Action Effectiveness Monitoring for the Lower Columbia River Estuary Habitat Restoration Program

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Action Effectiveness Monitoring for the Lower Columbia River Estuary Habitat Restoration Program Annual Report (October 2019 to September 2021)

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[1] Columbia River Estuary Study Taskforce
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ABBREVIATIONS AND ACRONYMS

AEM	Action Effectiveness Monitoring
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
CRD	Columbia River Datum
CREST	Columbia River Estuary Study Taskforce
EMP	Ecosystem Monitoring Program
ESA	Endangered Species Act
NMS	nonmetric multidimensional scaling
ORP	Oxygen Reduction Potential
PIT	passive integrated transponder
RPA	Reasonable and prudent alternative
SEV	Sum Exceedance Value
UAV	Unmanned Aerial Vehicle
USACE	U.S. Army Corps of Engineers
WSE	Water Surface Elevation

EXECUTIVE SUMMARY

The Lower Columbia Estuary Partnership (LCEP) manages the Action Effectiveness Monitoring (AEM) program with the goals of determining the impact of habitat restoration actions on salmon at the site and landscape scale, identifying how restoration techniques address limiting factors for juvenile salmonids, and improving restoration techniques to maximize the impact of restoration actions. To accomplish AEM program goals, LCEP implements the Columbia Estuary Ecosystem Restoration Program (CEERP) AEM Programmatic plan (Johnson et al. 2016), employs standardized monitoring protocols, and coordinates between stakeholders to collect and share AEM data. The AEM annual monitoring objectives were to quantify post-restoration hydrology, temperature, habitat, and vegetation within restoration sites and to determine post-restoration fish use at selected sites.

Twenty-six restoration sites in 2020 and twenty-two in 2021 received AEM data collection (Figure 1, Table 1). All monitoring was conducted following standardized protocols outlined in Roegner et al. (2009). Four restoration sites were selected for Level 2 monitoring (Table 2) in 2020 and 2021 using the prioritization criteria outlined in Johnson et al. (2016). Three associated reference sites were chosen to establish a before-after reference impact monitoring design, which puts pre- and post-restoration site data into ecological context (Table 2).

To better meet the goals and objectives of the AEM Program, the results of this report are presented in the form of Tableau dashboards. On this platform, LCEP has publicly disseminated multiple datasets and analyses including hydrology, vegetation, sediment accretion, drone analyses, macroinvertebrates, fish, and other datasets. The following section provides a brief overview of the AEM Level 2 Monitoring sites from 2020 and 2021.

Wallooskee – Youngs Project
Project Sponsor: Cowlitz Indian Tribe

Need for restoration: Historically a dairy farm, the site had been disconnected from active tidal flooding for over a hundred years.

Project goals: Removing the levee and filling the borrow ditch will increase hydrologic connectivity during the tidal cycle and increase the spatial extent of inundation in the wetland. The restoration of a more natural tidal cycle will help restore ecosystem function by supporting a diverse native plant community, improving nutrient cycling, and increasing the quantity and quality of off-channel habitat for aquatic species.

Construction actions taken: In July 2017, tidal flooding was restored throughout the wetland by removing and lowering levees bordering the site. Additional channel enhancements were conducted in areas to expand channel density and access to wetland habitat. **Dagget Point** was selected as the local reference site for this project.

Executive Summary of Results: In just three years post-restoration, the Wallooskee restoration site has dramatically shifted from an agricultural field to a functioning tidal wetland dominated by native wetland plant communities. Using UAV imagery collected in 2020, 3 years post-construction, we have captured the full suite of habitat conditions that have developed across the site. In addition to a dramatic shift in plant community composition seen on the ground and through the areal imagery, we have also observed a dramatic shift in soil conditions and sediment accretion and erosion dynamics towards reference site conditions. Water surface elevation and temperature dynamics also match those of the contributing waterways, Youngs Bay and the Wallooskee River. While year 3-post restoration is still early in the life of a restored tidal wetland, results indicate Wallooskee is on a very successful trajectory towards a productive high-quality salmonid habitat. In further support of these conclusions, early results from the check-in fishing conducted in the spring of 2022, indicate the site is full of juvenile salmonids.

A complete analysis of the site including a fish survey, macroinvertebrates sampling, and a full drone analysis will be coming with the year 5 check-in of Wallooskee – Youngs in 2022. These data will be available in 2023.

Flight's End Project
Project Sponsor: Columbia River Estuary Study Taskforce

Need for restoration: The site was formerly a ponded habitat with agricultural land management and vegetation to attract waterfowl. Culverts, water control structures and artificial berms prevented salmonid access, regular inundation and altered historic hydrologic and geomorphic processes. These site conditions prevented the establishment of a native wetland vegetation mix, nutrient cycling, and restricted fish access. A vegetation survey undertaken in 2016 (pre-restoration) showed that wetted perimeters and historic prairie zones were dominated by Reed canarygrass (*Phalaris arundinacea*). The National Marine Fisheries Service (NMFS) collected juvenile salmonid data along the mainstem channel of Reach F showing high levels of genetic stock diversity for juvenile Chinook.

Project goals: The overall vision for Flights End wetlands was to increase connectivity to Crane Lake and the larger Multnomah Channel to create a network of habitats for salmonids and other species.

Project objectives: This restoration project aimed to connect 42 acres of floodplain wetlands to the Columbia River. The objectives of the project were: 1) Reestablishing hydrologic connectivity to Crane Lake and Multnomah Channel by the removal of artificial berms and culverts and creating a network of channels, and 2) Establishing a native wetland vegetation community by selective marsh plain lowering and replanting these areas with a native emergent – wet prairie mix.

Construction actions taken: Construction occurred in 2017, and construction actions included the removal of two culverts, the artificial berm, and marsh plain lowering. Target elevations were achieved by using wetlands in the Crane Lake system and the larger Sauvie Island complex as design references. Specific actions included: 1) Remove artificial earth berm and two additional undersized culverts that blocked the historical channel, 2) Create two channel openings from Crane Slough into the wetlands, 3) Retention of a water control structure to allow managers additional stewardship options for a late summer drawdown of water for moist soil management, 4) Lower marsh plain surfaces to increase frequency, duration, and magnitude of water inundation, and 5) Replant lowered marsh plain with native emergent species and wet prairie species. The local reference site for this site is **Cunningham Lake (EMP).**

Executive Summary of Monitoring Results: Three years post-restoration, Flight's End has an extremely promising ratio of native to non-native plant communities; however, there is a tremendous quantity of bare ground, likely due to the extreme mowing that the site sees. Additionally, the site continues to have a water control structure active, with water levels remaining significantly elevated at the site (holding water at 3 meters) compared to the reference site, Cunningham Lake (holds water at 2.1 meters). However, based on the restored channel connectivity elevation of 2.4 m, Flight’s End now provides salmonid accessibility throughout the year, mirroring habitat accessibility conditions at the reference site. Neither the low marsh nor the high marsh at Flight's End is keeping pace with forecasted sea level rise; however, soil conditions remain consistent with the local reference. It is recommended that the land management reduce the extent and the height of mowing to allow for natural plant community development and provide natural detrital flux to occur within the wetland complex.

A complete analysis of the site including a fish survey, macroinvertebrates, and a full drone analysis will be coming with the year 5 check-in of Flights End in 2022. These data will be available in 2023.

La Center Wetlands (Phase 1) Project
Project Sponsor: Lower Columbia Estuary Partnership (LCEP)

Need for restoration: In 2013, LCEP identified the constraints at the site, including impaired flow regimes, habitat complexity, and impaired fish passage.

Project goals: The overall project goal was to restore hydrologic and geomorphic processes at the two sites, La Center Wetland East and La Center Wetland West.

Project objectives: Project Specific objectives were to 1) Increasing inundation frequency and develop a flow regime that mimics the East Fork Lewis River (EFLR) on the site’s seasonal wetlands and floodplains to provide seasonal fish access to 453 acres of emergent marsh habitat through four levee breaches, 2) Creating riparian buffers along the side-channels by removing invasive species and planting native plants, 3) Improving instream and off-channel habitat diversity and complexity by adding 200-300 pieces of large woody debris (LWD) to the wetlands and newly created off-channel habitat, and 4) Improving fish passage by removing weirs and culverts. Redesign the engineered side-channel to allow fish passage at all flows.

Construction actions taken: Construction at these sites occurred in 2015, and efforts included levee breeches, weir and culvert removals, and riparian revegetation. Specifically, 1) Levee Breaches increase the connectivity of the sites to mainstem EFLR, increasing periods of inundation and floodplain habitat available for salmonids and other species, 2) Wier and Culvert removals enhance fish passage through the sites and restore hydrologic processes, and 3) Side channel and off-channel habitat enhancements through LWD placements increased habitat complexity and provide substrate for macroinvertebrates and organic matter input.

La Center Wetlands were restored in 2015. **La Center Phase 2**, a nearby wetland with a water control structure with similar conditions to La Center Wetlands in Pre, was used as a **control site**, to identify the benefits of the restoration process.

Executive Summary of Results: In just five years post-restoration (2020), La Center Wetlands have dramatically shifted to a functional fluvial wetland along the East Fork Lewis River. Hydrologic connectivity post-restoration mirrors those water levels observed in the East Fork, indicating a successful reconnection with the mainstem. While suffering from high temperatures (9% inhospitable and 24% marginal), these conditions also mirror those observed in the East Fork Lewis River, with higher than optimal temperatures occurring in the late summer months. Additionally, salmonid habitat opportunity analysis shows a significant improvement in fish accessibility across both sites. Year 5 soil conditions (2020) show well-developed wetland soil characteristics with low ORP conditions in the low marsh Wapato dominated zones. Across the restored wetlands, we have also observed native vegetation cover surpassing those levels observed at the control wetland. Macroinvertebrate species are also approaching optimal values; we have observed an increase in the abundance of Diptera, Copepods, and Oligochaetes across the sample years. Lastly, Fish sampling conducted in 2021 (a year late due to Covid-19 travel restrictions) resulted in a high number of sub-yearling, unmarked Chinook Salmon (20% of the catch). Collectively these data indicate that the La Center Wetlands are on track to be productive high-quality salmonid habitats. We will conduct a year 10 check-in of the site in 2025

Wallacut River Project
Project Sponsor: The Columbia Land Trust

Need for restoration: Due to a tide gate, the site had been disconnected from active tidal flooding for many years.

