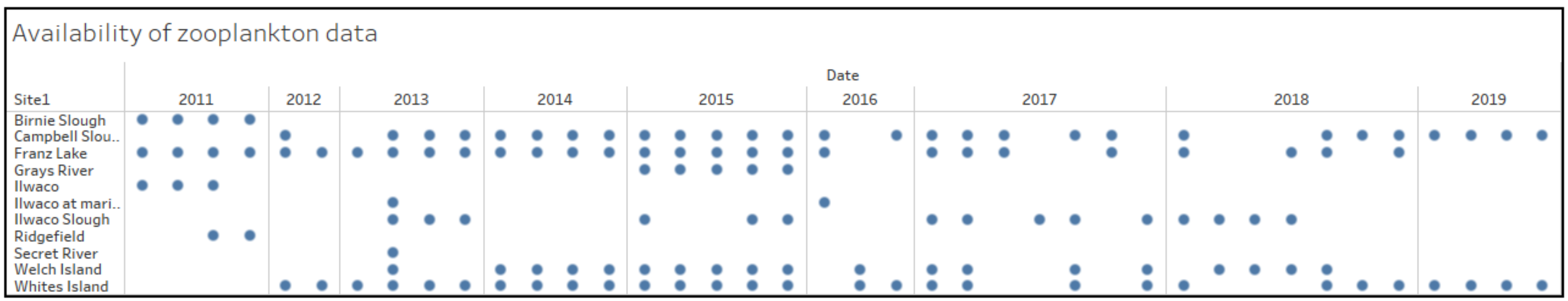
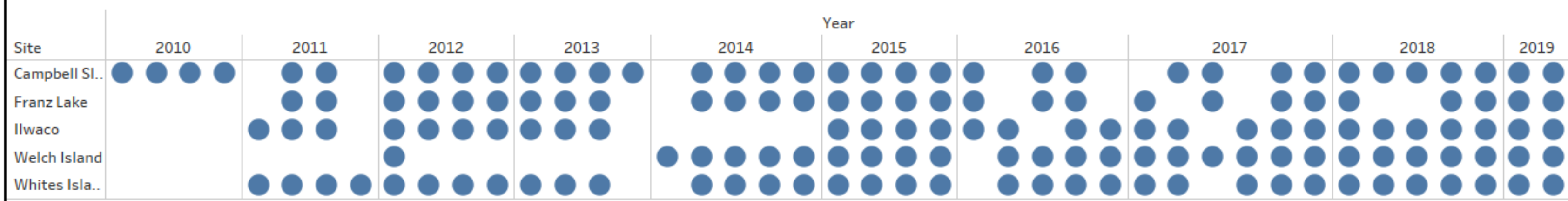


Table 3-3 Summary of sampling effort for collection of phytoplankton data by site and year(s) conducted at EMP sampling sites. Each circle represents a sampling event.

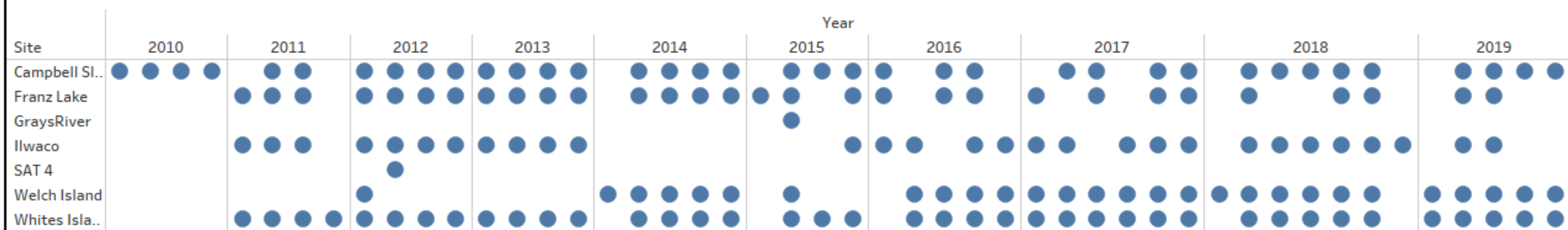


Availability of isotope data: Primary Producers



Availability of carbon and nitrogen isotope data for vegetation and aquatic primary producers in the lower Columbia River.

Availability of isotope data: Fish



Developed for Bonneville Power Administration

Authors (OHSU): Tawnya D. Peterson, Joseph A. Needoba
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information, please contact skidd@estuarypartnership.org

2 - Nutrients and Chlorophyll *a* Dashboard

Water quality standards are developed to protect humans and wildlife. Nutrients are required to support ecosystem productivity, where primary producers rely on key nutrients to build biomass through the process of primary production. However, when nutrient concentrations get too high, this can lead to overgrowth of bacteria and noxious species, which can result in large swings in dissolved oxygen and pH that is deleterious to fish and other aquatic wildlife.

The EMP monitors for nutrients - including nitrate, phosphate, silicic acid, nitrite, and ammonium - at the status and trends sites to better understand when and if nutrients become too low to support biological production or too high to ensure good habitat for growth and survival of salmonid species.

Chlorophyll is an indicator of primary production in the water column, and therefore monitoring this quantity helps us understand whether biological production at the off-channel marsh sites is at a level that supports or threatens juvenile salmonids.

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Navigate to Section 5 - Food web modeling

Summary of nutrient and chlorophyll data

The five EMP sites can be grouped into three types: Iwaco, with its marine influence, Welch Island and Whites Island, with high winter nutient concentraitons that decline over the spring and summer due to drawdown by primary producers; and Campbell Slough and Franz Lake Slough, which have much more variability in nutrient concentrations, particularly in the summer months.

Below are graphs showing nutrient concentrations at the EMP sites, as well as an analysis of cluster groups based on concentrations of nitrate and phosphate. Chlorophyll data are shown for all sites. In addition, climatology of the average chlorophyll concentration for a given site and month/year is shown.

Below are graphs showing nutrient concentrations at the EMP sites, as well as an analysis of cluster groups based on concentrations of nitrate and phosphate. Chlorophyll data are shown for all sites. In addition, climatology of the average chlorophyll concentration for a given site and month/year is shown.

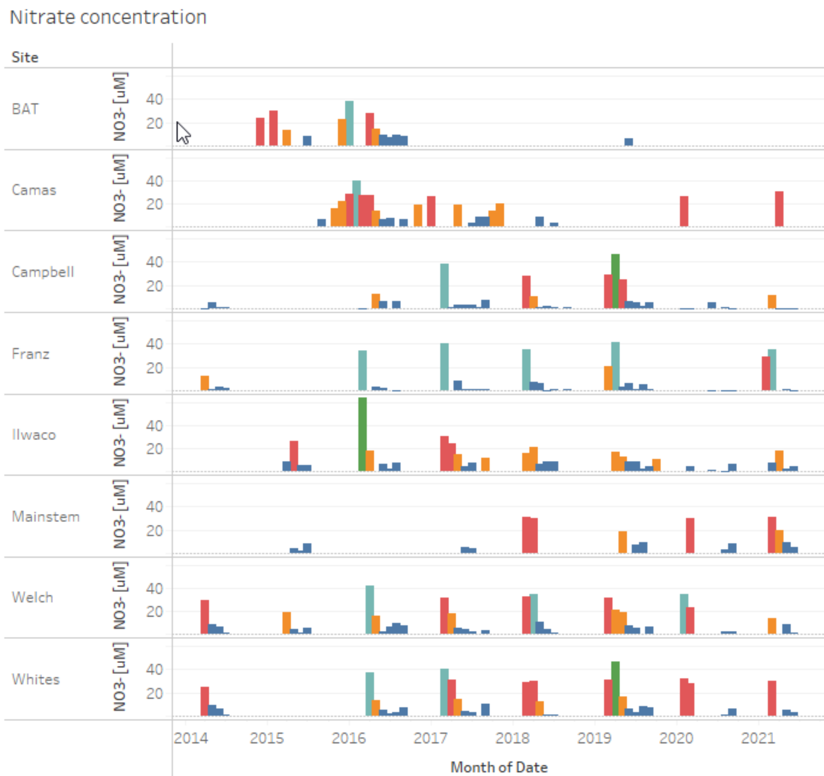


Fig. 3-1. Plots showing nitrate concentration (uM) at sites in the lower Columbia River over time colored by placement in one of five cluster groups. Clusters are based on concentration as follows: Cluster group 1 = 7.6 uM; Cluster 2 = 14.4 uM; Cluster 3 = 21.2 uM; Cluster 4 = 3.01 uM; and Cluster 5 = 29.3 uM.

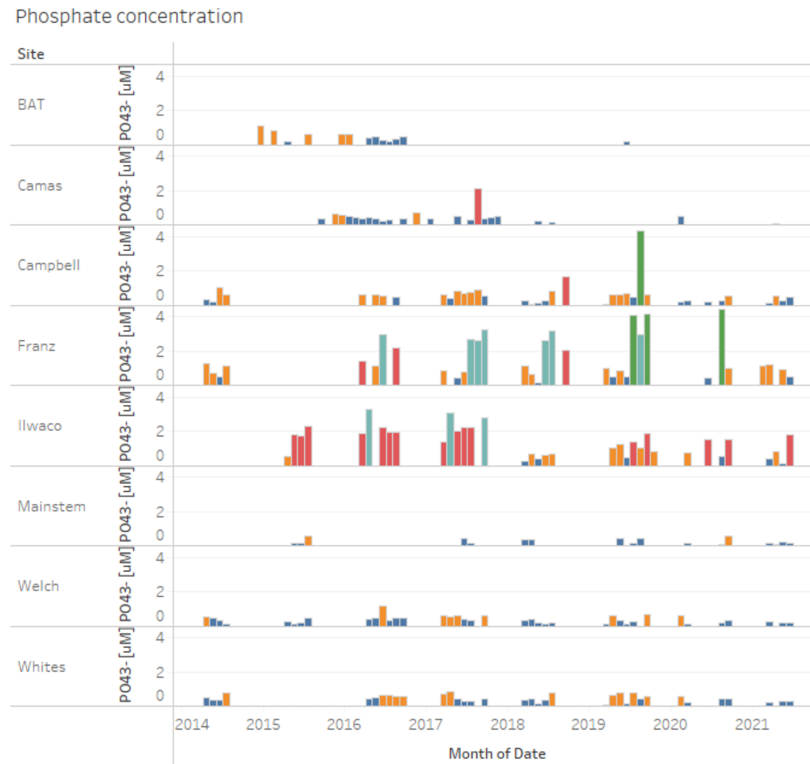


Fig. 3-2. Plots showing phosphate concentration (uM) at sites in the lower Columbia River over time colored by placement in one of five cluster groups. Clusters are based on concentration as follows: Cluster group 1 = 0.31 uM; Cluster 2 = 0.76 uM; Cluster 3 = 1.87 uM; Cluster 4 = 2.93 uM; and Cluster 5 = 4.25 uM.

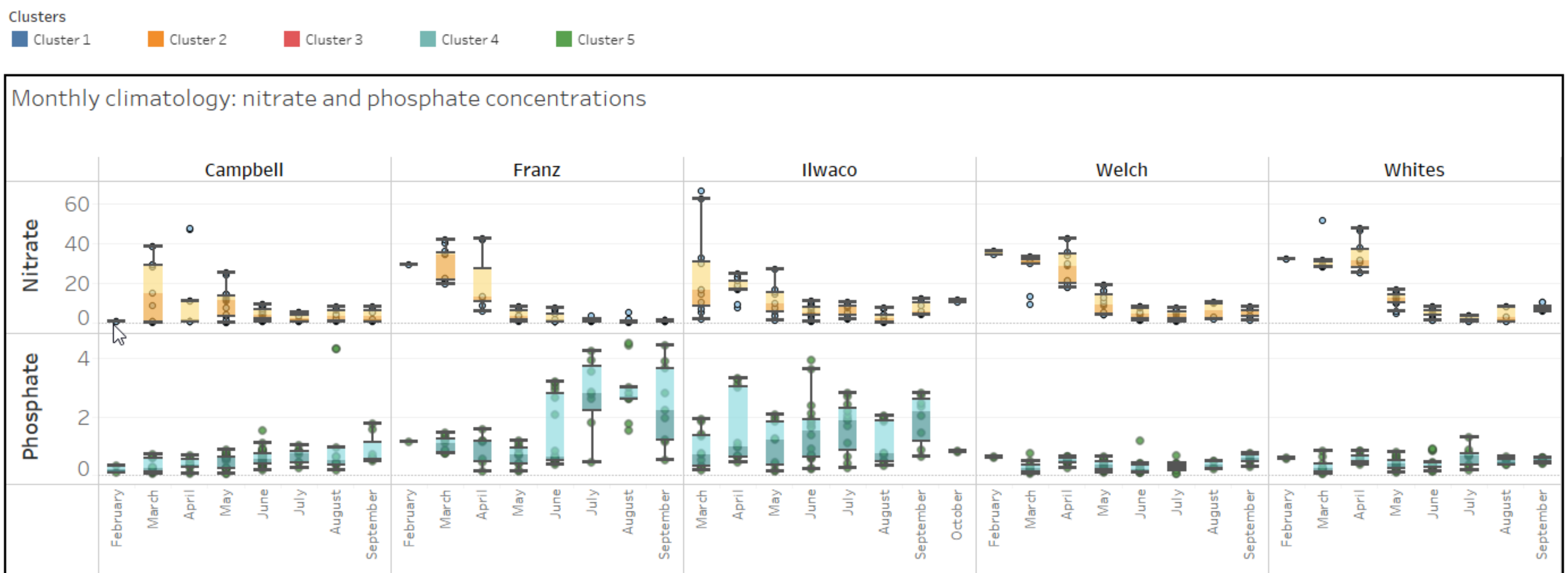
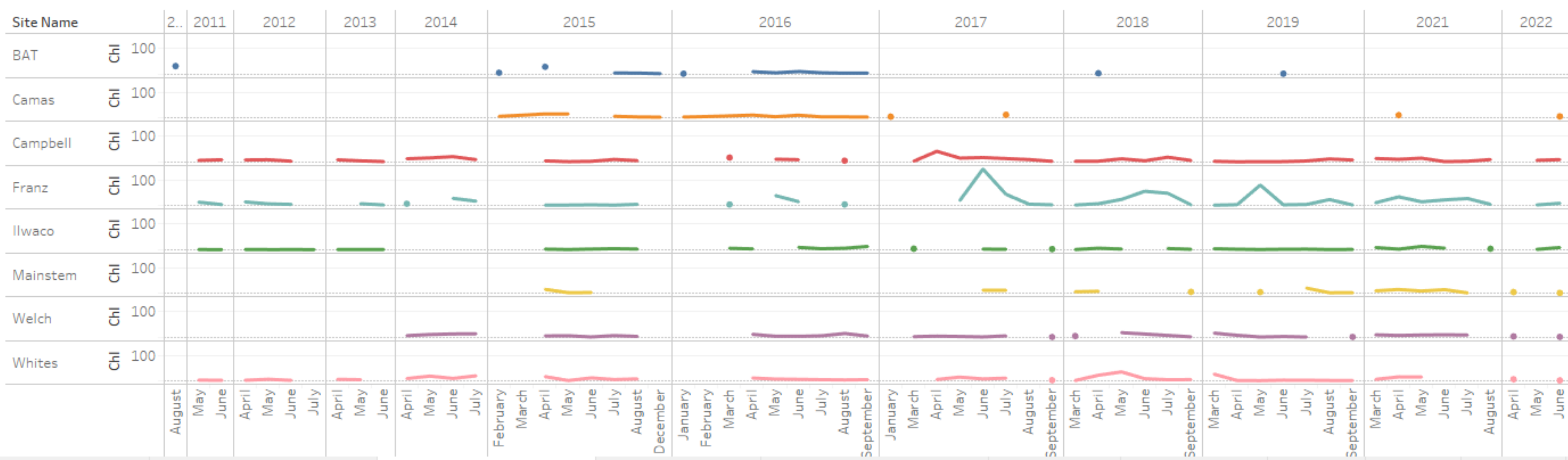


Fig. 3-3. Box and Whisker plots showing climatology of nitrate and phosphate concentrations at EMP sites (Campbell Slough, Franz Lake Slough, Ilwaco, Welch Island, and Whites Island) between 2014 and 2021.

Chlorophyll concentrations in the lower Columbia River estuary



Monthly climatology: Chlorophyll

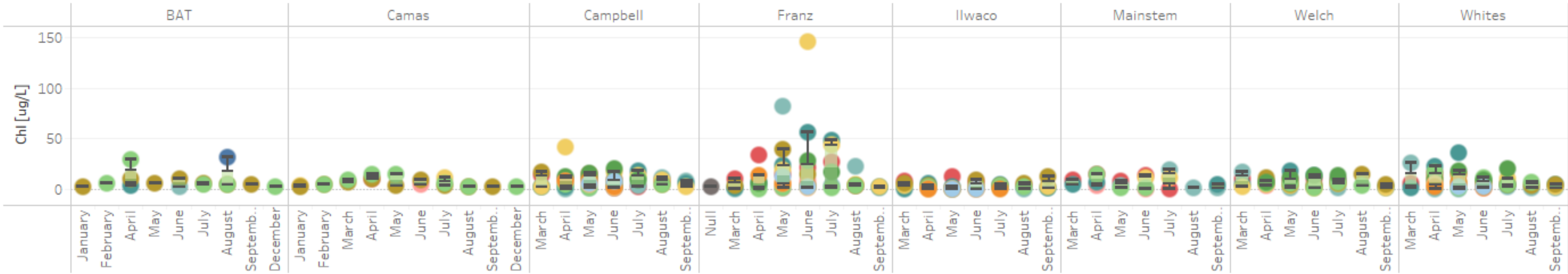


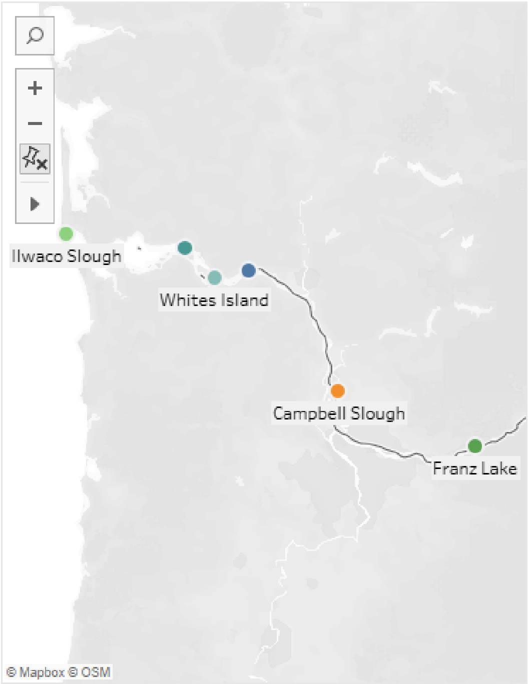
Fig. 3-5. Monthly climatology of chlorophyll a at sites in the lower Columbia River.

Developed for Bonneville Power Administration

Authors (OHSU): Tawnya D. Peterson, Joseph A. Needoba
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

Phytoplankton Abundances and Composition by Site

Site Map



General Results: Phytoplankton species composition has been found to vary by site, by season, and by year of observation. The EMP sites span 146 miles along the lower Columbia River, with one site above the confluence of the Willamette-Columbia Rivers, three sites between the confluence and the most tidally influenced site near the mouth of the river, and one site in the reach influenced directly by inputs from coastal marine waters.

i) *Spatial variation.*
Phytoplankton composition varies spatially, from marine-influenced assemblages at Ilwaco Slough & marina in the summer months to assemblages dominated by small, motile species at sites farther removed from the river mainstem. During periods when river flow and water levels are high, phytoplankton composition across sites is more similar than it is during periods of low flow.

ii) *Temporal variation.*

Discussion:

Action Guide: Hover your mouse over a bar in the bar charts below to highlight it across the page. Use the filter to the right to adjust the years being displayed.

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Navigate to Section 2 - Nutrients

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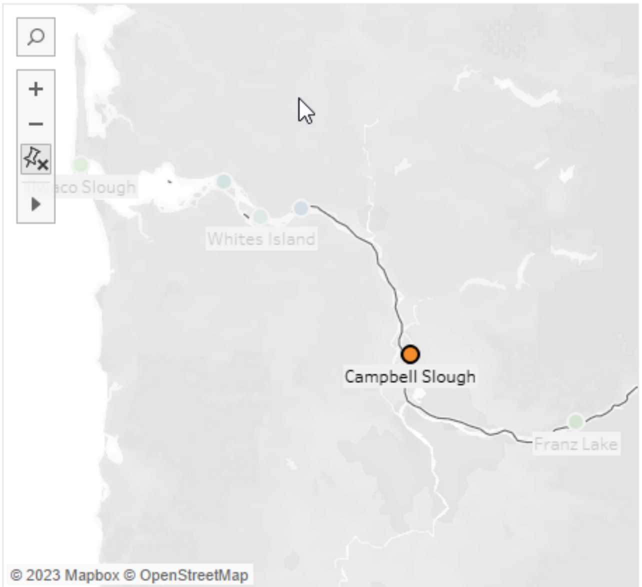
Class
Bacillariophyce..
Chrysophyceae
Cryptophyceae
Cyanophyceae
Dinoflagellates
Euglenophyceae
Flagellates
Others
Chlorophyceae
Chrysophytes
Diatom
Dinophyceae
Euglonophyceae
Greens
Rotifer
Phytoplankton Abundance and Species Composition (Log Scale)
EMP Projec..
2011
2012
2013
2014
2015
2016
2017
2018
2019
Ilwaco Slough
Welch Island
Whites Island
Campbell Slough
Franz Lake
Cells/ml
100,000
10,000
1,000
100
10
1
0.1
March
April
May
June
July

2b Site Specific Phytoplankton Composition

Site Map



Site Selected: Campbell Slough

Currently Pending Further Analysis

Action Guide: Click on a site within the map to the left to view that site's data and writeup. Hover your mouse over a bar in the bar charts below to highlight it across the page. Use the filter to the right to adjust the years being displayed.

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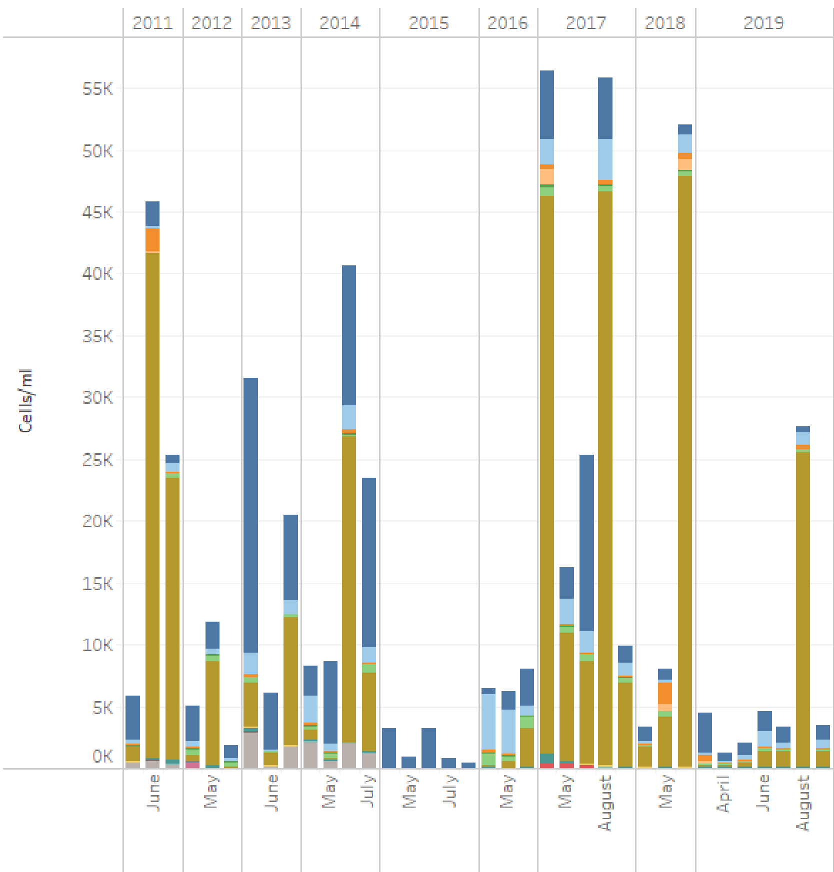
Year of Date

(Multiple values)

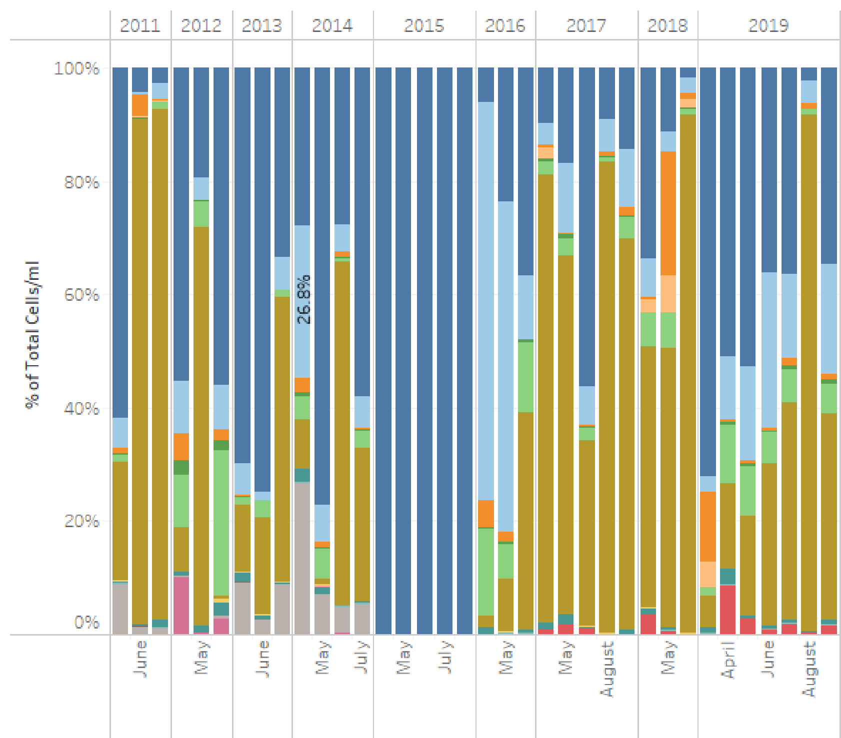
Class

Bacillariophyce..
Chlorophyceae
Chrysophyceae
Chrysophytes
Ciliophora
Cryptophyceae
Cyanophyceae
Diatom
Dinoflagellates
Dinophyceae
Euglenophyceae
Euglonophyceae
Flagellates
Greens
Others

Campbell Slough - Total Phytoplankton Abundance



Campbell Slough - Percent Contribution to Total Phytoplankton Community



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Authors (OHSU): Tawnya D. Peterson, Joseph A. Needoba
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information, please contact skidd@estuarypartnership.org

4-Zooplankton Assemblages at EMP sites

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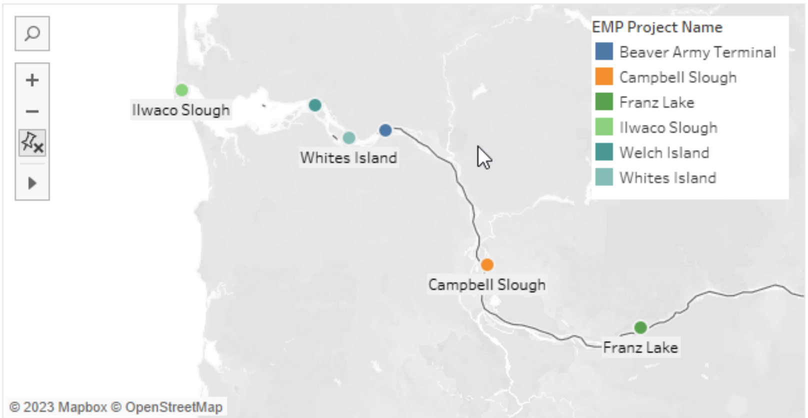
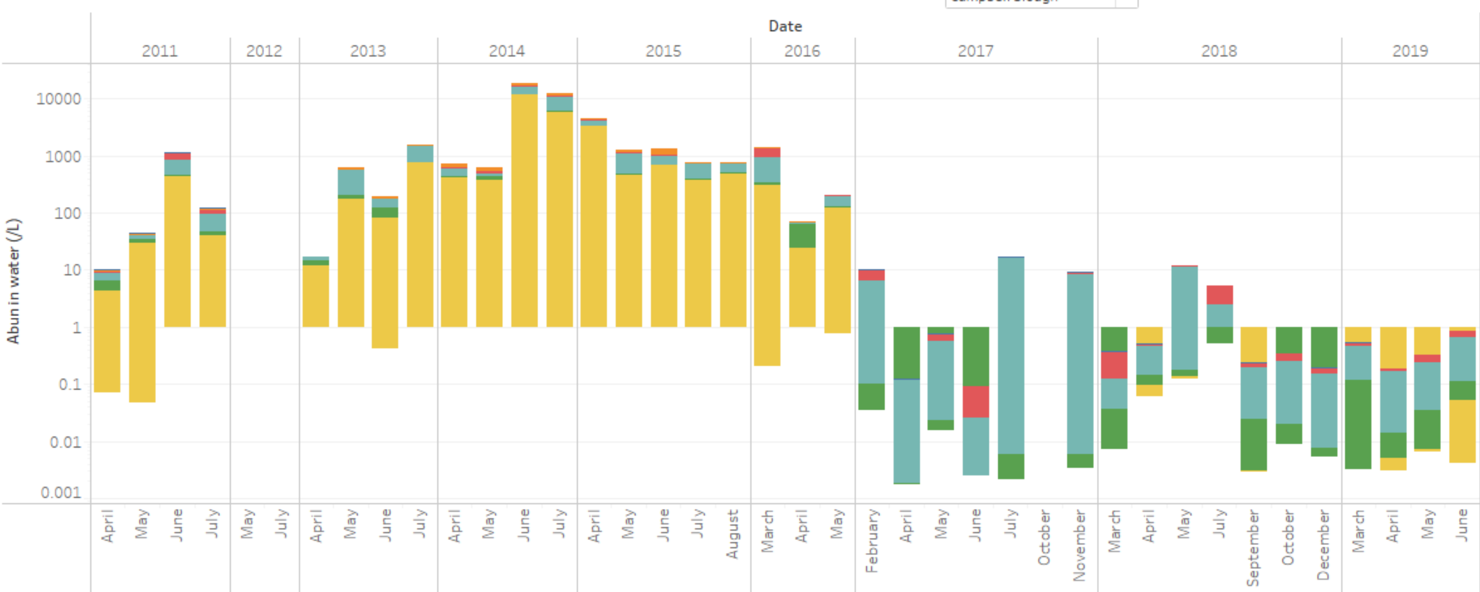
Site Map