Project goals: Project goals at this restoration site were to increase the spatial extent of inundation to provide habitat opportunity for salmonids and other species.

Project objectives: Specific objectives included: 1) Removing the levee and filling the borrow ditch will increase hydrologic connectivity during the tidal cycle, and 2) The restoration of a more natural tidal cycle will help restore ecosystem function by supporting a diverse native plant community, improving nutrient cycling, and increasing quantity and quality of off-channel habitat for aquatic species.

Construction actions taken: In 2016, tidal influence on the Wallacut Slough was restored by removing barriers (tide gates) throughout the system. Additional channel enhancements were conducted in areas to expand channel density and access to wetland habitat. Wallacut River was restored in 2016. The local reference site for this site is Ilwaco Slough (EMP).

Executive Summary of Monitoring Results: At the year 5 post-restoration check-in, Wallacut River has dramatically shifted from a disconnected diked and drained field into a productive salmonid habitat. Overall, post-restoration, the site is very similar hydrologically to its reference site Ilwaco Slough with a similar percent time of accessibility and optimal salmonid conditions. Based on our monitoring, however, sediment accretion at the sites (both the restoration site and the reference site) is not expected to keep pace with the forecasted sea level rise. Wallacut Slough is primarily a high marsh site while Ilwaco Slough is mostly low marsh, so soil parameters are not completely comparable; however, salinity and pH conditions were lower at the restoration site than at the reference site and ORP is higher at the restoration site. These differences in soil conditions are mainly tied to the difference in hydrology observed across the reference and restoration site (low marsh vs. high marsh), however, it is possible with more time Wallacut River's soil conditions will shift further overtime. Specifically, it is anticipated that the site's soil salinity will continue to increase and lead to high pH conditions. The development of these soil conditions will help reduce the amount of Reed Canarygrass found on the site overtime These results are unsurprising as it is well documented that the restoration of high marsh soil and plant community conditions is much slower s than those of low marsh wetland areas (Kidd 2017). Wallacut River has seen a significant decrease in bareground since restoration and an increase in native species abundance, like those observed at Ilwaco Slough. Additionally, we've found macroinvertebrate communities are comparable between the sites. During the 5-year fish check-in, Wallacut had a lack of salmonids, but this is likely simply due to the timing of the fishing; all monitoring indicates the site is hosting robust salmon habitat conditions. We will conduct a year 10 check-in of Wallacut River in 2026.

North Unit Ph 1 Ruby Project
Project Sponsor: Columbia River Estuary Study Taskforce

Need for restoration: Water-control structures placed in channels connecting Ruby Lake to Cunningham Slough were outdated, restricting fish and degrading water quality. These structures also reduced channel velocities, altering sediment transport throughout the wetland. The lack of prolonged inundation also allowed Reed canarygrass to out-compete native wetland vegetation.

Project goals: The overall goal for this restoration project is to create a mosaic of wetland habitats that support juvenile salmonids by increasing tidal connection, reestablishing historical hydrology, and increasing habitat complexity.

Project objectives: The project-specific objectives are: 1) Improving habitat quality and opportunity by improving access to Cunningham Slough and reducing non-native vegetation to allow the establishment of native wetland mix, and 2) Utilizing Adaptive management practices to maintain habitat quality.

Construction actions taken: Ruby Lake restoration occurred in 2013, and construction actions included removing water control structure, channel enhancements, strategic marsh plain lowering and implementation of a vegetation enhancement plan. These techniques were aimed at increasing habitat opportunity at the site. Specifically, 1) Removal of the water control structure and channel enhancements will restore tidal connectivity to the site, increasing periods and levels of inundation at the site, and 2) Marsh plain lowering to target elevations based on reference wetlands like Cunningham Lake and riparian revegetation assists in the establishment of a native vegetation community, while staying inundated for longer, which reduces the chances of Reed canarygrass germination and survival. The local reference site for this site is **Cunningham Lake (EMP).**

Executive Summary of Monitoring Results: In the eight years since construction, Ruby Lake has matured from an unconnected lake into a productive salmonid habitat. Post-restoration, the habitat accessibility and temperature conditions at Ruby Lake generally mirror those observed at the reference site, Cunningham Lake. Due to the water control structure at Ruby Lake, pre-restoration the site was 100% inaccessible to salmonids in 2013. Post-restoration, the site has become accessible 85-78% of the year between 2014-2020. Compared to Cunningham Lake (EMP), the temperatures are slightly less hospitable, with elevated temperatures observed in July and August. Sediment accretion at Ruby is expected to keep pace with forecasted sea level rise in the high marsh elevations of the site. Additionally, soil conditions were also found to be consistent with Cunningham Lake based on elevation zone, with lower ORP conditions found in Ruby Lake – North which is primarily low marsh and higher ORP conditions found in Ruby Lake – South which is primarily high marsh. The ratio of non-native vegetation cover remains consistent between both sites. The overall living plant cover at Ruby Lake has increased over 20% since the year 5 check-in, much of this being an accumulation of Wapato (Sagittaria latifolia) in the scraped-down low marsh areas. Average Wapato abundance on the site has increased from 16% in 2018 to 44% in 2021, outpacing the reference site levels of 20% Wapato at Cunningham Lake. In 2021, Ruby Lake did, however, have an abundant amount of standing dead cover likely due to the very hot/dry summer of 2021 and the grazing occurring at the site. Macroinvertebrate abundances remained constant throughout all years. In year 5, Ruby Lake was found to host a diversity of fish species including salmonids. A full year 10 check-in is planned at Ruby Lake for 2023.

Horsetail Creek PIT Array
A PIT tag array was operated at Horsetail Creek between 2014 - 2019 to determine the type and residency time of salmonids at the site and address uncertainties related to fish passage through long culverts. The PIT Array was decommissioned in 2021; this report presents a summary of patterns observed.

Salmon from throughout the Columbia River Basin were detected at the Horsetail PIT array. Chinook salmon were the most numerous species detected of juvenile fish, and coho were the most numerous species detected of adult/Jacks. The mid-Columbia Basin was the origin of the largest number of PIT-tagged salmon detected at Horsetail, followed by the Snake River Basin, the lower Columbia River, the upper Columbia Basin, and the Yakima Basin. These detection patterns are most likely the result of how many PIT-tagged salmon of each species were released from each basin and the proximity of the release site to the Horsetail array.

Juvenile residence times were relatively short, most lasting less than one day and, in most cases less than one minute. However, steelhead, spring/summer run and fall run Chinook showed greater variability in residence times, with several fish residing five or more days. Two juvenile steelheads appear to have used the Horsetail restoration site as a prolonged rearing area. Both steelhead had been barged and were detected a short time after the barge dump date. One individual resided for an impressive 115 days. The second steelhead resided for 67 days and was then detected on an adult ladder at Bonneville, The Dalles, and John Day Dams. The detection history of both fish indicates that the Horsetail restoration site may be used as an extended rearing site for precocious juveniles.

For adult/Jack salmon detected at the Horsetail array, residence times did not have the same range as for juveniles. Coho salmon had the longest residence times with a maximum of 18 days, followed by steelhead with a maximum of 12 days. Coho were the most numerous adults detected, and their residency patterns indicate that adult salmon also tuck into small tributaries. Horsetail and Oneonta Creeks may provide cool water refuge for returning adults. Fish tagged as adults tended to be detected in October, shortly after they had been tagged and released, and were not likely to be seeking thermal refuge. However, one-third of salmon that were tagged as juveniles and then detected as an adult were first detected during August or September, when river temperatures tend to be highest. This indicates that adults may use Horsetail/Oneonta Creeks as a cold-water refuge during their upstream migration. Additionally, all but one of those adults detected during August and September originated from either the upper Columbia or Snake River Basins.

Residence times were impacted by whether salmon successfully navigated the culvert. Combining juveniles and adults, the median residence time for salmon that did not pass the culvert was 5 minutes. In contrast, the median residence time for salmon that did pass the culvert was 33 hours. There could be two explanations for this observance; 1) salmon that can pass the culvert will spend more time in the area, or 2) because it takes more time to pass the culvert, those fish that do pass have longer residence times. A more intensive analysis of the data would be able to look at the average length of time it took to pass from the downstream to the upstream side of the culvert and determine whether explanation 2) above is valid.

Time of year influenced whether salmon were able to pass the culvert successfully. During August, when water levels are seasonably low and water temperatures high, no salmon were detected on the upstream antennas. This includes adult salmon from interior basins that nosed into Horsetail/Oneonta Creek, potentially for cold water refuge. However, 15% of salmon detected only on the downstream antennas were detected in August.

In summary, juvenile and adult salmon have the potential to access and benefit from the Horsetail Creek restoration site. Whether a salmon can access the site depends on the time of year and water levels, as the culvert may block access during times of low water levels. However, the PIT detection array has demonstrated that salmon from every major interior subbasin interact with the confluence of Horsetail/Oneonta Creeks and the Columbia River, and that some individuals, especially some steelhead, reside for extended periods in the area.

MANAGEMENT IMPLICATIONS

Action effectiveness monitoring measures changes to physical and ecological processes that influence the ability of restoration sites to support juvenile salmonids. In addition, AEM data provides project managers with vital information to determine if project design elements are meeting goals or if adaptive management is required.

At the site scale, restoration projects are leading to the reestablishment of natural physical processes that support juvenile salmonids. Data has shown that site water levels respond immediately to hydrologic reconnection. Water temperatures at the restoration sites are generally warmer than nearby mainstem waters but were generally suitable during the spring and early summer juvenile outmigration periods. The higher temperature at restoration sites can be attributed to shallower water depths, and this trend is mirrored in results seen at Ecosystem Monitoring Program (EMP) sites (Kidd et al. 2019).

As the goals of restoration activities include improving fish access to historic floodplain habitats and the quality of those habitats, we wanted to verify that fish are using restored sites. We chose to employ a “status check” of fish use at five years post-restoration. We collected fish occurrence data at Wallacut River and La Center Wetlands and found juvenile salmonids at all locations. The presence of juvenile salmonid indicates that restoration benefits fish. The PIT array at Horsetail Creek detected out-migrating upriver juvenile and adult salmonid species visiting the site for a few hours to several days.