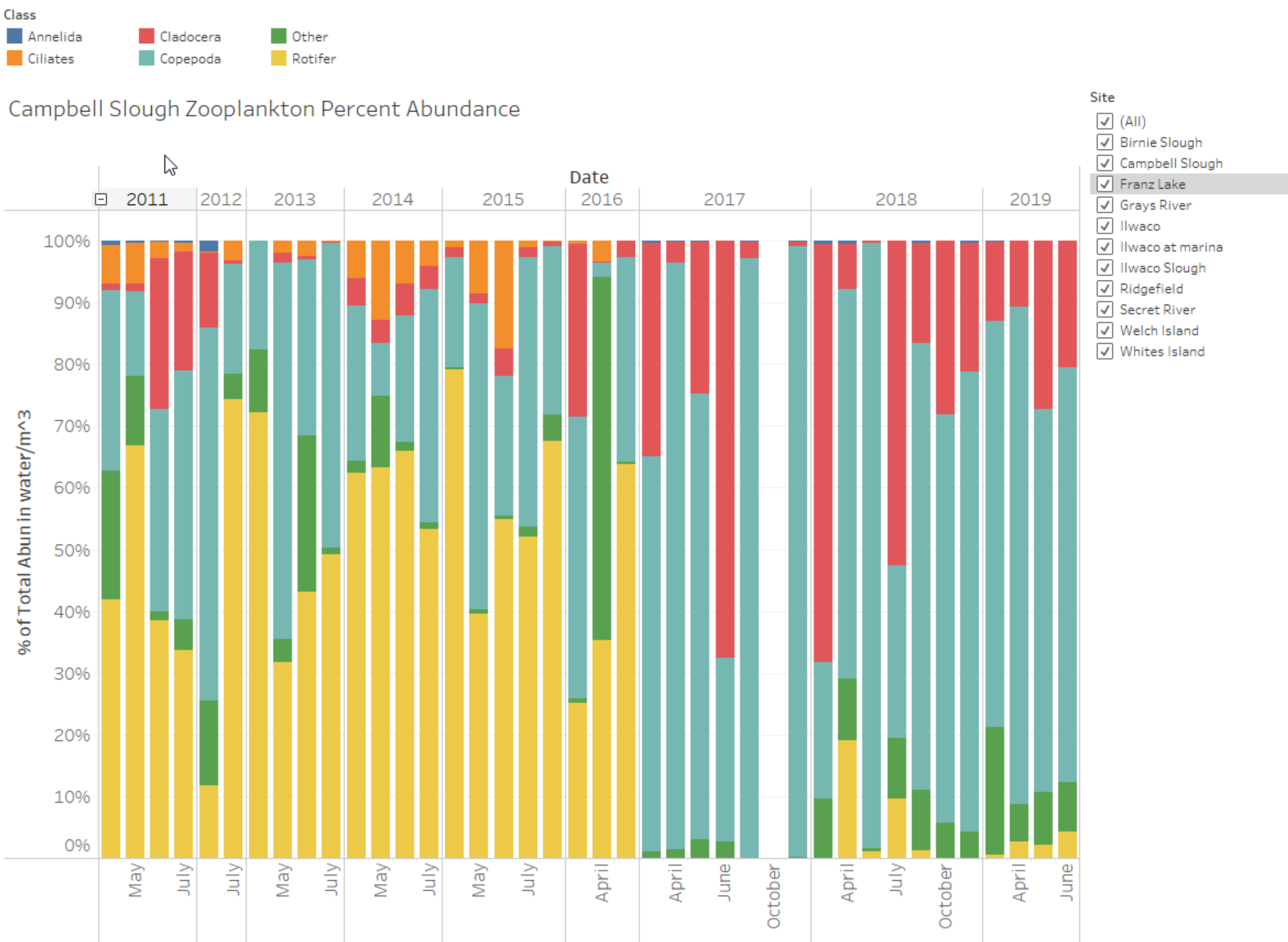


Campbell Slough Zooplankton abundance (*Log Scale*)

Site Name Param

Campbell Slough

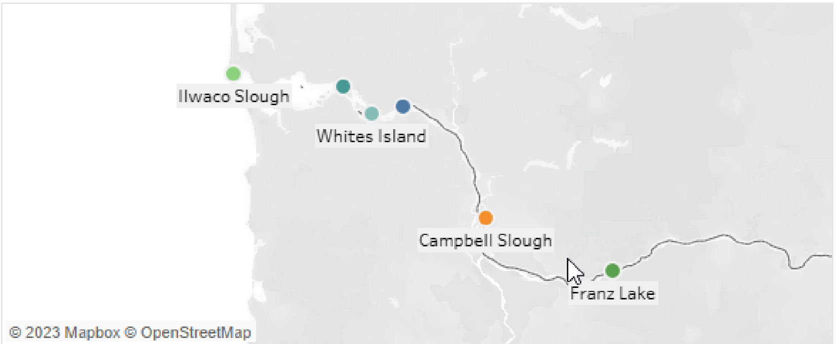




% of Total Abun in water/m^3 for each Date Month broken down by Date Year. Color shows details about Class. Details are shown for Date Year and Site1. The view is filtered on Class, Date Year and Site1. The Class filter keeps 6 of 6 members. The Date Year filter has multiple members selected. The Site1 filter keeps 11 of 11 members.

5-Food web characterization and modeling

Site Map



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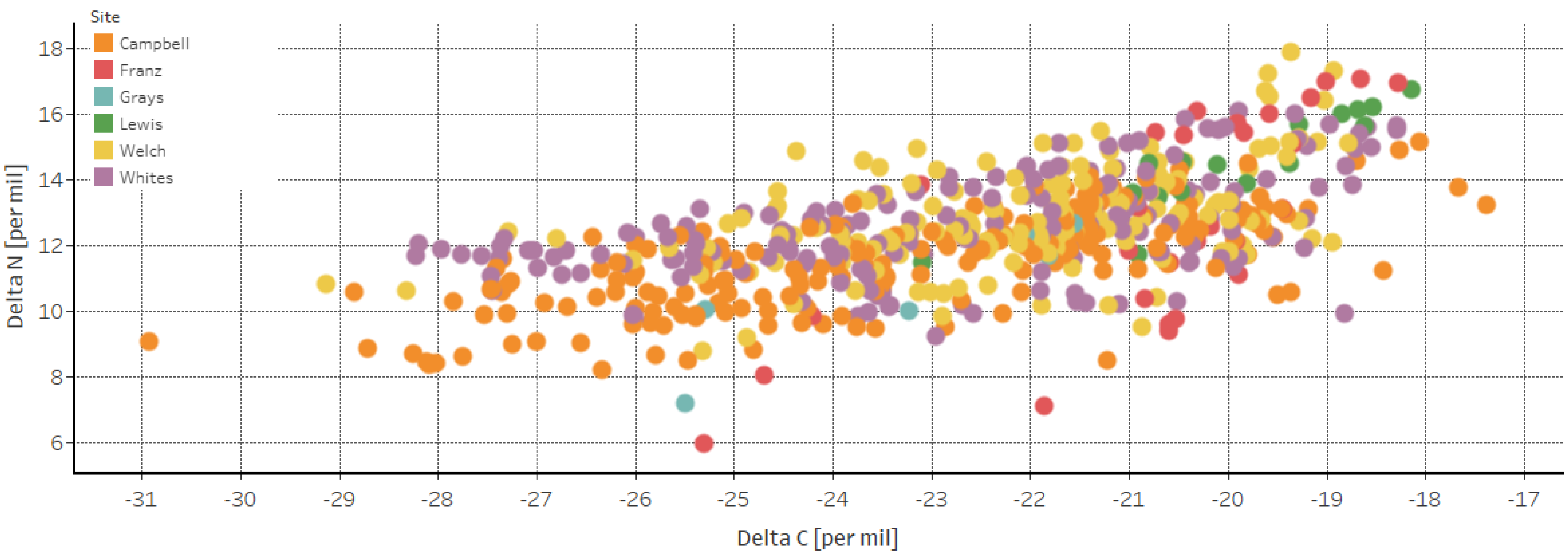
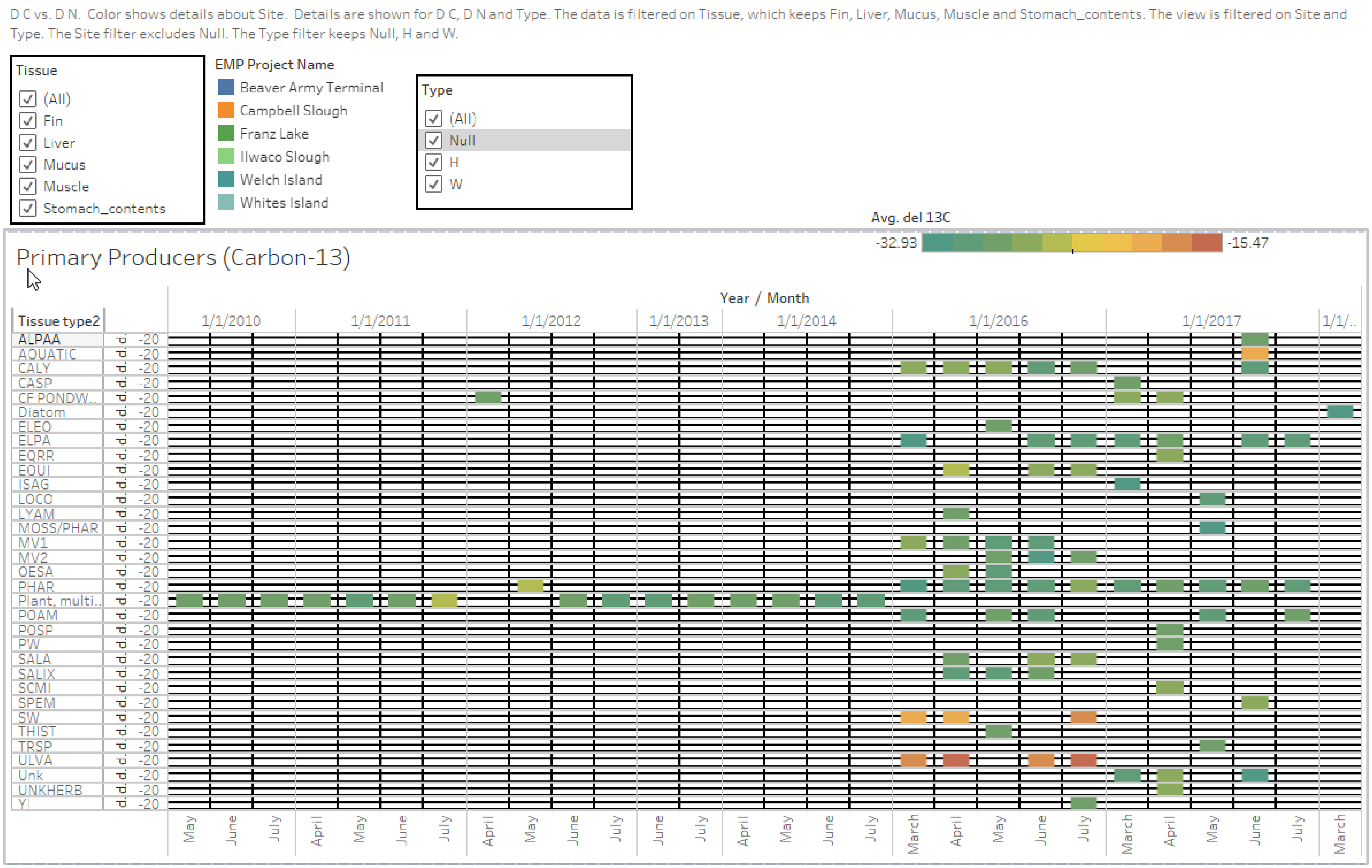
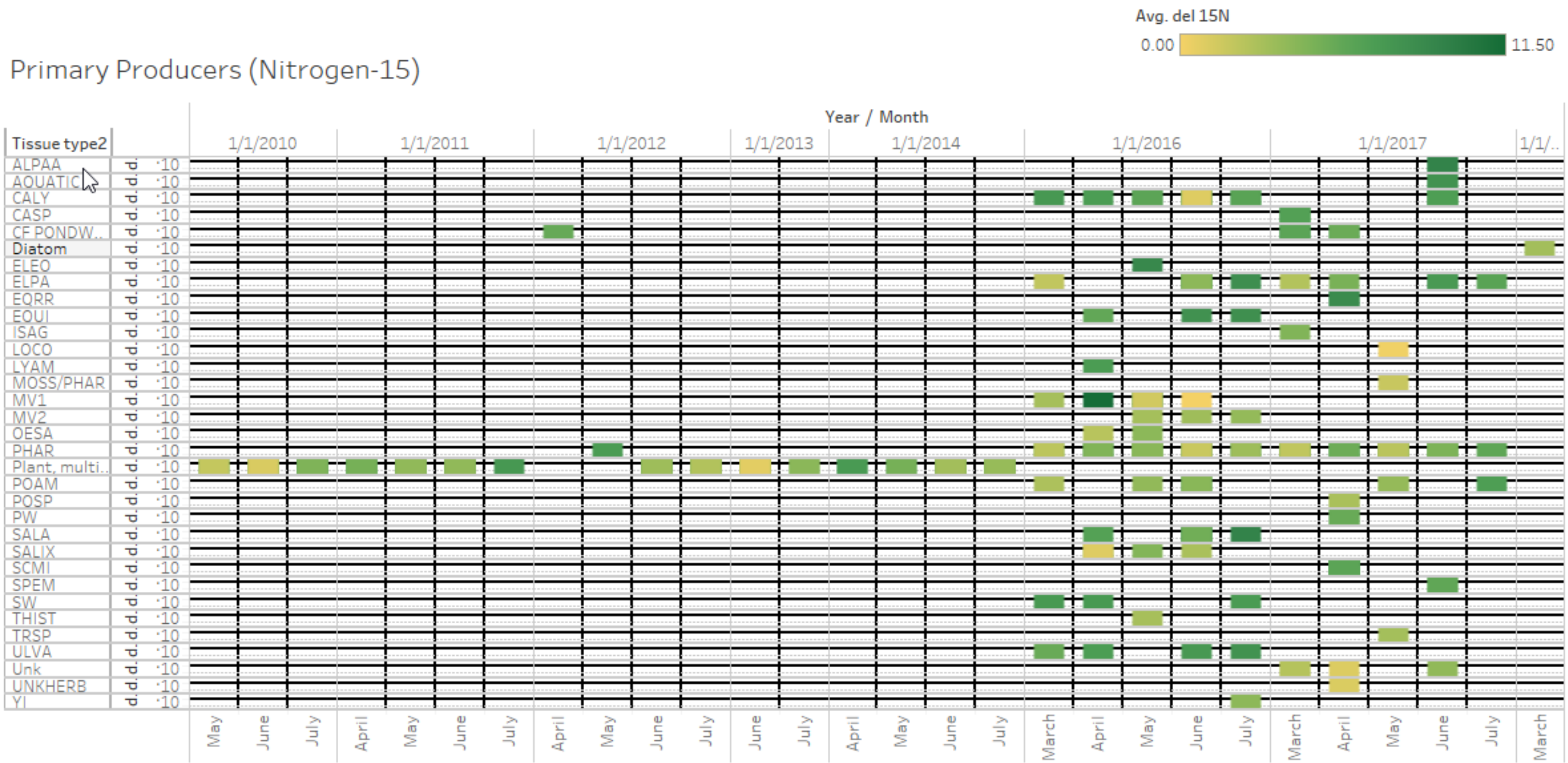
Salmon tissue



D C vs. D N. Color shows details about Site. Details are shown for D C, D N and Type. The data is filtered on Tissue, which keeps Fin, Liver, Mucus, Muscle and Stomach_contents. The view is filtered on Site and Type. The Site filter excludes Null. The Type filter keeps Null, H and W.


D C vs. D N. Color shows details about Site. Details are shown for D C, D N and Type. The data is filtered on Tissue, which keeps Fin, Liver, Mucus, Muscle and Stomach_contents. The view is filtered on Site and Type. The Site filter excludes Null. The Type filter keeps Null, H and W.
Tissue
(All)
Fin
Liver
Mucus
Muscle
Stomach_contents
EMP Project Name
Beaver Army Terminal
Campbell Slough
Franz Lake
Ilwaco Slough
Welch Island
Whites Island
Type
(All)
Null
H
W
Avg. del 13C
-32.93
-15.47
Primary Producers (Carbon-13)
Year / Month
Tissue type2
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/1/2016
1/1/2017
ALPAA
AQUATIC
CALY
CASP
CF PONDW..
Diatom
ELEO
ELPA
EQRR
EQUI
ISAG
LOCO
LYAM
MOSS/PHAR
MV1
MV2
OESA
PHAR
Plant, multi..
POAM
POSP
PW
SALA
SALIX
SCMI
SPEM
SW
THIST
TRSP
ULVA
Unk
UNKHERB
YI
-20
May
June
July
April
March

Primary Producers (Nitrogen-15)



Developed for Bonneville Power Administration

Authors (OHSU): Tawnya D. Peterson, Joseph A. Needoba
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

Welcome to the Macroinvertebrate Ecosystem Monitoring Dashboard

Developed for Bonneville Power Administration
Authors (University of Washington): Kerry Accola, Jason Toft
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao
Other Major Contributors: Jeff Cordell and the UW Wetland Ecosystem Team

For more information please contact skidd@estuarypartnership.org

Lower Columbia Estuary Partnership
BONNEVILLE POWER ADMINISTRATION
UNIVERSITY of WASHINGTON

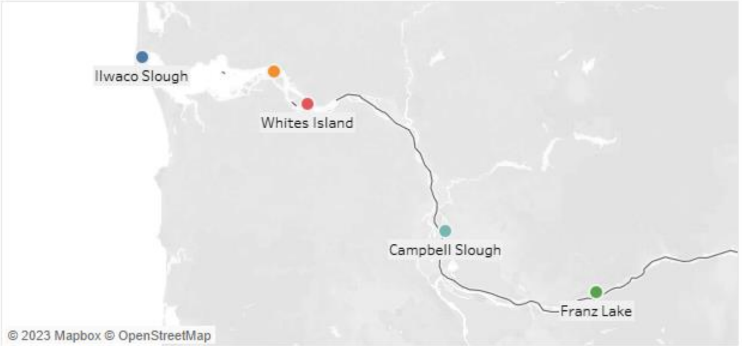
Navigate to Section 1 - Sampling Effort and Data Inventory

Navigate to Section 2 - Salmon Diets

Navigate to Section 3 - Neustons

Navigate to Section 4 - Benthics

Site Map



This Dashboard contains macroinvertebrate community data. Please click any of the buttons below to access more data and other metrics.

Navigate to Overview Dashboard

Navigate to Mainstem and Abiotic site conditions

Navigate to Habitat Structure

Navigate to Food Web analysis

Navigate to Fish Communities

Executive Summary

Juvenile salmon diets in the Lower Columbia estuary consist mostly of **amphipods**, **dipterans**, and **cladocerans**.

Young salmon consume primarily wetland insects (dipterans) at Franz Lake, the uppermost site, incorporate cladocerans at Campbell Slough, transition to dipterans and amphipods at Welch Island and Whites Island, and consume primarily amphipds near the estuary mouth at Ilwaco Slough.

Diets are **most metabolically beneficial** to small salmon (30 - 59 mm). Larger salmon have higher metabolic costs that are directly influenced by larger body mass and higher water temperatures. Top salmon prey sources have small yet consistent contributions from benthic core and neuston tow samples.

Management Implications

Juvenile salmon have a steady presence in the Lower Columbia estuary even though temperatures regularly exceed minimal water temperature thresholds for salmon fitness. Higher energy consumption in the summer months indicates foraging behaviors that mitigate higher metabolic costs.

Habitat restoration and mitigation of high water temperatures will aid growth of juvenile salmon in the Lower Columbia estuary by promoting healthy water temperatures, a high-quality prey field, and optimal growing conditions for juvenile salmon.

Uncertainties

Elevated water temperatures associated with climate change create metabolic stressors for juvenile salmon, requiring increased energy intake. Young salmon may migrate to sea earlier, reducing their survival likelihood, if cold water refugia is limited.

It is unknown how salmon prey will be affected with long term changing water temperatures.

Navigate to Food Web analysis

Navigate to Fish Communities

conditions for juvenile salmon.

Uncertainties

Elevated water temperatures associated with climate change create metabolic stressors for juvenile salmon, requiring increased energy intake. Young salmon may migrate to sea earlier, reducing their survival likelihood, if cold water refugia is limited.

It is unknown how salmon prey will be affected with long term changing water temperatures.

Citation: Kidd, S.A., Edgar, I., Rao, S., Accola, K., Cordell, J., Chittaro, P.M., Grote, J., Hinton, S.A., Needoba, J.A., Peterson, T.D., Roegner, C., Toft, J.D., Borde, A.B., Corbett, C.A., Cook, L.P., Cullinan, V.I., Fuller, R.N., Hanson, A.C., Kuligowski, D., Lomax, D., Johnson, L.L., McNatt, R., Poppe, K., Zimmerman, S.A., Ylitalo, G.M, et al. 2023. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 17 (October 1, 2021 to September 30, 2022). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

Image above: Jason, Sarah, Ian, and Kerry at CREC 2023

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LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH ANNUAL REPORT

1 Sampling Effort and Data Inventory

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Go to Section 2.0 - Diets

Table 3.1.1 Table of taxa richness, by life stage (e.g. pupae, larvae, adult), for each year and month within each EMP site. Taxa richness is calculated for each net set and summed across all sets.

		Sample Type		
Year (Years)	Month	Benthic	Diets	Neuston
2008	April		28	
	May		106	
2009	May		61	
	June		17	
2010	April		43	
	May		110	
	June		84	
	July		98	
	August		48	
2011	May		54	
	June		34	
	July		7	
2012	February		28	
	March		25	
	April		42	
	May		123	
	June		85	
2013	March		15	
	May		151	
	June		77	
	July		65	
2015	April	102	13	403
	May	182	340	317
	June	148	95	228
	July	147		
2016	February			133
	March			66
	April	88	185	327
	May	157	327	349
	June	171		626
	July	158	124	225

Diets

Juvenile Chinook salmon are collected for diet analyses using boat or raft-deployed 38 x 3-m variable mesh bag seines. Fish are euthanized and stomachs are preserved in 10% formalin. In the laboratory, each prey taxon is counted, blotted dry, weighed to the nearest 0.0001 g, and identified to genus or species.

Neuston

To assess the availability of salmon prey, neuston tows are conducted in open water (in the center of the channel) and emergent vegetation (along the edge of the wetland channel). For overwater samples, a Neuston net (250 µm mesh) is deployed from a boat for an average distance of 100 m and samples the top 20 cm of the water column. For emergent vegetation, the Neuston net is pulled through a 10 m transect parallel to the water's edge to sample the top 20 cm of the water column. Samples are preserved in 95% ethanol. Due to processing discrepancies, neuston data previous to 2015 is not included in analyses.

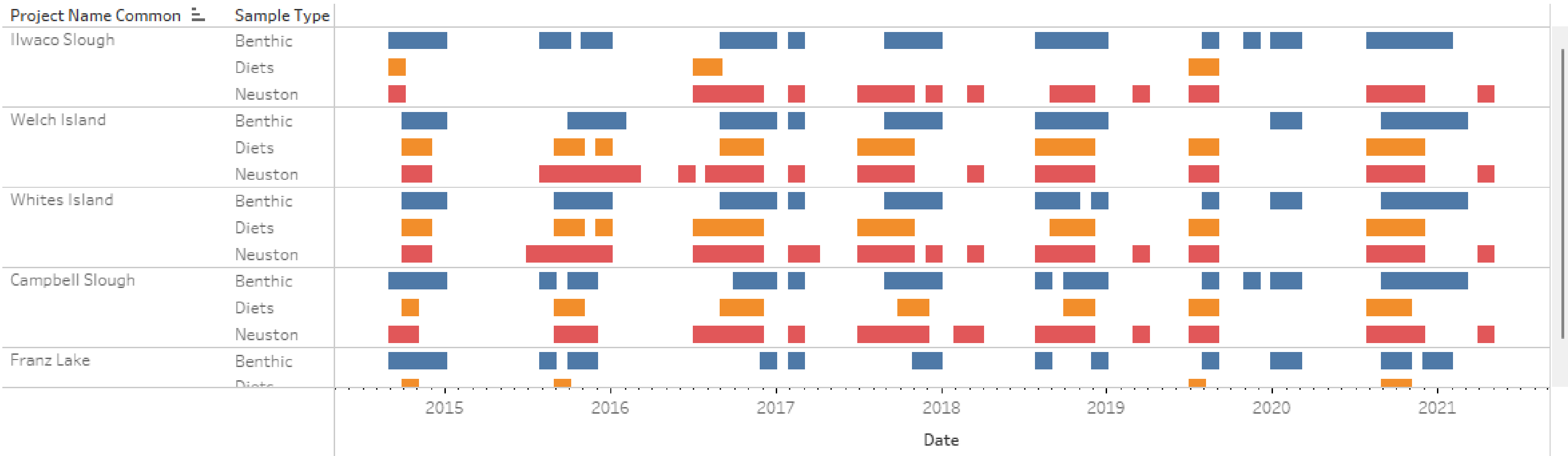
Benthic

To characterize the benthic macroinvertebrate assemblage, benthic cores are sampled adjacent to fish and prey sampling locations. Benthic cores are collected to a depth of 10 cm by driving a 2-inch diameter PVC pipe into the ground. Samples are collected monthly at a low tide among emergent vegetation when sediments were exposed, and preserved in 10% formalin. When possible, five samples are taken at each site. Benthic and neuston invertebrates are identified in the laboratory using high-resolution optical microscopy and taxonomic references. Each taxa is counted and weighed to the nearest 0.0001 g.

Sample Type

Benthic Diets Neuston

Table 3.1.2 Gantt chart of taxa richness, by life stage (pupae, larvae, adult), for each year and month within each EMP site. Taxa richness is calculated for each net set and summed across all sets. Chart is color-sorted by sample type.



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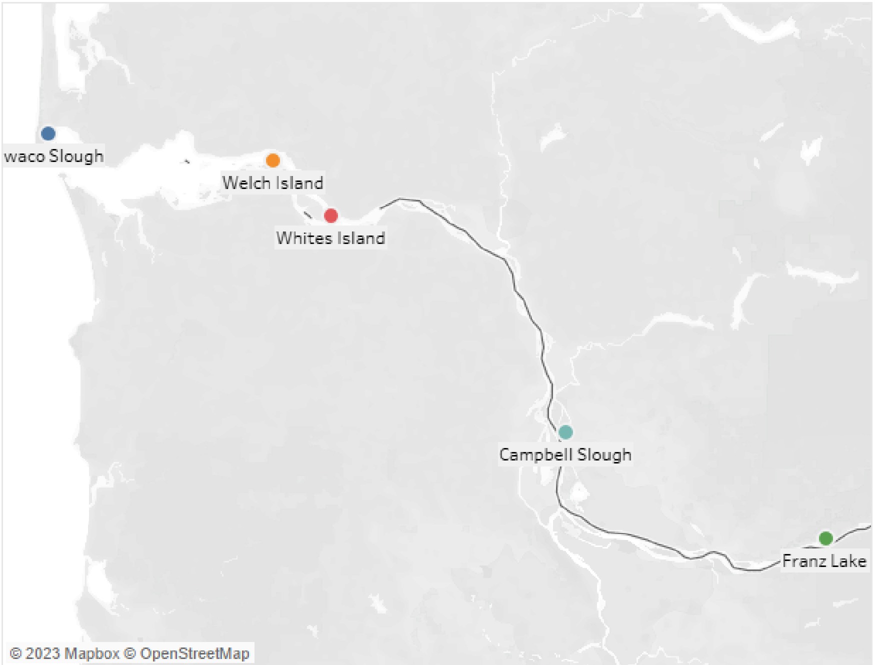
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao
Other Major Contributors: Jeff Cordell and the UW Wetland Ecosystem Team

For more information please contact skidd@estuarypartnership.org

Juvenile Chinook Diets



Return to Welcome Page

Return to Section 1 - Sampling Effort and Data Inventory

Go to Section 2.1 - Diets

Sites

- ☑ (All)
- ☑ Campbell Slough
- ☑ Cunningham Lake
- ☑ Franz Lake
- ☑ Ilwaco Slough
- ☑ Welch Island
- ☑ Whites Island

- Ilwaco Slough
- Welch Island
- Whites Island
- Campbell Slough
- Franz Lake

Juvenile Chinook Diet Composition

About: This dashboard provides results of the juvenile Chinook salmon diet composition at the EMP Sites.

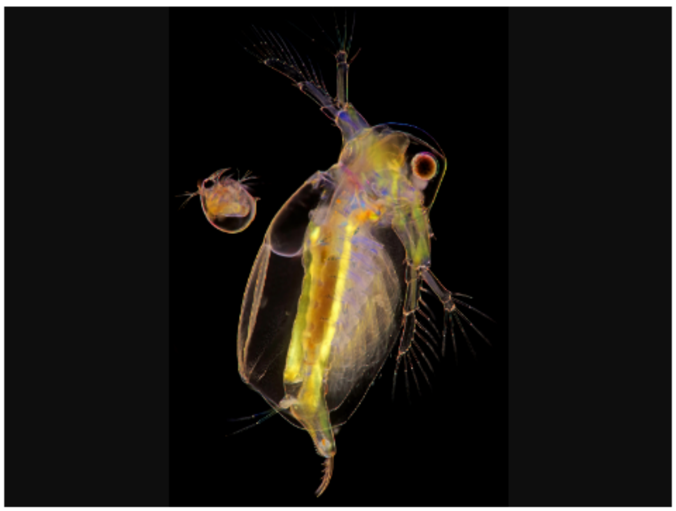
Results: Juvenile Chinook salmon diets consist primarily of dipterans and other wetland insects at Franz Lake and Campbell Slough (incorporating cladocerans at Campbell Slough), dipterans and amphipods at Whites Island and Welch Island, and mostly amphipods at Ilwaco Slough.

Action guide: Click on a site within the map to highlight a site. Use CTRL+Click to highlight multiple sites. Hover over a class to highlight it across to the other data table. Utilize the filter below to adjust the site being viewed.

Bonus action -- Click on a specific taxa to view an image of each macroinvertebrate.

Figure Invertebrate Taxa and Images: Invertebrate presence across all EMP Sites. Click the box to view image and hover over each box for more details.

Class	Taxa
Amphipoda	Americorophium salmonis
	Americorophium spinicorne
	Amphipod
	Amphipoda
	Corophiidae
	Crangonyx sp
	Gammaridea
	Hyalella azteca
	Hyallela azteca
	Hyallela sp
Animalia	Animal matter
Anthozoa	Actinaria
	Actiniaria



Highest abundances are Cladocerans, followed by Insects (dipterans) and amphipods. Amphipods contribute the most weight in diets, primarily at downstream sites. The majority of sampled juvenile Chinook are present at Campbell Slough, Welch Island, and Whites Island.

Years

2008 2021

Sites

Ilwaco Slough Welch Island Whites Island Campbell Slough Franz Lake

Figure 3.2.0.1: Invertebrate Abundances and Weights by Class of Taxa

Counts and weight (in grams) of prey items in juvenile Chinook stomachs from 2008 to present. Bar plots are sorted by prey Class and color-coded by site. Counts are log-scaled to account for orders of difference in prey counts.