AEM research shows that restoration sites are achieving increases in hydrologic connectivity and salmonid opportunity; however, plant community recovery is more variable across sites. Given the inherent inter-annual climate variability, it is difficult to predict specific restoration outcomes on a year-to-year basis. However, clear trends in plant community recovery across restoration sites persist, with high marsh elevations retaining reed canarygrass and other non-native species at years 3 and 5post-restoration. The lack of high marsh plant community recovery is echoed in the soil conditions identified in these locations, which retain lower soil salinity, pH, and greater ORP levels than found at reference sites. Additionally, areas within restoration sites that have undergone heavy construction impacts and grading are seen to recover on a slower timeline. Alternatively, we have observed that both soil and dominant native plant communities recover quickly (within five years post-restoration) in areas found at moderately low to mid-wetland elevations. Across all these findings, wetland elevation is used as a proxy for restored wetland hydrology which, in combination with soil conditions, is the ultimate mechanism driving restoration outcomes throughout the estuary (e.g., Bledsoe and Shear 2000, Neckles et al. 2002, Davy et al. 2011, Mossman et al. 2012, Gerla et al. 2013, Kidd 2017). Through our AEM research, we have found that the re-establishment of natural physical and hydrological processes in sites can be accomplished in a short period of time but understanding how these wetland sites respond ecologically will require longterm monitoring. Ultimately, this continued monitoring will elucidate longterm trends and improve our understanding of the connections between physical processes, habitat responses, and the resulting benefits to juvenile salmon.

AEMR Program Recommendations

Suggestions for Project Design

- Both restoration design and evaluation would benefit from using predictive modeling to determine the restoration of aquatic, marsh, and shrub-scrub plant communities. This type of modeling can be easily accomplished by incorporating anticipated restored hydrology and site elevations, and comparable reference site conditions (Hickey et al. 2015). These data can also provide a platform for evaluating different restoration scenarios, such as considering different levels of hydrologic reconnection or marsh plain lowering and the impacts on multispecies and plant community habitat recovery (Hickey et al. 2015)[3].
    - Across multiple restoration projects, we have seen very high and very low marsh elevations struggle to recover native plant cover within a 5-year timeline. Moving forward, predictive modeling could aid in restoration design (and adaptive management efforts) to maximize the restoration of the mid to moderately low marsh elevations, which have been shown to recover native plant habitat and soil conditions quickly post-restoration (throughout the Estuary).
    - In addition, this will also aid project planning for determining seeding and planting zones in target high marsh areas for non-native species control and shrub-scrub development.

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[3] We are currently using this Ecosystem Modeling Approach (Hickey et al. 2015) at Steigerwald National Wildlife Refuge and Multnomah Channel Natural Area to evaluate and design for desired restoration outcomes.

- Assessing restoration success and goal-reaching post-restoration would also be easier given predictive maps and data could be compared to conditions observed post-restoration.

Suggestions for Project Monitoring

Site topography and Reference Sites

- Accessibility to ground survey technology such as RTK GPS systems has increased dramatically over the last five years, and these systems allow us to efficiently map the overall topography of wetlands and their plant communities and channels. With this technology, we can assess the compatibility of reference and restoration wetland sites. Similar elevation gradients (and hydrology) should be sampled within reference and restoration sites for meaningful comparisons to be made post-restoration (and to aid in project design). In this report, we have highlighted that the reference site elevations have generally been a poor match with each restoration site's restored elevations. Moving forward, we will aim to alter monitoring plans to sample more overlapping elevation gradients between the restoration and reference sites to correct these issues. Additionally, upon choosing reference sites to inform project design and post-restoration project success, elevations and (anticipated) hydrology should be compared to ensure that reference elevation data is an appropriate proxy for hydrologic conditions.

Hydrology

- Hydrology is a critical component of all wetland restoration efforts and should be monitored for project planning, design, and success assessment. During project design, clear hypotheses should be developed to define hydrologic changes anticipated from restoration efforts. For monitoring, data loggers need to be placed in areas that are anticipated to experience these hydrologic changes post-restoration and remain in the same location pre- and post-restoration. Given the number of issues we have experienced through the years with data loggers, we recommend having at least one redundant logger be placed within the site (nearby or at the same location) that can provide additional data in case of equipment failure (which is common). Loggers need to be maintained at least every six months, and we recommend all deployment and retrievals follow the new and more detailed monitoring protocols to avoid data loss (Kidd et al. 2018).

Sediment Accretion and Erosion, Channel Cross-Sections

- Understanding sediment accretion and erosion dynamics across the floodplains of newly restored wetlands is critical for tracking wetland and channel development and longterm topographic trajectories. Sediment dynamics across restoration sites can be highly variable, making it challenging to track meaningful change without intensive and extensive monitoring efforts. We recommend shifting our current approach of sediment monitoring (one or two sediment benches placed within a site) to a more targeted application of these methods. Before restoration occurs, specific areas of interest should be selected, and multiple sediment monitoring benches (a minimum of 6) should be installed along the elevation gradient and within these targeted areas. Within the sediment bench monitoring area (between the pins), we recommend tracking dominant plant community development and soil characteristics to aid data interpretation. Channel cross-section monitoring should be similarly focused, and extreme care should be taken to resurvey the exact location of the cross-section for meaningful results to be obtained. Both channel cross-section and sediment benches need to be resurveyed using RTK GPS technology to provide topographic context and increase data usability. Updated monitoring protocols are currently in development for these methods (Kidd and Rao, 2019).

WETLAND PLANT COMMUNITY

- Native wetland plant communities provide a critical base of the salmonid food web and are essential for determining wetland restoration success (Rao et al. 2020). We have found that monitoring a randomized selection of vegetation plots each year creates a great amount of variability in the data and makes determining what change has been caused by the restoration and what change is due to the new randomized sampling difficult. There are two approaches to addressing this issue: (1) continue to randomize the plots annually but significantly increase the overall total number of plots surveyed, or (2) only randomize the plots during the first year of monitoring and re-visit these same plots year after year. We recommend (2)—re-visiting the same plots year after year, which provides a clear path to assessing plant community changes over time and does not increase the overall amount of time required to conduct sampling. Additionally, as shown in this report, the collection of soil data, alongside plant community data, can be very informative when evaluating wetland development and restoration. We recommend integrating soil data collection as an essential metric for Level 2 monitoring across sites. Further vegetation and soil monitoring recommendations are forthcoming as we work on a comprehensive update to the *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary* (Roegner et al. 2008).

UTILIZING UAV TECHNOLOGY: SITE TOPOGRAPHY, PLANT COMMUNITY MAPPING

- The accessibility and applicability of Unmanned aerial vehicles (UAV) and associated sensor technology have made significant strides in the last several years. Using some of the most affordable equipment and software available, we have shown that large-scale site wetland plant community and topographic mapping are possible and accurate (Kidd et al. 2020). Mapping dominant native and non-native plant communities across large portions of restoration sites can aid the evaluation of project success post-restoration and guide both active restoration project design and post-restoration project adaptive management efforts. Moving forward, we are working to refine our UAV monitoring methods to include tracking channel and floodplain topographic development in our analysis and reporting. We are also exploring ways of evaluating biomass and carbon stores across reference and restored wetlands using our UAV and sensor technologies. Further UAV vegetation monitoring methods and recommendations will be included in the comprehensive update to the

Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary (Roegner et al. 2008).

FISH AND MACROINVERTEBRATE MONITORING

- AEMR Level 2 monitoring does not encompass comprehensive fish or macroinvertebrate monitoring as part of the standard habitat monitoring protocol. Level 2 monitoring includes limited macroinvertebrate monitoring (one or two neuston tows a year following the Level 2 monitoring schedule) and a one-time fish sampling event at year five post-restoration. Given the spatial and temporal variability of both fish and macroinvertebrate populations seen across the longterm EMP reference sites (Rao et al. 2020), we have concluded that a more comprehensive macroinvertebrate and salmonid sampling effort is required for meaningful post-restoration food web conditions to be evaluated. Limited fish monitoring shows that juvenile salmonids are present in restoration sites after tidal reconnection. Still, without intensive monitoring efforts, the number of fish using the site can be challenging to ascertain. Furthermore, it is unknown if the number of fish accessing a site increases as the habitat moves toward a reference state. A better understanding of how physical processes influence habitat conditions and how these resulting habitat conditions support juvenile salmonids are vital in quantifying the overall impact of restoration efforts. Adding longterm ecosystem monitoring at a select number of restoration sites would allow these sites to be tracked alongside the Ecosystem Monitoring Program. The EMP sites have years of accumulated status and trends in fish, macroinvertebrate, water quality, and habitat data which could be used for ongoing comparative analysis and evaluation. Selecting focal restoration sites of interest and conducting intensive fish and macroinvertebrate monitoring efforts at these sites, similar to the level of monitoring achieved across EMP sites (Rao et al. 2020), would allow for the recovery of fish use and macroinvertebrate communities to be assessed over the longterm and aid in the interpretation of how physical changes to habitat directly influence the salmonid food web.

FREQUENCY OF MONITORING

- Currently, Level 3 monitoring is conducted 1-year pre-restoration through year 5 post-restoration, and Level 2 monitoring is conducted pre-, 1-, 3-, and 5-years post-restoration. Results from the last six years of the AEMR Level 2 and 3 monitoring indicate that restoration outcomes can be slow and variable, with sites not achieving reference level native plant community conditions by year 5 post-restoration (Johnson et al. 2018, and this report). Given these observations, we recommend that level 3 monitoring continue to occur pre through 5-, 8-, and 10-years post-restoration and that Level 2 monitoring should also be conducted at year 8 and year 10 post-restoration. Adding years 8 and 10 to monitoring for all level 2 and 3 metrics will aid in understanding the longterm impacts of our restoration efforts and allow for monitoring over a broader spectrum of annual climate conditions. Additionally, we recommend UAV plant community mapping occur across all Level 2 and 3 sites pre-restoration and 3-, 5-, 8-, and 10-years post-restoration. These additional data and longer-term monitoring windows will provide greater context to assess restoration actions and outcomes and help us test ongoing hypotheses about how shifts in climate and river discharge conditions impact restoration outcomes. Synthesis reports of site conditions at years 8 and 10 post-restoration will also provide meaningful insight for ongoing adaptive management and restoration efforts.