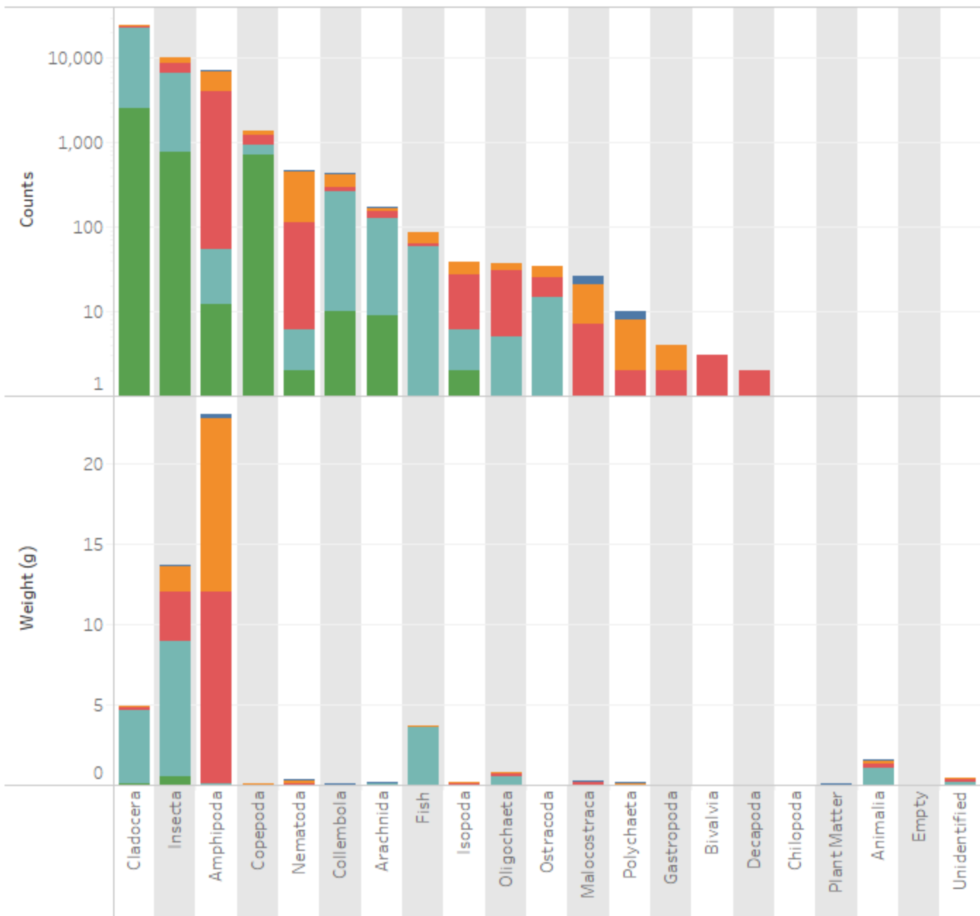
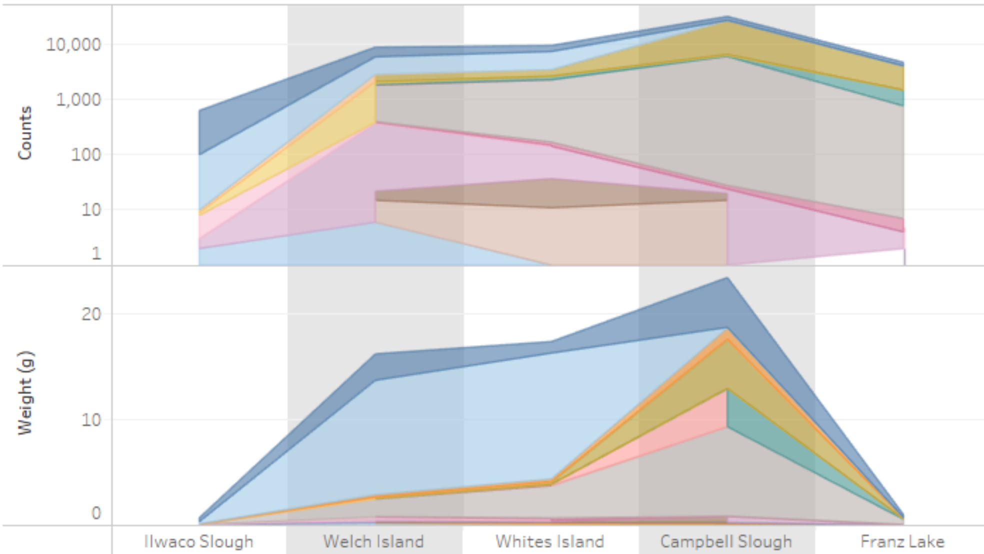
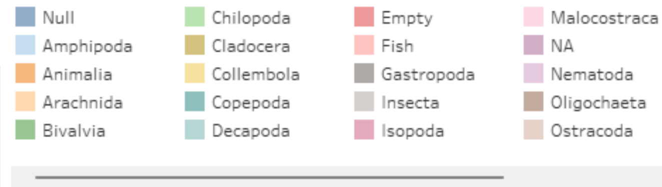


Figure 3.2.0.2: Invertebrate Abundances and Weights by Site

Counts and weight (in grams) of prey items in juvenile Chinook stomachs from 2008 to present. Area plots are sorted by site and color-coded by prey Class.



Legend: Invertebrate Taxa



There is a trend of decreasing occurrence of insects (dipterans) in diets downstream, and an increase of amphipods in the diets. Diet amounts are largest at Campbell Slough, Welch Island, and Whites Island due to the majority of sampled juvenile Chinook being present at these locations.

Developed for Bonneville Power Administration

Authors (University of Washington): Kerry Accola, Jason Toft

Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

Other Major Contributors: Jeff Cordell and the UW Wetland Ecosystem Team

Juvenile Chinook Diets Further Analysis

Return to Welcome Page

Return to Section 2.0 - Diets

Go to Section 3 - Neuston

Sites

- ☑ (All)
- ☑ Campbell Slough
- ☑ Cunningham Lake
- ☑ Franz Lake
- ☑ Ilwaco Slough
- ☑ Welch Island
- ☑ Whites Island

- Ilwaco Slough
- Welch Island
- Whites Island
- Campbell Slough
- Franz Lake

Juvenile Chinook Diet Composition

Results: Amphipods (mainly *Americorophium* spp,), dipterans (mainly chironomids), and cladocerans are also the prey with the highest Index of Relative Importance for juvenile salmon in all size classes, which accounts for prey counts, weight, and frequency of occurrence in diets.

Discussion: Most salmon are unmarked (likely wild) and smaller fish have lower maintenance metabolism. Energy and instantaneous ration values do not increase with fish length, indicating that diets at these sites are most advantageous to smaller salmon.

Action guide: Click on a site within the map to select a site. Use CTRL+Click to select multiple sites. Hover over a class to highlight it across to the other data table. Utilize the filter below to adjust the site being viewed.

Figure 3.2.1.1: Dot plots representing energetic and metabolic components of juvenile Chinook diets among sites, by fish fork length (mm). Energy Ration (ER) measures energy consumption and is the sum of prey energy density in diets dependent on salmon body weight. Instantaneous Ration (IR) measures fish foraging performance by acccounting for the sum of prey weight in individual salmon stomachs dependent on salmon body weight. Maintenance Metabolism (MM), or metabolic upkeep, is the cost of metabolism for fish and is influenced by fish size and water temperatures.

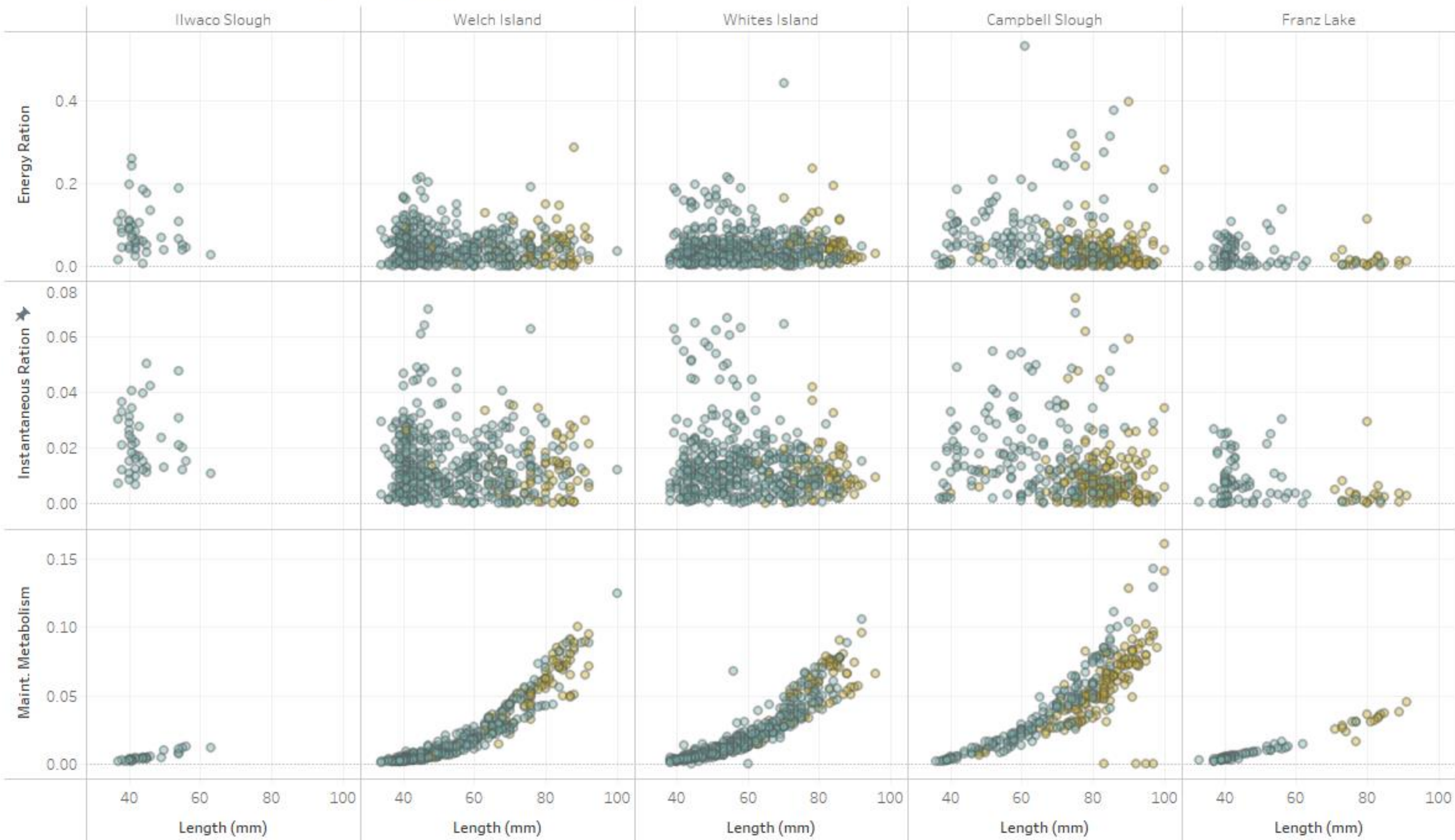
Length (mm) 32 — 100

Years 2008 — 2021

Mark Or Tag

- 0
- 1
- AD
- AD/CWT
- Bismark brown
- CWT
- None

Figure 3.2.1.2. Invertebrate Abundances and Weights by Class of Taxa



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For more information please contact skidd@estuarypartnership.org

Neuston Sampling

Return to Welcome Page **Return to Section 2.1 - Diets**

Go to Section 4 - Benthics

Neuston Sample Invertebrate Composition

About: Neuston tows along the water surface at emergent vegetation and open water habitats have a diverse array of benthic, epibenthic, terrestrial riparian, and planktonic taxa.

Results: Small planktonic taxa, like copepods and cladocerans, are numerically abundant. Collembolans (springtails) and insects are also relatively abundant. Even with low densities, the large size of amphipods, gastropods, and isopods account for much of the sample weights.

Discussion: Top salmon prey of amphipods and dipterans are present in samples. Amphipod densities are low in all locations but are higher downstream, specifically in open water samples, where their densities are highest at Ilwaco Slough. In emergent vegetation samples, average densities of dipterans are typically lower downstream and higher upstream.

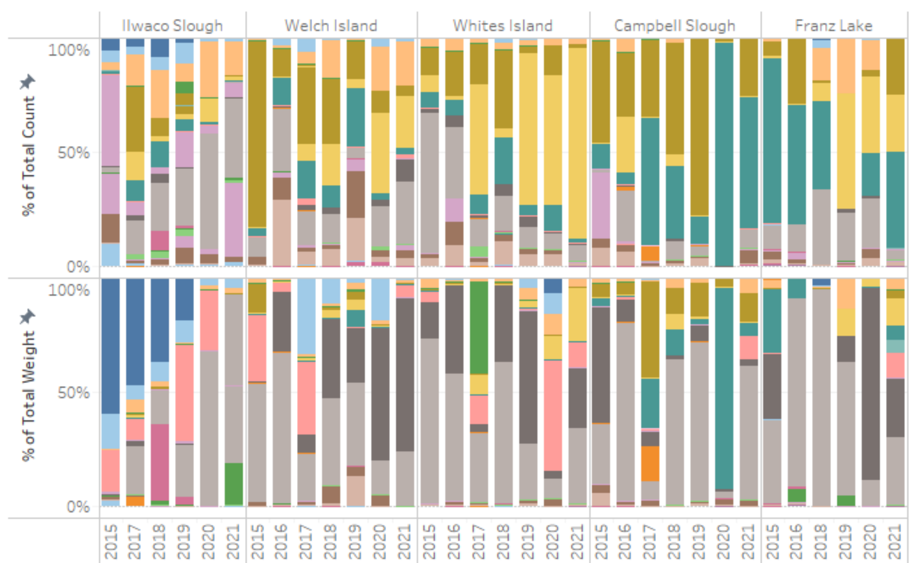
Action guide: Click on a site within the map to select a site. Use CTRL+Click to select multiple sites. Hover over a class to highlight it across to the other data table. Utilize the filter below to adjust the site being viewed.

Bonus action: Click on a specific taxa's box in the left pane to view that macroinvertebrate.

Figure Invertebrate Taxa and Images: Invertebrate presence across all EMP Sites. Click the box to view image and hover over each box for more details.

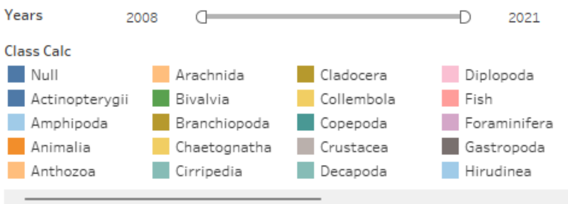
Class	Taxa	
Amphipoda	Americorophium salmonis	■
	Americorophium spinicorne	■
	Amphipod	■
	Amphipoda	■
	Corophiidae	■
	Crangonyx sp	■
	Gammaridea	■
	Hyalella azteca	■
	Hyallela azteca	■

Emergent Vegetation Invertebrates



[redacted]

Figure 3.3.1 (right): Bar plots of the counts and weights (g) of invertebrates in emergent vegetation and open water neuston tows. Plots are sorted by year and site, and color-coded by Class of invertebrate.