SYNTHESIZING RESTORATION RESULTS

- The most meaningful analysis of restoration success would incorporate all habitat level monitoring metrics across a site to identify the recovery of salmonid habitat over time. We have developed a site-wide assessment of habitat opportunity that extends across the wetland's active floodplain (Johnson et al. 2018). This incorporates floodplain topography, water surface elevation (water depth), water temperatures, and dominant plant communities to highlight salmonid habitat conditions across the active floodplain of restoration and reference sites. See this tableau link for the habitat opportunity assessment of Wallooskee – Youngs Project. This dynamic floodplain mapping approach could also be used to evaluate the impacts of climate change and shifting river discharge on wetland habitat conditions throughout the Columbia Estuary.

INTRODUCTION

Program History

The Action Effectiveness Monitoring (AEM) program is managed by the Lower Columbia Estuary Partnership (LCEP) under LCEP's Ecosystem Monitoring Program contract with Bonneville Power Administration and the Northwest Power Conservation Council's Fish and Wildlife Program. As part of the Columbia Estuary Ecosystem Restoration Program (CEERP), this program provides the Bonneville Power Administration (BPA), restoration partners (e.g., USACE and CREST), the Environmental Protection Agency, and other stakeholders with data to assess the success of restoration projects in the lower Columbia River and estuary.

In 2008, during the program's pilot phase, the Estuary/Ocean subgroup (EOS) recommended four projects for AEM. The selected AEM sites were monitored annually until 2012 and represented different restoration activities, habitats, and geographic reaches of the river. The initial phase of AEM resulted in site scale monitoring and the standardization of data collection methods but also highlighted the need for expanded monitoring coverage, paired restoration and reference sites, and comparable monitoring to ecosystem status and trends monitoring to evaluate reach and landscape scale ecological uplift.

To provide monitoring at all restoration sites, three monitoring levels are implemented at restoration sites as follows:

> <u>Level 3</u> – includes "standard" monitoring metrics: water surface elevation, water temperature, sediment accretion, and photo points that are considered essential for evaluating the effectiveness of hydrologic reconnection restoration. This monitoring is done at all restoration sites within the CEERP. Project sponsors conduct level 3 monitoring.
> <u>Level 2</u> – includes the Level 3 metrics and metrics that can be used to evaluate the site's capacity to support juvenile salmon. These metrics include vegetation species and cover, macroinvertebrate (prey species) composition and abundance, and channel and wetland elevation. This "extensive" monitoring is done at a selected number of sites chosen to cover a range of restoration actions and locations in the river. It is intended to provide a means of monitoring an "extensive" area. LCEP conducts level 2 monitoring.
> <u>Level 1</u> – includes Level 2 and 3 metrics and more "intensive" monitoring of realized function at restoration sites, such as fish use, genetics, and diet. Since Level 1 monitoring is more expensive, it is conducted at fewer sites with the goal of relating the Level 1 results to the findings of Level 2 and Level 3 monitoring. The USACE conducts level 1 monitoring.

Program Overview

LCEP manages the Action Effectiveness Monitoring (AEM) program with the goals of determining the impact of habitat restoration actions on salmon at the site and landscape scale, identifying how restoration techniques address limiting factors for juvenile salmonids, and improving restoration techniques to maximize the impact of restoration actions.

To accomplish AEM program goals, LCEP implements the Columbia Estuary Ecosystem Restoration Program (CEERP) AEM Programmatic plan (Johnson et al. 2016), employs standardized monitoring protocols, and coordinates between stakeholders to collect and share AEM data. The AEM annual monitoring objectives were to quantify post-restoration hydrology, temperature, habitat, and vegetation within restoration sites and to determine post-restoration fish use at selected sites.

The goals of the AEM program are to:

1. Determine the benefit of restoration actions for juvenile salmonids at the site, landscape, and ecosystem scale.
2. Improve restoration and monitoring techniques to maximize the benefits of habitat restoration projects.
3. Use the results of intensive AEM (Level 1) to focus extensive AEM efforts (Level 2 and 3) and link fish presence and habitat recovery outcomes through a line of evidence approach.

To meet these goals, LCEP is engaged in the following tasks:

1. Implementing AEM as outlined in the Estuary RME plan (Johnson et al. 2008), Programmatic AEM plan (Johnson et al. 2016), and following standardized monitoring protocols (e.g., Roegner et al. 2009) where applicable.
2. Developing longterm datasets for restoration projects and associated reference sites.
3. Coordinating between stakeholders to improve AEM data collection efficiency.
4. Supporting a regional cooperative effort by all agencies and organizations participating in restoration monitoring activities to create a central database to house monitoring data.
5. Capturing and disseminating data and results to facilitate improvements in regional restoration strategies.

Twenty-six restoration sites in 2020 and twenty-two in 2021 received AEM data collection (Figure 1, Table 1). Level 2 and Level 3 sites for 2022 – 2023 are presented in Figure 2. The specific monitoring actions for these two years involved quantifying water surface elevation, water temperature, habitat opportunity, and vegetation at restoration sites. At years 1, 3, and 5 post-restoration, macroinvertebrate data are collected at a single sampling event to determine community composition at the sites. Additionally, at year 5, post-restoration fish data are collected to determine the composition of the fish community. To put ecological changes at restoration sites into context, the program incorporated data from reference sites monitored in the Ecosystem Monitoring Program (EMP), which focuses on characterizing the status, trends, and juvenile salmonid usage of relatively undisturbed emergent wetlands.

All monitoring was conducted following standardized protocols outlined in Roegner et al. (2009). In 2020, due to the COVID-19 pandemic, Level 3 metrics were not collected at some restoration sites, and macroinvertebrate or fish data were collected in 2021. In 2020, five restoration sites received Level 2 monitoring, and 26 restoration sites received Level 3 monitoring. A PIT tag array was operated at Horsetail Creek to determine the type and residency time of salmonids at the site and address uncertainties related to fish passage through long culverts. In 2021, four restoration sites received Level 2 monitoring, and 22 restoration sites received Level 3 monitoring. Additionally, in 2021, we conducted status fish sampling at Wallacut and La Center Wetlands (year 6 post-restoration) to identify fish presence five years post-restoration.

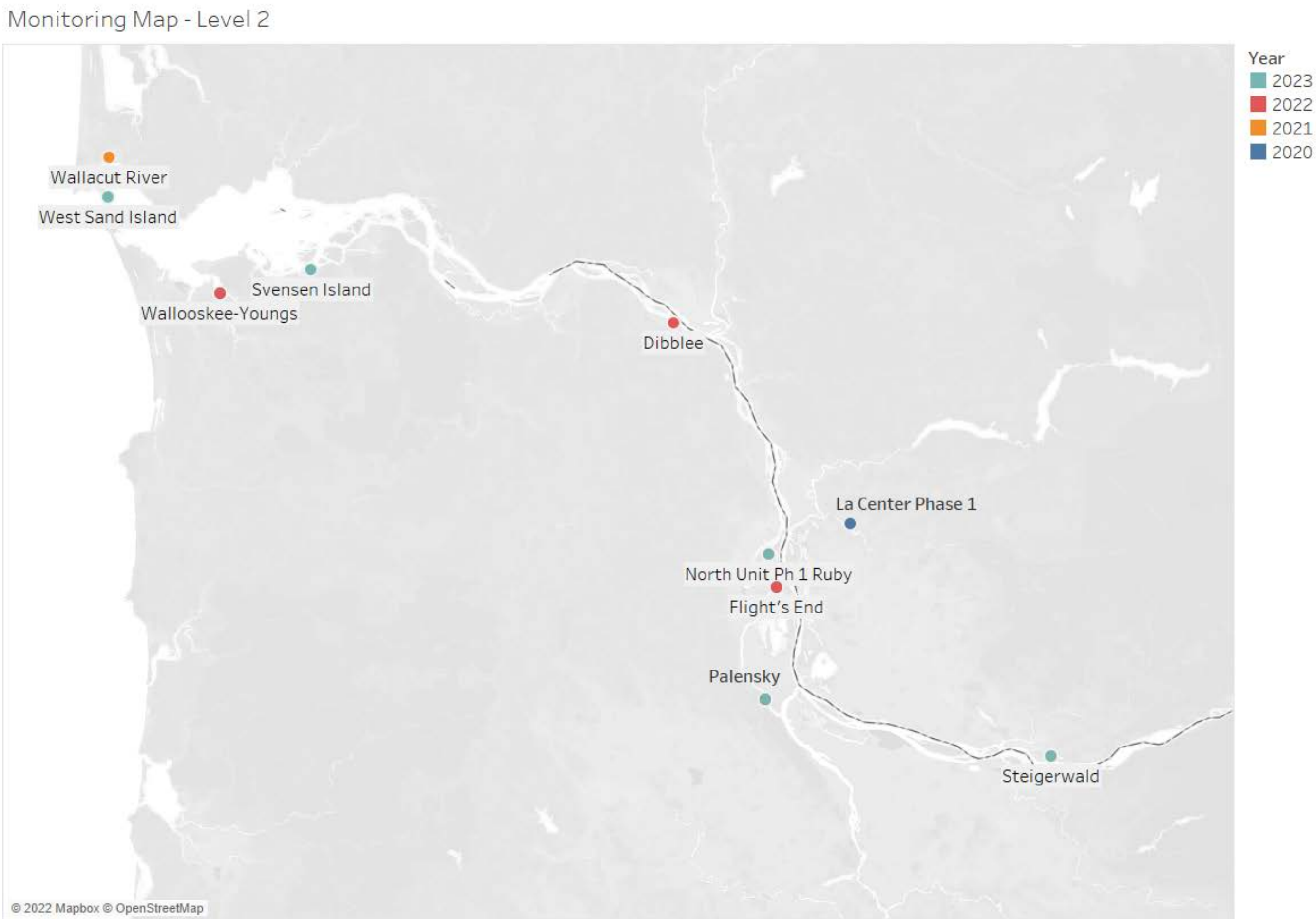

Figure 1: AEMR Level 2 monitoring planned for 2020-23. See Table 1 for details.

Monitoring Map - Level 3

Figure 2: AEMR Level 3 monitoring planned for 2022-23. See Table 1 for details.

Monitoring Inventory

Types of M..	Project Name Common (W..	Projected C..	Project Lev..	2017	2018	2019	2020	2021	2022	2023	2024
				Monitoring Year							
Level 2 Monitoring	Campbell Slough	2005	EMP	●	●	●	●	●			
	Cunningham Lake	2005	EMP	●	●	●	●	●			
	Dibblee	2012	CREST	●							
	Flight's End	2017	CREST	●	●		●		■		
	Franz Lake	2008	EMP	●	●	●	●	●			
	Ilwaco Slough	2011	EMP	●	●	●	●	●			
	John R Palensky	2021	CREST					●	■	◆	◆
	La Center Wetlands	2015	LCEP		●		●	●			
	North Unit Ph 1 Ruby	2013	CREST		●			●		◆	
	North Unit Ph 2 Millionaire	2014	CREST	●							
	North Unit Ph 2 Widgeon	2014	CREST	●							◆
	Secert River	2012	EMP		●						
	Steamboat Slough	2014	COE	●		●					
	Steigerwald	2022	LCEP			●		●			
	Svensen Island	2022	CLT							◆	
	Wallacut River	2016	CLT	●		●					◆
	Wallooskee-Youngs	2017	LCEP		●		●	●			
	Welch Island	2012	EMP	●	●	●	●	●			
	West Sand Island	2020	CREST							◆	
	Whites Island	2009	EMP	●	●	●	●	●			
Level 3 Monitoring	Bear-Marys-Ferris	2018	CREST			●	●	●			
	Buckmire Ph 1	2015	CREST	●		●					
	Campbell Slough	2005	EMP					●			
	Crane-Domeyer	2016	CREST	●	●	●	●				
	Dairy Creek/Sturgeon Lk	2018	CREST	●	●		●				
	Dibblee	2012	CREST			●					
	Elochoman Slough Lower	2015	CLT		●	●					
	Flight's End	2017	CREST					●			
	Government Island	2019	CREST	●		●					
	Horsetail	2013	LCEP	●	●	●	●				
	John Day River #11	2020	CREST			●					
	John R Palensky	2021	CREST		●	●	●				
	Kandoll Farm	2013	CLT			●	●	●	●		
	Kerry Island	2016	CLT				●		●		
	La Center Wetlands	2015	LCEP		●	●	●	●			
	Louisiana Swamp	2013	LCEP			●	●				
	McCarthy Creek	2019	CREST					●			
	Mill Road	2011	CLT	●	●	●	●	●	●		
	North Unit Ph 1 Ruby	2013	CREST	●	●		●	●			
	North Unit Ph 2 Millionaire	2014	CREST	●							
	North Unit Ph 2 Widgeon	2014	CREST	●							
	North Unit Ph 3 Jack	2015	CREST	●	●	●					
	Otter Point	2012	CREST	●	●						
	Sharnelle Fee	2014	CREST	●	●	●					
	Steamboat Slough	2014	COE			●	●	●			
	West Sand Island	2020	CREST	●		●			●		
	Westport Slough (USFWS)	2016	CREST	●							
	Willow Bar	2016	CREST	●	●	●	●	●			
Pit-Tag Fish Data	Dairy Creek/Sturgeon Lk	2018	CREST			●	●	●	●	●	
	Horsetail	2013	LCEP	●	●	●					
	Steamboat Slough	2014	COE			●					
	Steigerwald	2022	LCEP							◆	◆

Data Inventory
- ● Data Available
- ◆ Planned
- ■ Scheduled

Data Inventory
- Data Available (green)
- Planned (yellow)
- Scheduled (orange)

Table 1. Summary of AEMR accomplished or planned from 2012 through 2023. For a more detailed breakdown, please see the Tableau link

Data Visualization and Reporting

To better meet the goals and objectives of the AEM Program, the results of this report are presented in Tableau. Tableau is a user-friendly data visualization software capable of processing, summarizing, and displaying large quantities of geospatial and non- geospatial data. It is an interactive platform that encourages data exploration by researchers and allows the target audience to follow the story presented by analysts and explore the data themselves.

Tableau 2022.2 can store and query vast quantities of data in a user-friendly manner. It requires no knowledge of any coding to start, making it extremely quick and easy to pick up and use; however, if one is more coding inclined, Tableau allows for one to directly write advanced queries and analyses in a variety of languages including SQL, Python, and R. Additionally, Tableau is built for collaboration. Multiple people can connect to and analyze the same datasets and seamlessly contribute to the same workbook. Furthermore, all tableau work is often easily adaptable each year as one collects more data or adds additional sites to the analyses. One simply needs to update the base database (e.g., adding another six months of measurements to a hydrology database), and the graphs, plots, and analyses will all automatically update with the additional data.

While there are multiple software tiers ranging from free to paid with various privacy options, Tableau can and does meet most of LCEP's needs for data QA/QC, analysis, and visualization. At LCEP, we utilize Tableau Desktop for most of our base work; Tableau Online hosts our data and collaborates with fellow researchers; Tableau Prep Builder quickly checks and prepares our data for analysis, and Tableau Public publish our work to the world at large. Of these, Tableau Public is completely free, while Tableau Desktop and Prep Builder cost as little as $70 per year. The online space varies in cost depending on the number of users and quantity of data required.

We have publicly disseminated multiple datasets and analyses including our hydrology, vegetation, sediment accretion, drone analyses, macroinvertebrates, fish, and other datasets and analyses in the form of Tableau dashboards, often designed to accompany reports. These dashboards provide an opportunity for project sponsors, researchers, and other interested parties to visualize and self-explore the evolution of restoration sites from pre-monitoring to their current states as well as share and communicate these results to landowners, project managers, and other members of the public in an easily digestible manner.

The layout of the Results section has also been modified to meet ERTG better Revisit templates' needs. Level 2 site results presented in this report are accompanied by basic project information – background of the project, goals, objectives of restoration, and restoration actions. The experimental design and parameters for monitoring have also been included in this report. The results of these monitored parameters are linked to tableau dashboards in this report.

METHODS

Site Selection 2020 and 2021

Four restoration sites were selected for Level 2 monitoring (Table 2) in 2020 and 2021 using the prioritization criteria outlined in Johnson et al (2016). Three associated reference sites were chosen to establish a before-after reference impact monitoring design, which puts pre- and post-restoration site data into ecological context (Table 2). This report summarizes the results for level 2 monitoring metrics for all sites surveyed in 2020 and 2021, except for Steigerwald, which is still under construction.

Table 2. Sites included in Level 2 monitoring in 2020.

RKM	Site	Project Management	Description	Construction	Pre	1 yr	3 yr	5 yr	Reference site
22	Wallooskee-Youngs	LCEP	Tidal reconnection, Dike breaches, channel network development, non-native plant community treatment	2017	2015	2018	2020	*2022*	Daggett Point (RKM 22)
141	La Center Wetlands	LCEP	Dike breaches, Wier and Culvert removals, Off-channel enhancements, and revegetation	2015	2015	2016	2018	2020	La Center Control (RKM 141)
143	Flight's End Wetlands	CREST	Marsh plain lowering, native revegetation, and new tide gate	2017	2017	2018	2020	2022	Cunningham Lake (RKM 145, EMP site)
200	Steigerwald	LCEP	Full channel and tidal reconnection, alluvial fan restoration, and targeted marsh plain lowering	*2022*	2019	*2023*	*2025*	*2027*	Reed Island (RKM 200), and Franz Lake (RKM 221, EMP site)

Table 3: Sites included in Level 2 monitoring in 2021

RKM	Site	Project Management	Description	Construction	Pre	1 yr	3 yr	5yr	8yr	Reference Site
6	Wallacut	CLT	Full channel and tidal reconnection, non-native plant community treatment with herbicides	2016	2014	2017	2019	2021	*2023*	Ilwaco Slough (RKM 6, EMP site)
142	North Unit (Phase 1) – Ruby Lake	CREST	Full tidal reconnection targeted marsh plain lowering.	2013	2013	2014	2016	2018	2021	Cunningham Lake (RKM 145, EMP site)

142	John R Palensky	CREST	Full channel and tidal reconnection and targeted marsh plain lowering	2021	2021	*2022*	*2024*	*2026*	*2028*	MCNA (RKM 142), Cunningham Lake (RKM 145, EMP site)
200	Steigerwald	LCEP	Full channel and tidal reconnection, alluvial fan restoration, and targeted marsh plain lowering	*2022*	2019	*2023*	*2025*	*2027*	*2029*	Reed Island (RKM 200), and Franz Lake (RKM 221, EMP site)

Habitat Monitoring
Methods from the protocol "Lower Columbia River Estuary Habitat Action Effectiveness v1.0" were used to evaluate changes related to restoration actions and quantify ecological uplift (Roegner et al. 2009, Protocol ID: 460).

We surveyed vegetation cover and composition (Method ID 822) to assess 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 (Method ID 818) was recorded to track the effectiveness of lowering marsh elevations (soil scrape down) to control invasive vegetation and promote native plant species growth. At each restoration site, two vegetation monitoring areas were established – one in an area directly impacted by restoration actions and one in an area indirectly affected by restoration actions. Two vegetation sampling areas provide an overview of overall site condition pre- and post-restoration. Sediment Accretion (Method ID 818) was measured to determine if constructed wetlands are self-sustaining by installing sediment benches at the low marsh and high marsh areas of the site. Water Temperature (Method ID 816) was measured to determine habitat suitability for juvenile salmonids. Water Surface Elevation (Method ID 3982) was measured to assess the opportunity for juvenile salmonid species to access the site and determine the timing and level of wetland inundation.

Soil survey - Within each quadrat, in-situ surface soil salinity, conductivity, pH, ORP and temperature were measured. (Bledsoe and Shear 2000, Neckles et al. 2002, Davy et al. 2011, Mossman et al. 2012, Gerla et al. 2013). All soil surveys were conducted in saturated soil conditions, timed near peak low tide (lowest tidal elevation), and surveyed from highest to lowest elevation. Although these soil parameters are dynamic over time depending on the precise environmental conditions present and the duration of tidal flooding, the logic in taking these in-situ samples was to capture the general gradient among the different plant communities. If all samples were collected under similar conditions and at similar intervals of time, they would become more comparable to each other. Redox potential (ORP), pH, conductivity, salinity, and temperature data were collected using Extech soil probes. For detailed information about these soil parameters and tidal wetland restoration, see Kidd 2017.

Macroinvertebrate Monitoring

Sampling

Macroinvertebrate samples were collected using Neuston Tows in 2021 at six restoration and four reference sites to quantify community composition and the availability of prey resources for juvenile salmonids at Level 2 restoration sites and compare these communities to reference sites. Sites not sampled in 2020 due to COVID-19 lockdowns were included in 2021. Two Neuston samples were collected and combined into one composite sample from emergent vegetation during May at each site. 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. Samples were preserved in plastic containers with 95% ethanol and rose Bengal solution and transported to the University of Washington for identification. Container lids were wrapped with electrical tape to prevent evaporation during transit and before processing. Sampling procedures were in accordance with USGS Western Ecological Research station SFBE & Nisqually Indian Tribe's Pelagic Invertebrate Standard Operating Procedures.