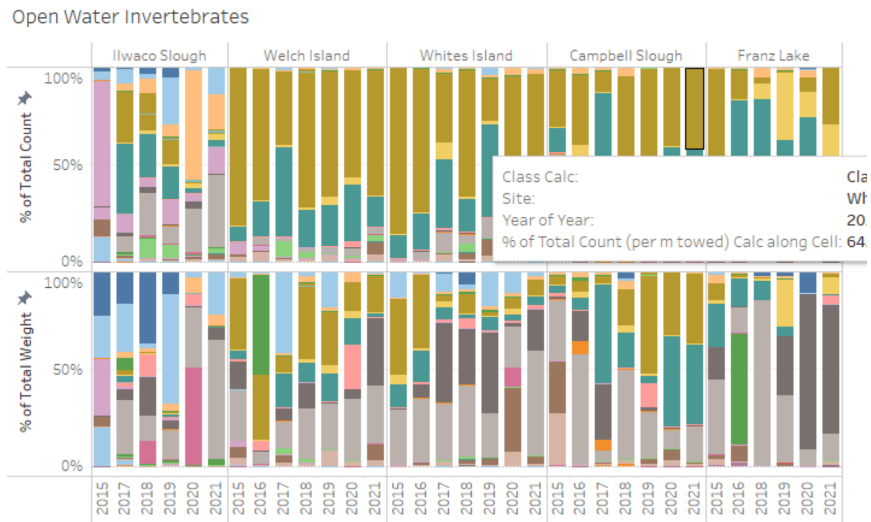
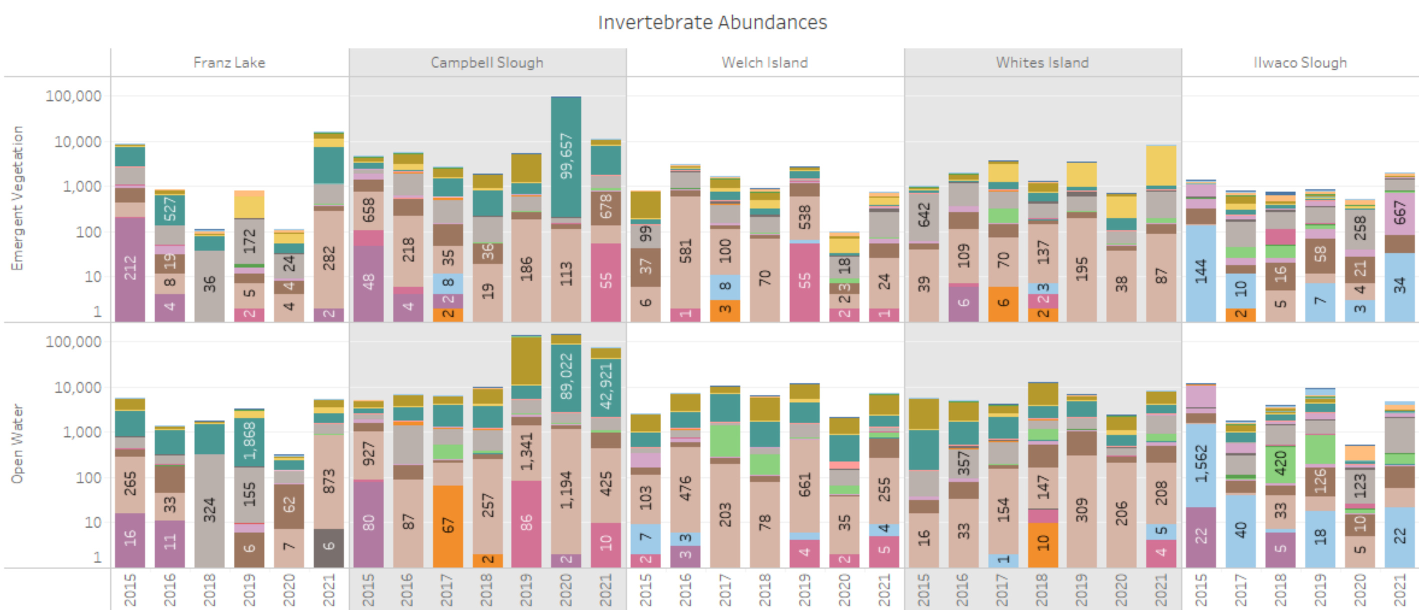
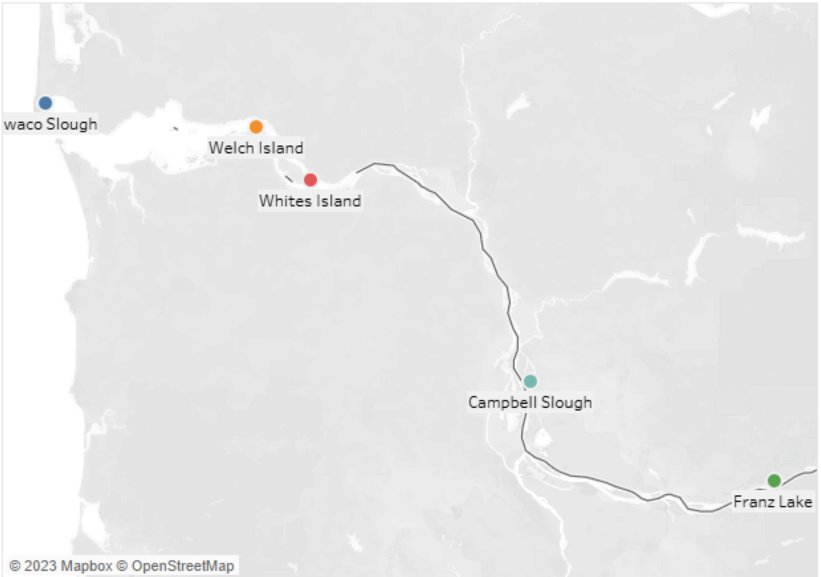


Figure 3.3.2: Abundances of prey items in emergent vegetatation and open water neuston tows. Bar plots are sorted by year and site and color-coded by prey Class. Counts are log-scaled to account for orders of magnitude difference in prey counts.



Benthic Sampling



Return to Welcome Page

Return to Section 3 - Neuston

Benthic Core Sample Invertebrate Composition

About: Benthic cores sample invertebrates living in bottom substrates.

Results: Benthic core invertebrates are interannually and spatially consistent. Top salmonid prey taxa differ in benthic cores but are not predominant: **cladocerans** are rare, **amphipods** are present closer to the river mouth at Ilwaco Slough, and **dipterans** are present further upstream from Ilwaco Slough.

Discussion: Top salmon prey of amphipods and dipterans are present in samples. Amphipod densities are low in all locations but are higher downstream, where their densities are highest at Ilwaco Slough. Average densities of dipterans are typically lower downstream and higher upstream.

Action guide: Click on a site within the map to select a site. Use CTRL+Click to select multiple sites. Hover over a class to highlight it across to the other data table. Utilize the filter below to adjust the site being viewed.

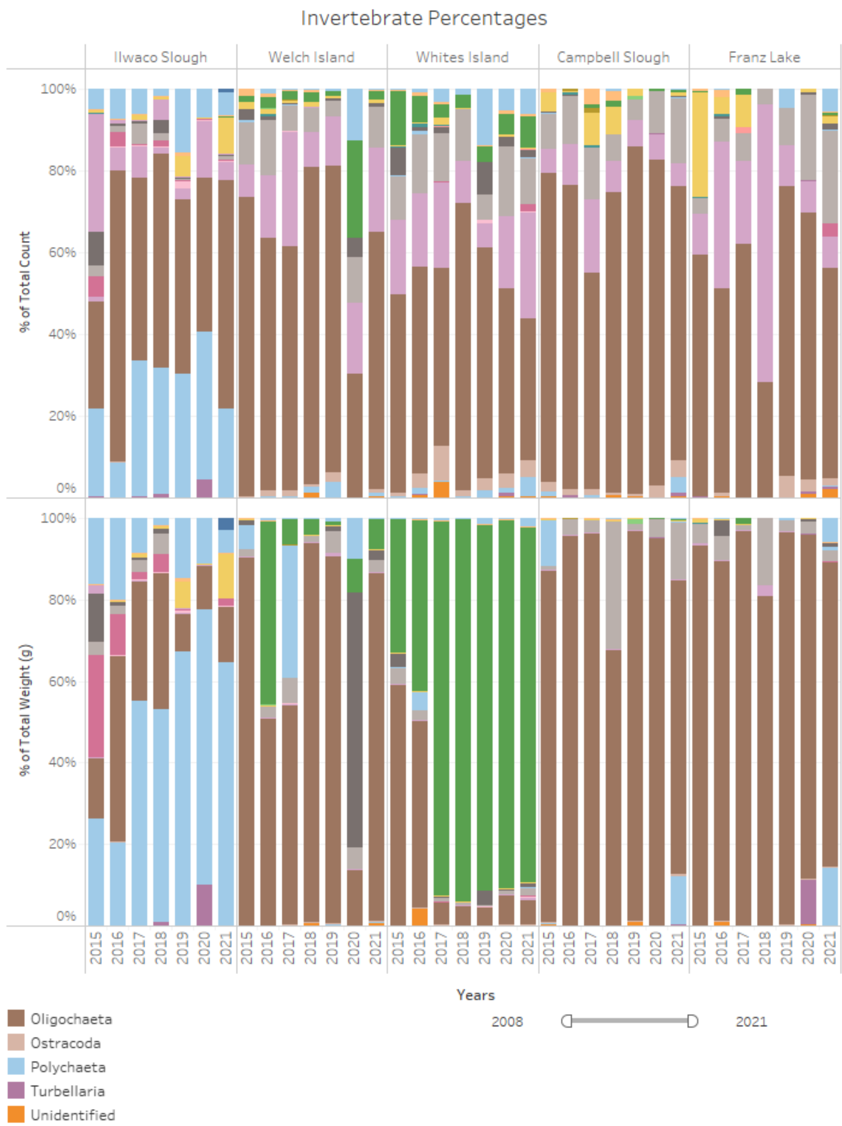
Bonus action: Click on a specific taxa's box in the left pane to view that macroinvertebrate.

Figure Invertebrate Taxa and Images: Invertebrate presence across all EMP Sites. Click the box to view image and hover over each box for more details.

Class	Taxa
Amphipoda	Americorophium salmonis
	Americorophium spinicorne
	Amphipod
	Amphipoda
	Corophiidae
	Crangonyx sp
	Gammaridea
	Hyalella azteca
	Hyallela azteca
	Hyallela sp
Animalia	Animal matter
Anthozoa	Actinaria
	Actiniaria
	Anthozoa

Numerically, (as a percentage of counts of taxa/total counts), oligochates, then nematodes, dipterans, and polychaetes, are the most abundant taxa in cores. Gravimetrically (as a percentage of weight of taxa/total weight of taxa), oligochaetes, bivalves, and polychaetes comprise the most weight in cores.

Figure 3.4.1: Bar plots of the counts and weights (g) of invertebrates in benthic core samples. Plots are sorted by year and site, and color-coded by Class of invertebrate.



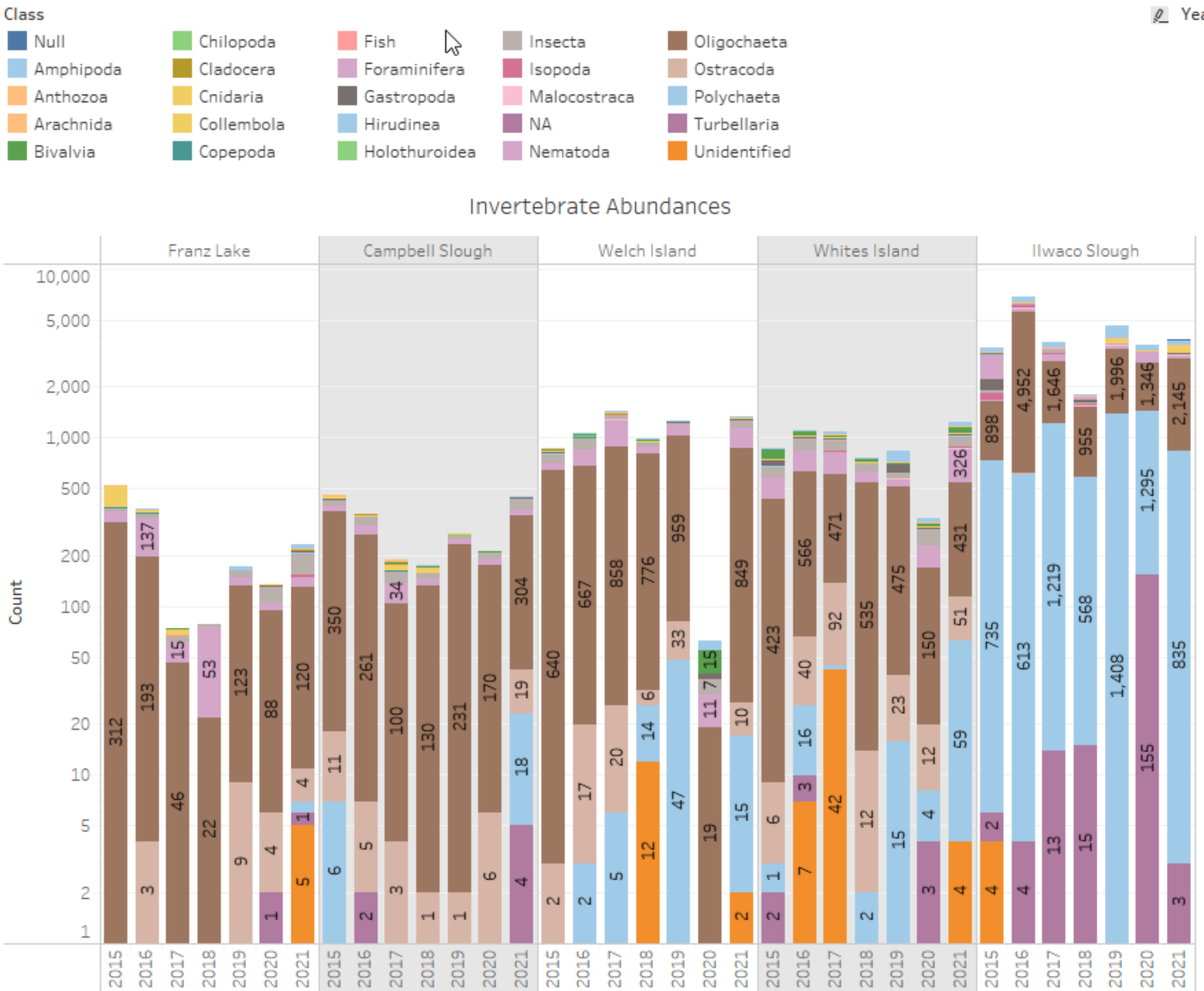


Figure 3.4.2: Abundances of prey items in benthic core samples. Bar plots are sorted by year and site and color-coded by prey Class. Counts are log-scaled to account for orders of difference in prey counts.The highest invertebrate densities occur at Ilwaco Slough, where annual densities are typically over 1M.

Developed for Bonneville Power Administration

Authors (University of Washington): Kerry Accola, Jason Toft
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao
Other Major Contributors: Jeff Cordell and the UW Wetland Ecosystem Team

Welcome to the Fish Ecosystem Monitoring Dashboard

Navigate to Section 1 - Sampling Effort and Data Inventory

Navigate to Section 2 - Fish Community

Navigate to Section 3 - Salmon Metrics

Developed for Bonneville Power Administration
Authors (NOAA): Jeffery Grote, Susan Hinton, and Curtis Roegner
Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact monitoring@estuarypartnership.org

Overview Map

Executive Summary of Fish Results

Examinations of fish communities for all years of sampling show that all five trend sites are different from each other. The one exception is that Welch and Whites, when compared directly to each other, are similar. Thirteen major families of fish have been consistently present at the trend sites. Within those families, the fish species range from native marine species at Ilwaco Slough, to freshwater native and non-native species at the remaining EMP trend sites sampled through 2022. Chinook salmon are captured at all five trend sites and are often the numerically dominant salmonid species. Chum salmon (primarily at Ilwaco Slough) and coho salmon (primarily at Franz Lake) have also been captured at the five sites in low numbers.