Laboratory Methods

Invertebrates collected in neuston tows 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. The number of individuals in each taxonomic group was counted for each sample.

Fish Monitoring

Fish presence and community composition were assessed at Wallacut and La center wetlands between April and May 2021. Wallacut fish data were collected at year 5 post-restoration, while La center fish data were collected at year 6 post-restoration – this delay was caused due to COVID-19 lockdowns which prohibited the researchers from traveling to the site. Fish sampling occurred at three areas at each site – Wallacut Slough was fished in different channels. La Center West was sampled in the main channel and pond (Figure 3, Figure 4)

Figure 3: Fish Sampling locations in Wallacut.

Figure 4: Fish sampling areas in La Center West.

Fish were collected at the Wallacut using two different methods, a pole seine (PS; 7.6m x 1.8m, 10 mm mesh size) and winged trap nets (TN; 1.0m opening with 10.0 mm mesh size). A 7.6m pole seine was the only gear used during the sampling at La Center. No boats were required based on sampling areas and types of equipment used. Both sites were sampled at high tide to ensure maximum daily water levels before sampling. All non-salmonid fish were identified to the species level, counted and released. All salmonids were measured (fork length, nearest mm), 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 and released. A genetic sample was taken from the caudal fin on all captured Chinook salmon at both restoration sites. The temperature in degree Celsius and Dissolved Oxygen (DO, mg/l) was measured (Table 4). Due to the soft mud, large amounts of algae, and low water levels, the area swept during sampling was not calculated or standardized.

Table 4: Sampling efforts at Sites in 2021

RKM	Site	Sampling date	Number of Efforts (Pole Seine or Trap Nets	Temperature (°C)	Dissolved Oxygen (DO) (mg/l)
6	Wallacut	21-Apr-2021	7	17.1	9.7
6	Wallacut	22-Apr-2021	6	15.9	8.9
141	La Center Wetlands – Pond	18-May-2021	4	17.4	6.3
141	La center Wetlands – Channel	18-May-2021		16.0	8.6
141	La Center Wetlands – Pond	20-May-2021	5	16.4	6.3
141	La center Wetlands – Channel	20-May-2021		16.0	8.6

Horsetail Creek PIT Array

A PIT detection array at Horsetail Creek was installed in 2013 following the restoration actions in Horsetail Creek, located in the Columbia River Gorge. The array was situated on the upstream and downstream sides of a culvert passing underneath I-84, which connects the confluence of Horsetail and Oneonta Creeks with the Columbia River. The system consisted of a Biomark Fish TRACKER IS1001-MTS distributed Multiplexing Transceiver System (MTS). The MTS unit receives, records, and stores tag signals from 10 antennas, which measure approximately 6' by 6' and are mounted on the north and south sides of the 5-barrel culvert system under the freeway. The system was powered by an 840-watt solar panel array and supported by a 24-volt, 800 amp-hour battery bank backup. The unit was connected to a fiber optic wireless modem that allowed daily downloads of tag data and system voltage monitoring updates.

The array was operational from 2014 – 2019, each year from late March or April to October or November. During winter, there was not enough daylight on the southern side of the Columbia River Gorge to provide ample power, so operations were intermittent. Due to the dynamic and extreme flows in the area, individual antennas often sustained damage and had to be repaired or replaced. Usually, repairs could not be done immediately because high water restricted access. Yet, each year we had antenna coverage on each side of the culvert (Table 5). In 2020, no maintenance or data was collected due to inaccessibility and COVID-19 Lockdowns. In 2021, the PIT Array was decommissioned, and parts were reused to build a new PIT Array at Steigerwald Lake National Wildlife Refuge. This report summarizes PIT Array results between 2014 – 2019.

Table 5: Number of working antennas on the downstream and upstream sides of the I-84 culvert each year

Year	Downstream	Upstream
2014	5	5
2015	5	5
2016	3	5
2017	3	3
2018	2	3
2019	3	4

Data collected at the Horsetail PIT array are intended to document the presence of salmon stocks accessing the restoration site, not to estimate the numbers of salmon using the site. Detection data depend upon the population of salmon in the Columbia River Basin that PIT-tagged each year. The number of salmon and the particular stocks that are PIT tagged varies annually, which impacts the patterns of detections from year to year.

Tagging information for each unique tag ID was downloaded from the PTAGIS regional PIT tag data depository (www.ptagis.org), from which species, rear type, release location and date were determined. Using these metrics, we developed a map of origin, enumerated salmon species and life history type from each major sub-basin, and calculated residence time for salmon detected at the Horsetail array. We also documented the percentage of each species/life history that successfully traversed the culvert to access the restoration site.

Analysis

Water-surface elevation (WSE)

WSE is the primary indicator of hydrographic conditions at a site. Continuous pre- and post-restoration water level data were collected at the restoration sites and a nearby outer reference channel. The sensors collecting data were surveyed for elevation so that depth data could be converted to water surface elevation and evaluated against wetland elevations.

Pre- and post-restoration hydrographs for the wetland channel were created and compared to those for the outer reference channel and a nearby reference site ("a site with little or no anthropogenic influence," Borde et al., 2012). An effective restoration project would have a WSE that matches the conditions of the reference site, indicating hydrology for the site was meeting restoration principles.

Water surface elevation was used to study inundation patterns at the sites. The percent of time each marsh was inundated was calculated daily across the elevation gradient at the sites. The average inundation daily, as measured by the average number 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 like the historic sum exceedance value (SEV) analysis; however, it is summarized by day instead of over the entire growing season (Kidd 2017).

Water Temperature

Monthly maximum 7-day moving average maximum (7-DMA) will be calculated for sites post-restoration to compare to an outer reference location and main stem conditions. The Columbia mainstem data collection station S8 (Washougal, EP) will be used for comparison. Previous research has shown that main stem temperatures do not vary substantially, and a single station adequately represents general main stem conditions for any given time period (Sager et al. 2014).

Habitat Opportunity Analysis

Habitat Access and Opportunity models were adapted from previously established analyses and are defined by the depth and temperature of water 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 determine optimal, marginal, and inhospitable habitat conditions as follows; optimal conditions require a water temperature of less than 17.5 °and C, and 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 maximum daily water depths and mean daily water temperatures. These water depths and temperatures were averaged across the site to develop a robust water temperature and depth model. These data were then used to summarize the post-restoration habitat opportunity (what are the temperature conditions that define these accessible habitats) across the entire site using the post-restoration wetland elevations collected during aerial surveys (UAV).

Sediment Dynamics and Sea Level Rise

The net accretion or erosion rate for high marsh and low marsh areas of the site was calculated by averaging measurements made along the 1-meter distance between the two sediment pins and finding the difference between a given year's average to the previous average. The net accretion or erosion rates were also compared to average rates of sea level rise to study the development of sites when compared to various sea level rise scenarios.

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 (USACE Model Report). 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 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 forthcoming.

Vegetation
To assess species richness (defined as the total number of species) and percent cover for the herbaceous vegetation community at a restoration site, we categorized plant species into native/non-native categories. We calculated species richness and relative cover for native and non-native plants out of the total assemblage for sampling episodes before and after restoration for restoration sites for which data were available.

UAV Plant Community Mapping
Quantifying the distribution and abundance of dominant plant communities over time is of fundamental importance to ecological and restoration effectiveness monitoring. Our ability to estimate plant distributions over large areas (i.e., several hectares) using traditional approaches (transect or quadrat methods) is limited because of the time and expense required. In 2020 we conducted aerial surveys at Wallooskee (Year-3) using an unmanned aerial vehicle (UAV) to develop a map of the current extent of dominant native and non-native plant community distributions across the restoration site.

Data Collection
A DJI Phantom 4 was outfitted with a Sentera Near Infrared (NIR) Camera was the UAV chosen to collect multispectral aerial images (visible or RGB, and NIR) of the restoration sites. At each site, Pix4D capture was used to create the flight polygon grid with overlaps of 80% fore-lap and 80% side-lap. The UAV was flown at 200ft above ground level (AGL), producing a high density of images (ground sampling distance (GSD) of 1.68 inches per pixel). Multispectral data was collected between 11 am and12 pm to ensure consistent light conditions at all sites.
Ground control points (GCPs) were placed at sites and surveyed to geo-reference the aerial images. Between 5 to 10 GCPs were placed at each site, depending on the range of terrain elevations at the sites. The GCPs were 1m x 1m, black and white rectangular cardboard cut-outs; the position and elevation of each were captured using a TOPCON Real Time Kinematic (RTK) GPS. Elevations of different vegetation communities were also collected to outline representative dominant plant communities on the site.

Figure 5: 1m x 1m rectangular ground control point (GCP)

Data Processing

Multispectral images collected by the UAV were imported into PIX4D mapper to create products that will aid in mapping vegetative communities at the site. Images from each camera were processed separately to obtain different products. RGB images were processed to obtain an Orthomosaic and a digital surface model (DSM), while NIR images were processed to determine the normalized difference vegetation indices (NDVI) of the vegetation at the site. Pix4D Mapper analyzed multiple points in the imported images to triangulate matches and create a 3D point cloud of the sites. The point cloud was then georeferenced using the collected GCP information to create an orthorectified mosaic of RGB data of the site and a corrected elevation model called a Digital Surface Model (DSM) (Figure 7). Pix4D processed NIR images in the same manner; however, in addition to producing an Orthomosaic and a DSM, the software also produced a mosaic of the NDVI for the site (Figure 6). The NDVI is a well-established indicator for presence and condition of vegetation at a site and ranges from -1 to +1. Negative values indicate no green biomass, and positive values indicate lush green biomass. Bare ground areas usually produce values of zero.

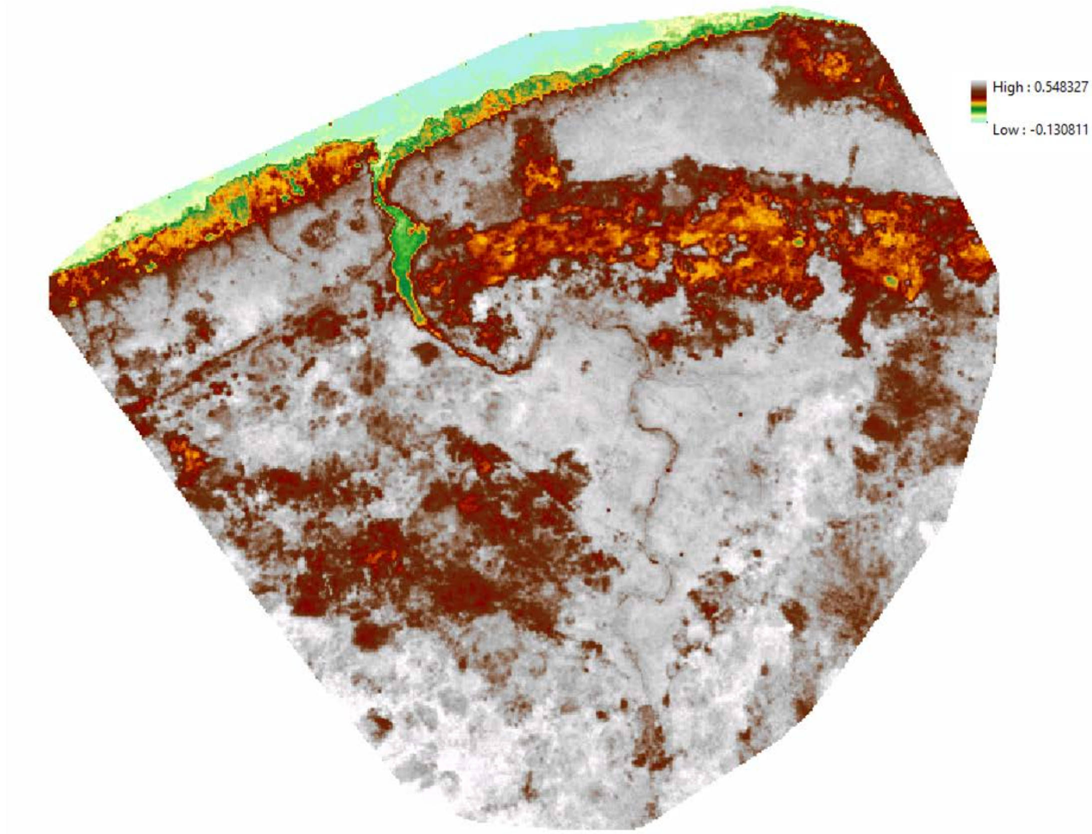

Figure 6: NDVI Mosaic for Wallacut Slough

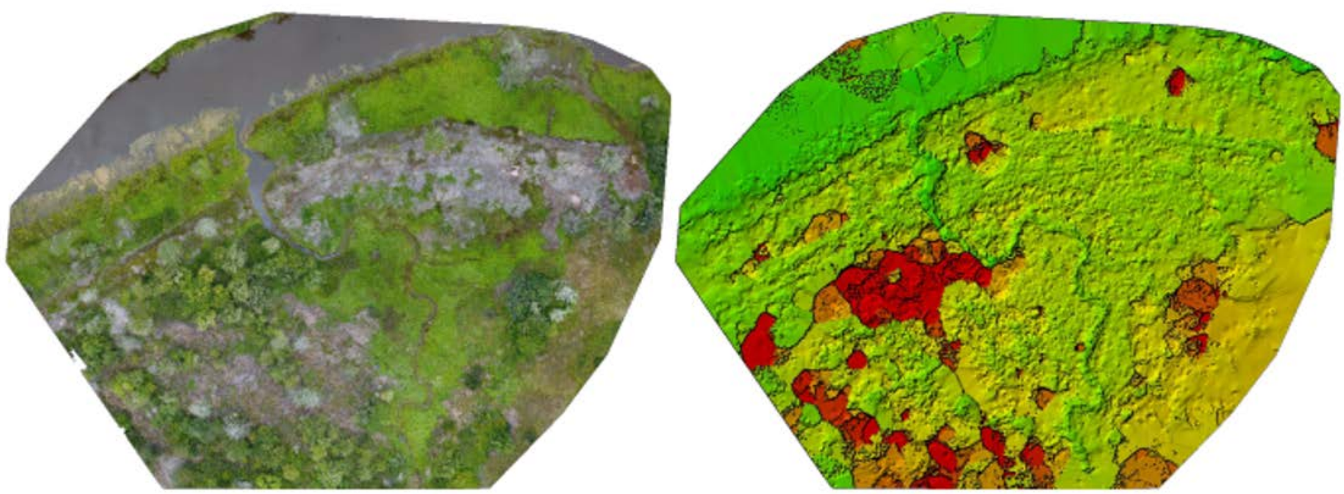

Figure 7: RGB Orthomosaic and Digital Surface model (DSM). The different colors on the DSM represent ranges of elevations present at the site, red color representing higher elevations and green representing low elevations.

Data analysis

RGB and NDVI orthomosaic were combined with the DSM and ground plant community survey data in ArcGIS and R statistical software was used to model the extent of dominant native and non-native plant communities across the site. These data were evaluated for accuracy using the plant community data collected during the ground survey. The final product of this analysis is a dominant plant community map of the site in addition to estimates (in acres) of the extent of these communities.

Macroinvertebrate Community

To assess community development at Level 2 monitoring sites, taxa information was consolidated into Orders and absolute and relative abundance was calculated and compared over time with their reference sites. Data analysis was done using Microsoft Excel and Tableau (2022.1) software.

Results

2020 – 2021 Water Years Overview

Habitat Restoration and Climate Variability

Longterm status and trends monitoring conducted through the Ecosystem Monitoring Program have underscored the importance and influence that shifts in annual climate and discharge conditions in the Columbia River have on tidal wetland food web dynamics and habitat conditions (Kidd et al. 2022, Rao et al. 2020, Kidd et al. 2019). Ongoing synthesis efforts of EMP data have revealed that plant community composition of both reference and restoration sites can be heavily impacted by discharge conditions in the Columbia during the growing season, resulting in annual shifts in both reed canarygrass and native wetland plant community abundance (Kidd et al. 2022, Rao et al. 2020, Kidd et al. 2019).

Annual climatic variations can also cause a shift in wetland and mainstem water temperatures and water biogeochemistry impacting local tidal wetland water quality conditions for salmonids. All wetland restoration sites in the estuary are impacted by these annual shifts in climatic and discharge conditions. This makes simple pre-post restoration comparison challenging to interpret, especially if extreme dry or wet years fall right before or after restoration occurred (Johnson et al. 2018). Comparing pre/post restoration success to that of a reference site tracked during the same time period can be a helpful way to account for the variability in annual conditions; however, it is critical to provide appropriate water year and climatic descriptions for any pre/post or time series analysis and comparison of habitat conditions across sites in the estuary. To aid in this, we have provided an excerpt from the 2022 EMP report below, highlighting the conditions experienced in 2020 and 2021. For a more detailed analysis of these data, please visit the EMP report directly (Kidd et al. 2022).

Overview of 2020 – 2021 and historical conditions

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 tends to dry, and river flows are low between June and October.

In 2020 there were high flows during winter (January and February), transitioning to low flows in March and April. After this, flows were moderate (close to average) for the spring freshet period (May-June), subsiding to low levels through the summer and autumn. There were strong peaks in discharge in early November and December, carrying through to January 2021. Aside from the early winter period, flows in 2021 were nearly the lowest in the time series and were similar to flows observed in 2015. The difference between 2021 and 2015 was that the former had no substantially high flows at any time, aside from a high peak in January and a moderate peak in February.

Similar to 2019, flows in 2020 could be characterized as having a moderate freshet but low flows otherwise, aside from the relatively high flows observed in January. Thus, 2020 and 2021 had low baseline flows relative to the 2010-2021 average. Cumulative flows for these years consist mainly of winter flows from December-February (primarily characterized as peaks associated with storm events) and the spring freshet, which was nearly absent in 2021.