Ilwaco Slough, sampled for fish since 2011, is the only trend site that is influenced by marine waters due to its proximity to the mouth of the Columbia River (rkm 6). The species most consistently captured (eight or more of the last 10 years of sampling) are the native threespine stickleback, staghorn sculpin and shiner perch and the non-native banded killifish. Two salmon species, chum and Chinook, are regularly captured at this site. Chum salmon was the dominant species (>= 90% of the total salmon numbers) except during 2012 and 2015, when few salmon were captured. Through 2022, six or less individual Chinook salmon were captured during eight of the eleven years of sampling. Most were unmarked salmon (presumed wild); however, marked salmon (presumed hatchery reared) were captured in 2017 and 2018. The majority of Chinook salmon captured at Ilwaco Slough were subyearlings (fork length <60mm, weight < 2 grams). Genetic analysis of unmarked and marked Chinook salmon captured at Ilwaco Slough has identified two stocks, Spring Creek group-fall and West Cascade-fall.

This Dashboard Provides a Brief Methods Overview and Links to all the Results Summaries: Click any of the buttons below to access more data.

Navigate to Overview Dashboard

Navigate to Mainstem and Abiotic site conditions

Navigate to Habitat Strucutre

Navigate to Food Web analysis

Navigate to Macroinvertebrate Analysis

Citation: Kidd, S.A., Edgar, I., Rao, S., Accola, K., Cordell, J., Chittaro, P.M., Grote, J., Hinton, S.A., Needoba, J.A., Peterson, T.D., Roegner, C., Toft, J.D., Borde, A.B., Corbett, C.A., Cook, L.P., Cullinan, V.I., Fuller, R.N., Hanson, A.C., Kuligowski, D., Lomax, D., Johnson, L.L., McNatt, R., Poppe, K., Zimmerman, S.A., Ylitalo, G.M, et al. 2023. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 17 (October 1, 2021 to September 30, 2022). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

LOWER COLUMBIA RIVER ECOSYSTEM MONITORING PROGRAM ANNUAL REPORT

LOWER COLUMBIA RIVER ACTION EFFECTIVENESS MONITORING AND RESEARCH ANNUAL REPORT

PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

Welch Island, sampled for fish since 2012, is a tidally influenced, freshwater marsh habitat in the lower Columbia River (rkm 53). The species most consistently captured (11 out of the 11 years of sampling) are the native Chinook salmon, threespine stickleback, and the non-native banded killifish. Chinook salmon comprised 96% or greater of the total numbers of salmon captured within a year and were captured each year. Chum were the second most frequently seen salmon, making up 4% or less of all salmon in a given year, and have been captured in seven of ten years of sampling. Each year 70–100% of the Chinook salmon captured at Welch Island were unmarked (presumably wild) juveniles. Genetic composition of unmarked Chinook salmon captured at Welch Island has been dominated by West Cascade-fall followed by upper Columbia River-summer/fall. There have been minimal instances of Snake River-fall, Spring Creek-fall, and Rogue River. Genetic composition of marked Chinook salmon at Welch Island had been comprised primarily of two genetic stock groups, West Cascade-fall and Spring Creek Group-fall.

Whites Island, sampled for fish since 2009, is a freshwater, tidally influenced marsh, located on the north side of Puget Island in the Columbia River (rkm 72). The species most consistently captured in all years are the native Chinook salmon and threespine stickleback and the non-native banded killifish. Five different species in the Salmonidae family have been identified at Whites Island since 2009. The site has been dominated by juvenile Chinook, followed by chum salmon. Coho, sockeye and mountain whitefish are other species of the Salmonidae family caught at the site. The majority of Chinook salmon captured were unmarked, making up 70–100% of the yearly total. For eight of the sampling years, unmarked juvenile Chinook fry have made up over half of all Chinook catches. Marked Chinook (presumed hatchery origin) were primarily fingerlings with the occasional yearling seen in 2009, 2010 and 2019. From the genetic stock analysis of unmarked Chinook salmon, seven different stocks have been identified since 2009. West Cascade-fall stock is the predominant group, comprising 80% or more of the fish analyzed. For marked Chinook, four genetic stocks have been identified at Whites Island since 2009. The two major groups are West Cascade-fall and Spring Creek Group fall.

Campbell Slough (rkm 149), sampled for fish since 2008, is a freshwater area that is highly influenced by Bonneville Dam discharge, and minimally influenced by standard tidal fluctuations. The species most consistently captured in all years are the native Chinook salmon, threespine stickleback, and the non- native banded killifish. Six species of the family Salmonidae have been observed in Campbell Slough since 2008. The most common species is Chinook salmon followed by chum salmon. Coho, cutthroat trout, sockeye salmon, and mountain whitefish are the remaining species in the Salmonidae family. Fry and fingerling unmarked juvenile Chinook make up most of the salmon catches at the site. No marked juvenile fry chinook have been captured at the site. Marked juvenile Chinook are primarily fingerlings. Seven distinct genetic stocks of marked and unmarked Chinook salmon have been found in Campbell Slough. The most consistent stocks for both marked and unmarked Chinook are Spring Creek Group-fall, followed by West Cascade-fall, although percentage contribution in catches vary extensively over the monitoring years.

Franz Lake, sampled since 2008, is a freshwater site located at the confluence of the Franz Lake outlet channel and the Columbia River (rkm 221). The water levels at this site are almost exclusively controlled by discharge from the nearby Bonneville Dam. High water levels in the spring and warm water temperatures in the early summer regularly prevent monthly fish sampling. The most consistently captured fish species (9 out of 11 years of sampling) are the native threespine stickleback, largescale sucker, northern pikeminnow, and the non-native banded killifish. Nine species of Salmonidae have been captured at this site in the past years, contributing to less than 5% of total catches per year at this site. This could be an outcome of lack of optimal conditions for sampling at this site, among other environmental factors. Salmon catches predominantly consisted of juvenile Chinook and coho. Juvenile Chinook at Franz Lake are primarily unmarked, and Chinook catches were strong in 2022, despite only sampling one month. The unmarked category of Chinook was predominantly fry (<60 mm fork length) making up more than 70% of those captured followed by fingerlings (60-100 mm fork length). Marked (presumed hatchery origin) Chinook have only been captured in 2008 and 2009. Genetics analysis of Chinook salmon over the course of the 14 years of sampling has been conducted on very few unmarked (23) and marked (41) individuals. No one group is dominant, and no discernable pattern can be seen among the stock groups identified. For unmarked Chinook salmon, stock groups include Spring Creek Group-fall, upper Columbia River-fall, Snake River-fall, West Cascade-fall, mid and upper Columbia-spring, and Willamette River-spring. For marked Chinook salmon, Spring Creek Group-fall are the most common, and West Cascade-fall and Willamette River-spring have also been present.

1 - Sampling Effort and Data Inventory

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Navigate to Section 2 - Fish Communities

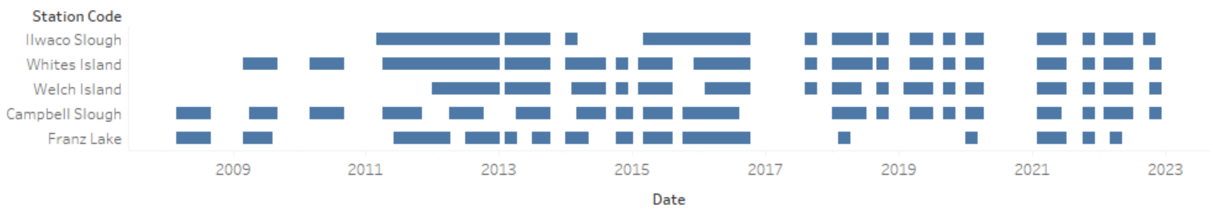
Navigate to Section 3 - Salmon Metrics

Overview of Sampling Effort and Data Inventory

The project goal is to collect fish for six months of the year at all sites, March-June and October. Occasionally conditions at a site prohibit sampling, such as extremely high or low water levels, water temperatures become to high for handling fish, or road conditions prevent traveling to launch sites. Fish are collected using a 38 x 3-m variable mesh bag seine (10.0 mm and 6.3 mm wings, 4.8 mm bag). Bag seine sets were deployed using a 17 ft Boston Whaler or 9 ft inflatable raft. Up to three sets were performed per sampling month, as conditions allowed. At each sampling event, the coordinates of the sampling locations, the time of sampling, water temperature, weather, habitat conditions, and tide conditions were recorded. All non-salmonid fish were identified to the species level and counted. For salmonid species other than Chinook, up to 30 individuals were measured (fork length, nearest mm), weighed (nearest gram), and released. Up to 30 juvenile Chinook salmon were euthanized in the field, measured, weighed, and retained for subsequent laboratory analyses (diet, genetic, lipid, and otolith). If present, an additional 70 Chinook were measured and released. Any additional Chinook were counted and released. All salmonids were checked for adipose fin clips, or other external marks, coded wire tags, and passive integrated transponder tags to distinguish between marked hatchery fish and unmarked (presumably wild) fish.

Gantt Chart

Table 1.1 Summary of fish sampling effort by site and year(s) conducted at EMP sampling sites.



Developed for Bonneville Power Administration

Authors (NOAA): Jeffery Grote, Susan Hinton, and Curtis Roegner
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For more information please contact monitoring@estuarypartnership.org

2- Fish Community

Overview Map

Return to Welcome Page

Return to Section 1 - Sampling Effort and Data

Navigate to Species Richness

Fish Community Overview Across EMP Sites:
Across our sites in 2022, we detected:

-**14 distinct fish families**, encompassing **22 taxonomic categories**. These categories often mix specific species with unidentified members within a family or genus.

Key findings include:

-**Threespine Stickleback**, **Chinook Salmon**, and **Banded Killifish** were consistently found at every site.

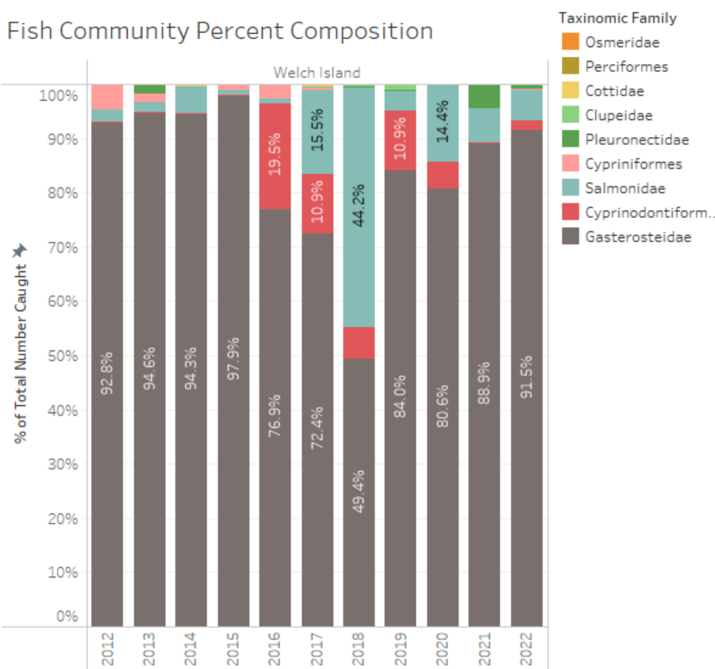
-Salmon Distribution:
Chinook was most widespread, being common and often dominant except at Ilwaco Slough, where **Chum** prevailed.
Chum appeared at three sites (Welch and White Islands, Campbell Slough) but didn't always dominate.
Coho were exclusive to Campbell Slough.

- Site-specific Dominance:
Ilwaco Slough: Dominated by Threespine Stickleback (79%).
Welch Island: Threespine Stickleback took the lead (92%).
Franz Lake: Chinook salmon dominated with 82%.
White Island: A balance between Chinook Salmon and Threespine Sticklebacks, each at 45%.

-Diversity Peak: Campbell Slough topped with 13 taxonomic categories, trailed by Ilwaco Slough at 10. Campbell Slough and Franz Lake regularly present the widest array of fish families and their respective species, notably hosting warm-water-tolerant or introduced species from families like Centrarchidae and Cyprinidae.

Navigating the Data: Click on the map to explore individual site data. For a multi-site view, use CTRL+Click.

Fish Community Percent Composition



Native vs Non Native Counts

		Non native	Native
Welch Island	2022	196	10,526
	2021	20	6,204
	2020	11	211
	2019	484	3,635
	2018	198	2,936
	2017	319	2,467
	2016	3,142	12,965
	2015	10	5,084
	2014	12	5,033
	2013	17	9,784
	2012	38	13,344

Gasterosteus aculeatus, Common name: Threespine Stickleback, Photo Credit: Ryan Hagerty, US Fish and Wildlife Service (click for more information)

Fish Community Counts

		Long-term Avg	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Welch Island	Gasterosteidae	**6,034**	9,814	5,535	179	3,462	1,547	2,016	12,390	4,988	4,759	9,271	12,412
	Salmonidae	**357**	594	392	32	154	1,385	432	133	43	264	192	308
	Cyprinodontiform..	**397**	196	17	11	451	184	305	3,136	6	12	17	37
	Cypriniformes	**141**	20			2	1	14	441	51	1	148	589
	Pleuronectidae	**73**	92	275		8	3			1	1	171	31
	Clupeidae	**12**		3		33	13	6		4			
	Perciformes	**5**						8	6				1
	Cottidae	**3**	6	2		9	1	5	1	1	1	1	4
	Osmeridae	**4**									7	1	

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Editors (Lower Columbia Estuary Partnership): Sarah Kidd, Ian Edgar, Sneha Rao

For more information please contact monitoring@estuarypartnership.org

3- Salmon Metrics

Overview Map

Images of Chinook Salmon - click for more information about the images

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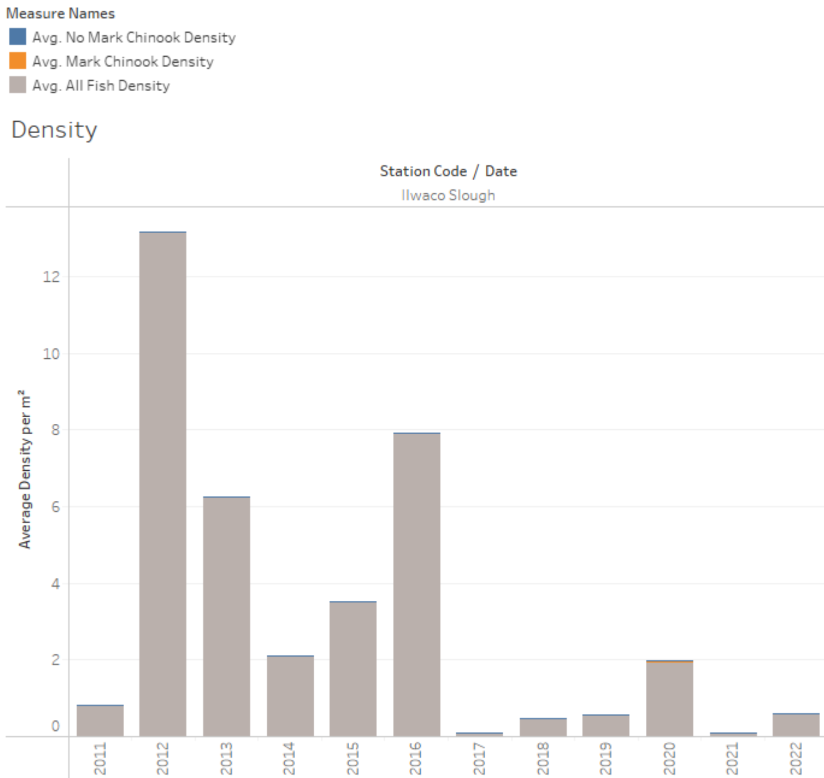
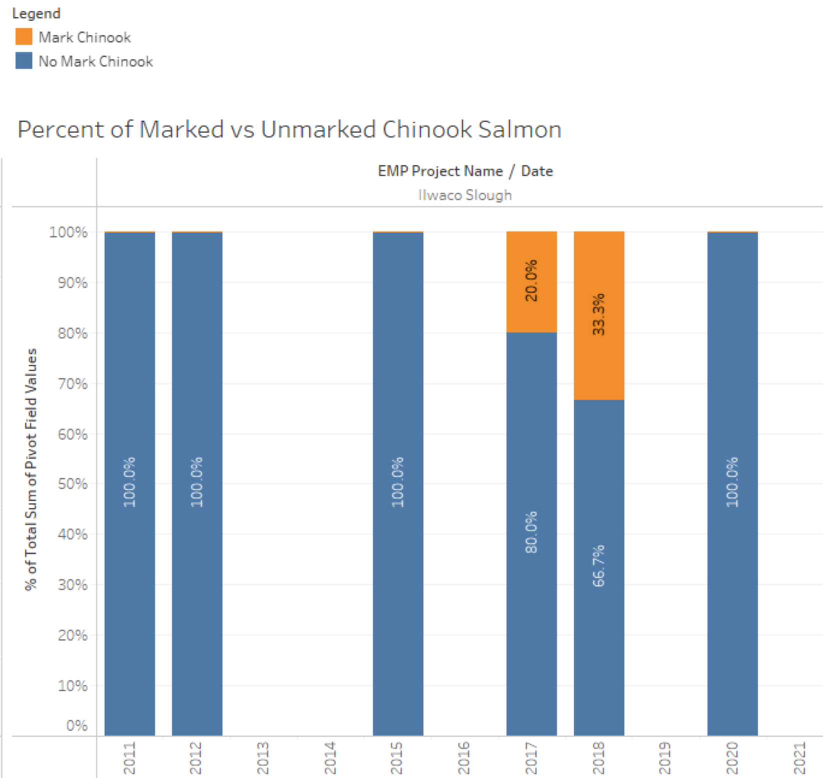
Navigate to Chinook Size and growth

Results Summary:

In 2022, unmarked Chinook salmon were captured at the EMP trend sites from March through June and again in November. The highest average densities of unmarked juvenile Chinook salmon were 2.23 per m^2 in April. Marked Chinook salmon were captured from April through June and again in November. The highest average densities of 0.11 fish per m^2 in April. Mean Chinook salmon densities by site and year are shown in 2022 Chinook density graph. In 2022 the density of unmarked Chinook salmon was highest at Whites Island (2.76 fish per m^2) and Welch Island (0.68 fish per m^2) and lowest at Ilwaco Slough (0.004 fish per m^2). Franz Lake was only sampled once due to high water but had strong April Chinook catches with a density of (0.24 fish per m^2). Campbell Slough Unmarked chinook catch density was 0.42 fish per m^2. Campbell Slough historically sees the greatest mix of unmarked and marked Chinook. Densities of marked Chinook salmon in 2022 were greatest at Campbell Slough; with a density of (0.11 fish per m^2) catches were slightly greater than in previous years. The densities of marked Chinook salmon in 2021 were generally within similar ranges as seen from 2008-2021 at all sites.

Action Guide: Click on the map to view a different site's data. Use **CTRL+Click** to select multiple sites.





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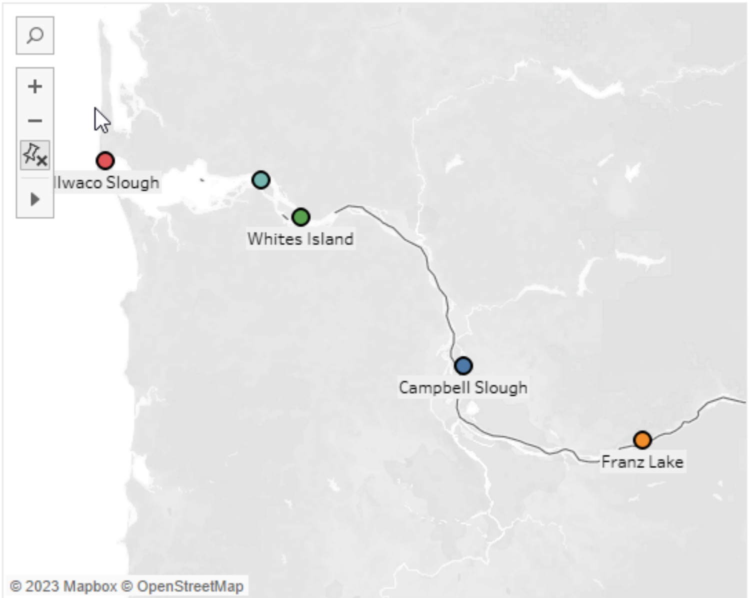
Species Richness

Overview Map



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Navigate to Salmon Metrics

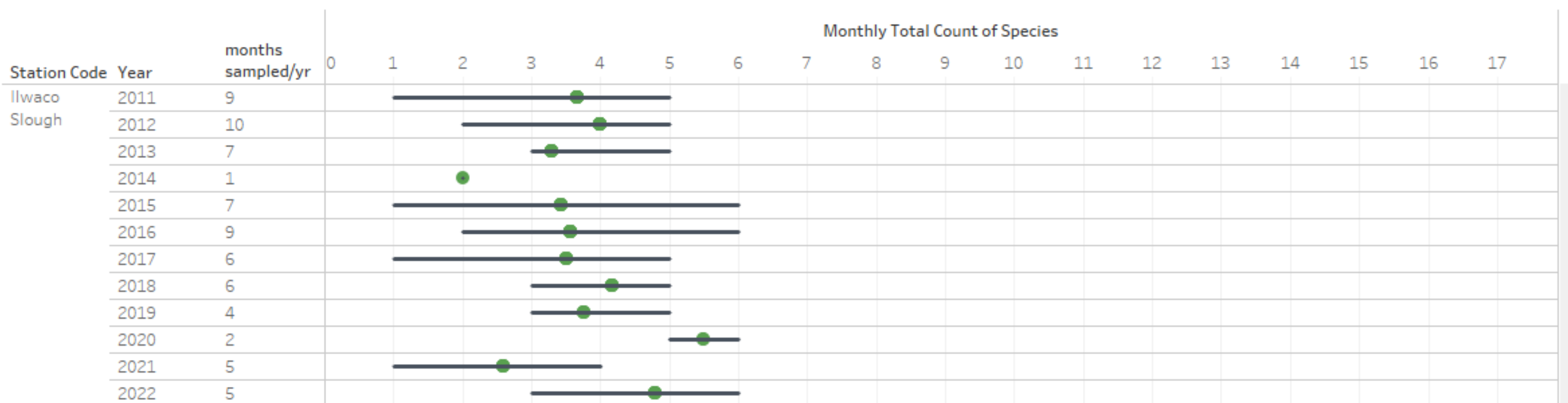
In 2022:
Mean species richness remained within expected values for each location.
For specific sites:
Ilwaco Slough, **Welch Island**, and **Whites Island**: Consistency is key. Mean species richness and monthly ranges across years consistently present 0-8 species/month.

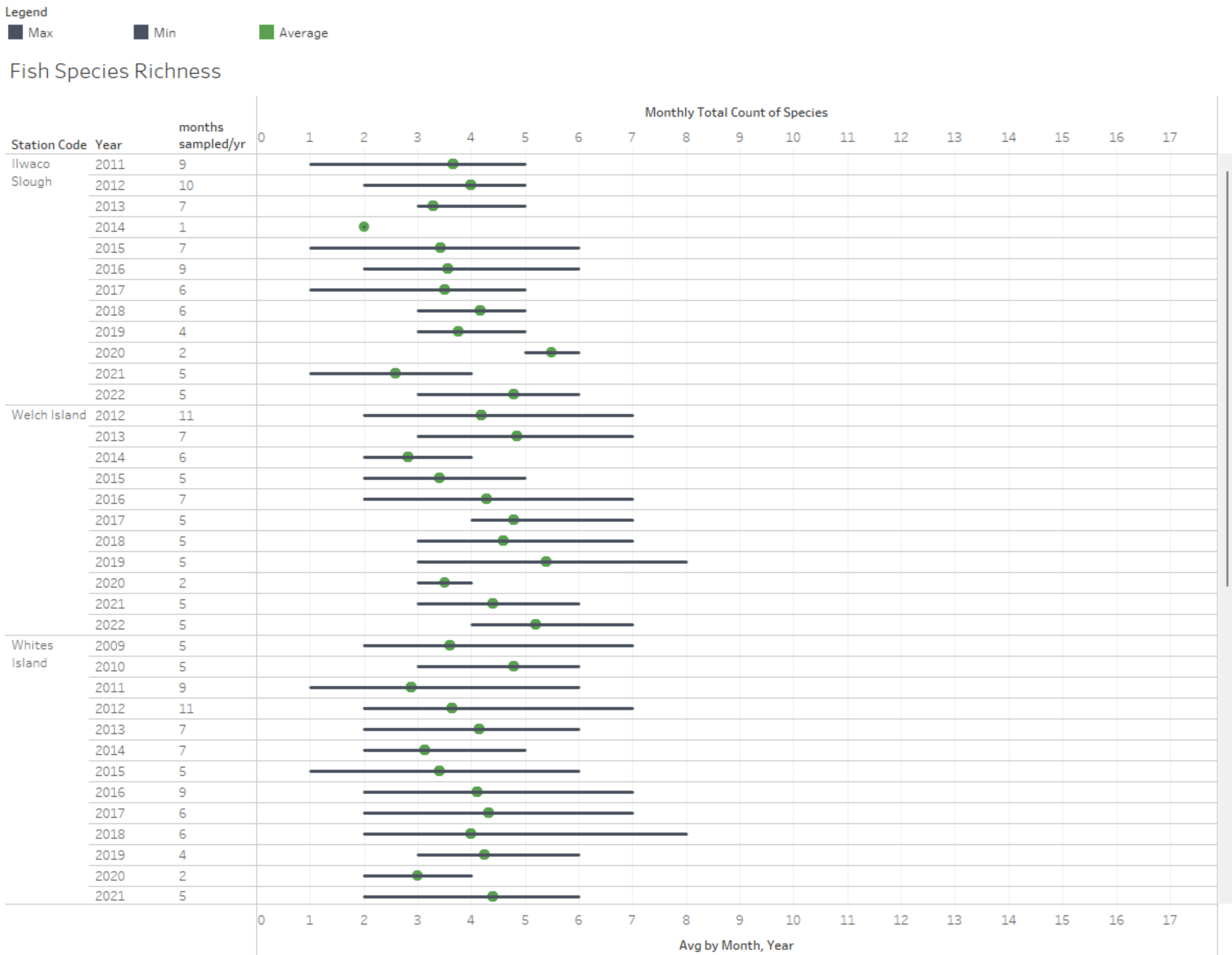
Campbell Slough and Franz Lake: They display a richer biodiversity, showcasing 0-18 species. These areas not only include but are predominantly influenced by non-native species that thrive in warm waters during low river flow phases.

Franz Lake's Unique Challenge: Variability in species richness here also responds to the limited sampling time each year. High water discharge from the Bonneville Dam often leads to flooding of the entire sample area, making data collection unfeasible.
..

Legend
Max Min Average

Fish Species Richness





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Chinook Length and Weight

Overview Map

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Action Guide: Click on the map to view a different site's data. Use **CTRL+Click** to select multiple sites.

Chinook Salmon Metrics Across EMP Sites:
In 2022, unmarked Chinook salmon were successfully caught across all sampled sites. Key findings include:

Whites Island: Averaged 56.40 mm (± 0.67) and 1.97 g (± 0.04).
Welch Island: Averaged 50.52 mm (± 0.87) and 1.49 g (± 0.05).
Campbell Slough: Showcased the largest fish, averaging 77.36 mm (± 0.81) and 5.87 g (± 0.04).
Ilwaco Slough: Averaged 61.25 mm (± 1.67) and 3.07 g (± 0.63).
Franz Lake: Averaged 52.86 mm (± 0.67) and 1.73 g (± 0.05).

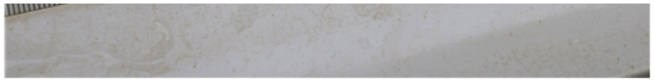
Within each site, yearly variations were evident, though no consistent trend appeared. For instance, 2022's unmarked Chinook at Whites Island mirrored sizes from 2018 and 2019. While Welch's Chinook were slightly smaller than in 2021, the average size resembled pre-2021 measurements. Despite limited catches at Franz and Ilwaco, both recorded near-peak averages in length and weight.

For marked Chinook, significant catches were noted at both Campbell Slough and Whites Island. Specifically:

Campbell Slough: Averaged 82.11 mm (± 2.21) and 6.46 g (± 1.01), maintaining consistent measurements over the past 12 years.
Whites Island: Averaged 78.50 mm (± 0.90) and 4.09 g (± 0.44), though this is based on only four samples.

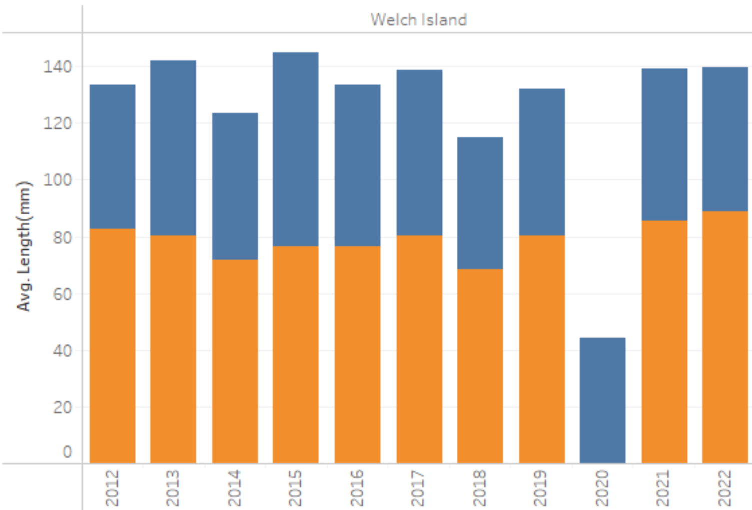
Understanding Markings: Markings help in research and tracking. While tagged fish carry specific identification labels, untagged ones lack any such identifiers. "Marked" fish have discernible markings, like tags, fin clips, or dye. Conversely, "unmarked" fish have no visible identifiers. The intent behind such markings often ties back to research aims or management strategies.

Marked (Tagged) vs. Unmarked (Not Tagged) Fish
- Not tagged
- Tagged

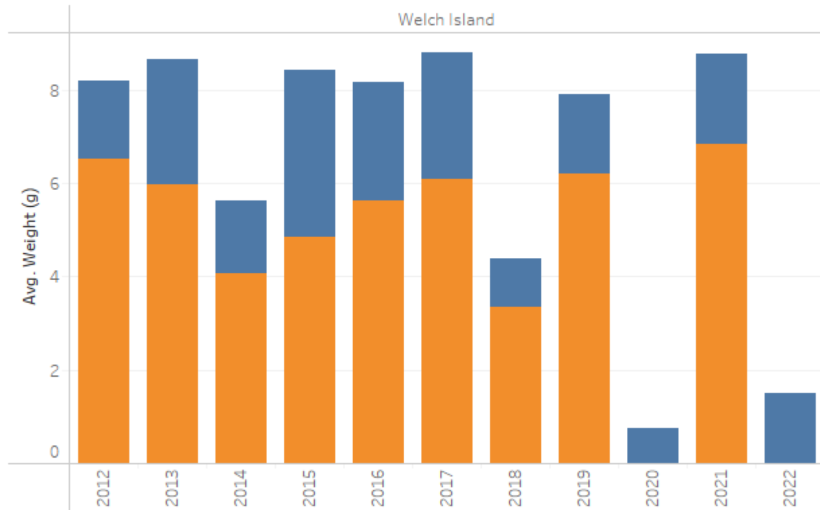


Marked (Tagged) vs. Unmarked (Not Tagged) Fish
Not tagged
Tagged

Chinook Salmon Length (mm) 2008 - 2022



Chinook Salmon Weight (g) 2008 - 2022



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