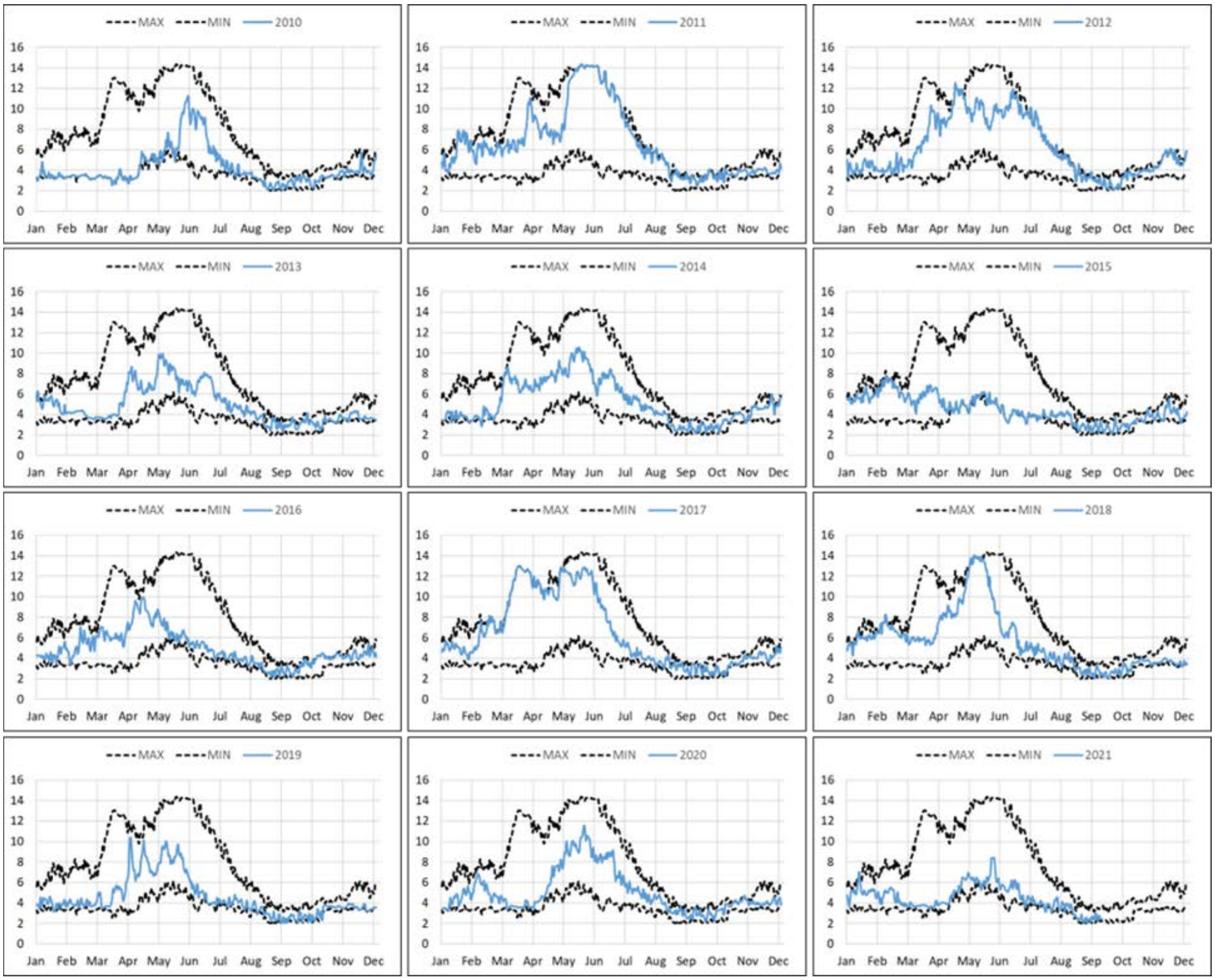

Figure 8. Daily water discharge (m^3/s) at Bonneville Dam. Panels show individual years between 2010-2021 (blue lines) and the daily max and min for all years combined. Vancouver gage web page shows recent flood stage years - https://water.weather.gov/ahps2/crests.php?wfo=pqr&gage=vapw1&crest_type=recent.

Wallooskee - Youngs

Basic Project Information

Project Description – Problem Statement, Goals, and Objectives

The Wallooskee restoration site is located in Youngs Bay, near the City of Astoria in Oregon. The 200-acre tidal reconnection restoration project was funded by BPA and is currently owned and managed by the Cowlitz Indian Tribe. Dr. Sarah Kidd, with LCEP, has been conducting restoration effectiveness monitoring at this site in partnership with the Cowlitz Indian Tribe since 2013.

Project goals are defined as:

"Removing the levee and filling the borrow ditch will increase hydrologic connectivity during the tidal cycle and increase the spatial extent of inundation in the wetland. The restoration of a more natural tidal cycle will help restore ecosystem function by supporting a diverse native plant community, improving nutrient cycling, and increasing quantity and quality of off-channel habitat for aquatic species."

Project Construction – Construction Actions

Historically a dairy farm, the site had been disconnected from active tidal flooding for over a hundred years before tidal reconnection. In July of 2017, tidal flooding was restored throughout the wetland by removing and lowering the levees that bordered the site. Additional channel enhancements were conducted in areas to expand channel density and access to wetland habitat.

Monitoring Plan

Experimental Design, Monitored Indicators, and Monitoring locations

Monitoring historically started at the Wallooskee project during pre-construction in 2013; this monitoring was conducted in partnership with the Cowlitz Tribe and Dr. Sarah Kidd, who included the project in her dissertation as a "control site" in the areas within the site that were actively managed for farming and a "reference site" in the fridge wetlands on the exterior of the levee system (not farmed) – results from this pre-restoration monitoring are included in her published dissertation (Kidd 2017). This monitoring entailed hydrologic monitoring with water surface and temperature loggers, sediment accretion and erosion monitoring, and vegetation monitoring.

In 2017, this monitoring effort was transitioned into the BPA AEMR monitoring format, and vegetation grids were added in two areas within the site. One focal plant community monitoring area was in the "North" of the site near a channel re-connection with Youngs Bay, and the other was located on the "South" portion of the site near a channel re-connection with the Wallooskee River (Figure 10, Figure 11). Additionally, Dagget Point was included in the monitoring effort as a nearby un-impacted reference site (Figure 9).

Figure 9: Wallooskee - Youngs Restoration Project Overview Map, depicting the locations of Wallooskee wetland and reference Dagget Point.

Figure 10: Map of "North" Sampling area at Wallooskee. Map shows vegetation grid and fall-out traps deployed during years 0 and 1. For years 4 and 5, the Macroinvertebrate sampling method was changed to neuston tows.

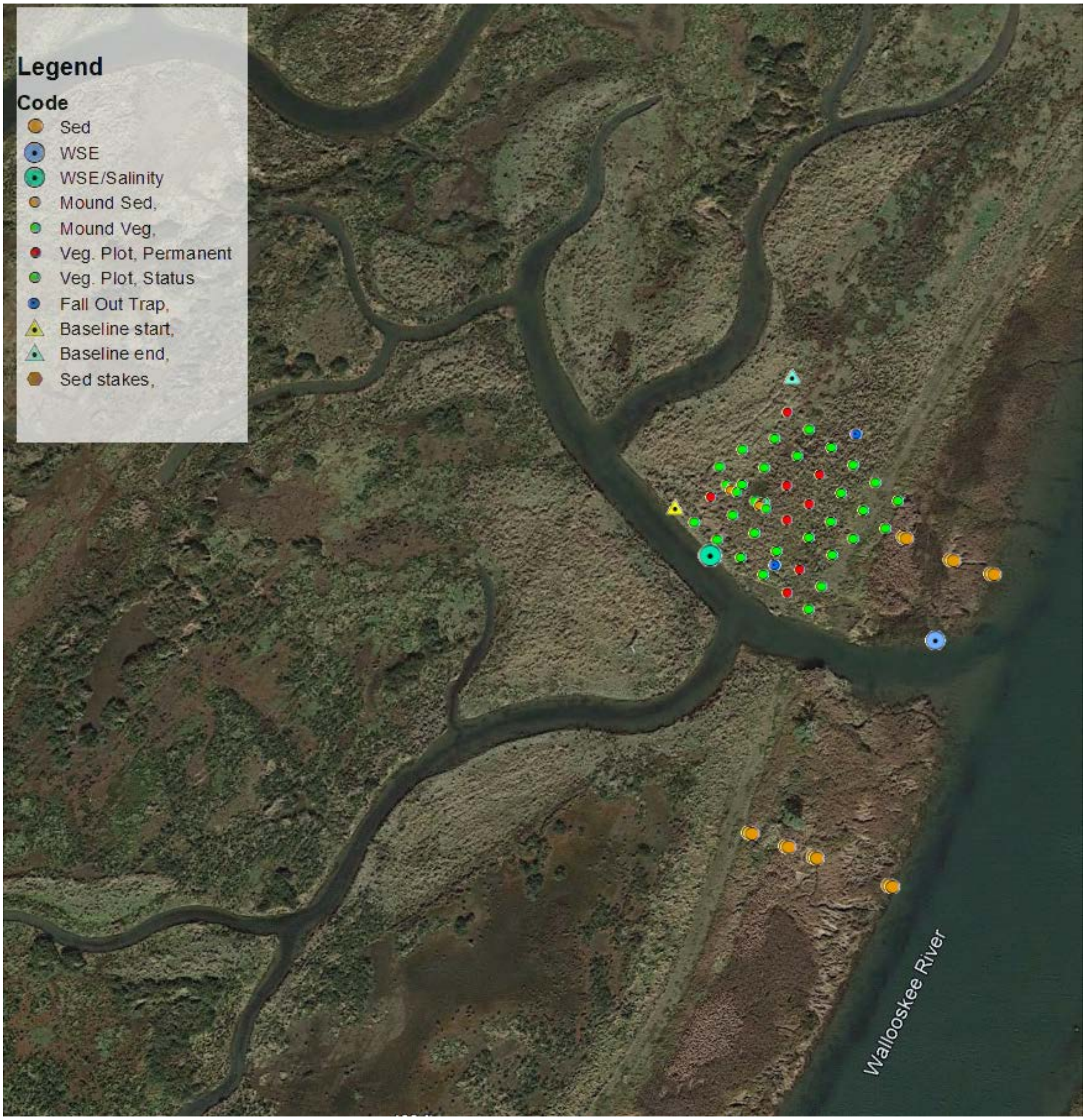

Figure 11: Map of Wallooskee "South" Sampling area. Map shows vegetation grid and fall-out traps deployed during years 0 and 1. For years 4 and 5, the Macroinvertebrate sampling method was changed to neuston tows.

The AEMR pre-restoration vegetation monitoring occurred in June of 2017. In accordance with the established BPA level 2 and 3 monitoring protocols, water surface elevation and temperature monitoring have occurred continuously since pre-construction (2014-2022), sediment accretion and erosion monitoring has been conducted annually. Vegetation monitoring has occurred in years 0, 1, 3, and 5 (planned July 2022) post-restoration. Due to the extreme tidal and sediment movement at the site, channel cross-sections were not collected (safety concerns). However, UAV imagery was collected in 2020 (Year 3) and is planned in 2022

(Year 5), providing full site digital terrain and vegetation models. Macroinvertebrate monitoring with fall-out traps has been conducted in years 0, 1, and neuston tows have been conducted in years 4 and 5 (year 3 was delayed due to Covid-19). Additionally, a fishing check-in was performed by NOAA in year 5 (April & May 2021). All data currently being collected in 2022 will be reported in 2023.

In addition to the BPA AEMR plant community monitoring, three high and three low marsh monitoring areas were established to evaluate how plant communities, soil conditions, and sediment accretion/erosion dynamics varied specifically between these two different constructed elevation ranges (Figure 12). Previous research on tidal wetland restoration in Young Bay (Kidd 2017) has noted a lag in high marsh recovery across restoration sites in the region. Directly monitoring these outcomes at Wallooskee provided an opportunity to further investigate this hypothesis and the mechanisms driving these potential outcomes. Additionally, understanding how topographic mounding influences the trajectory of restoration sites has been identified as a critical uncertainty in the lower Columbia River through the CEERP program (Diefenderfer et al. 2016).

Map of High and Low Marsh Monitoring

Figure 12: Overview Map showing locations of high and low marsh monitoring areas.

In this study, the high marsh monitoring areas were situated in areas that were mounded to create high marsh conditions during restoration and paired with nearby low marsh zones to capture similar flooding dynamics (between the high and low marsh zones) across the site.

Based on previous literature and data collected at the site (Kidd 2017), it was generally established that elevations above 1.9 meters were considered high marsh zones, while below this elevation, they were regarded as low marsh. Elevations greater than 1.9 meters generally receive significantly less flooding than those at this elevation (Kidd 2017).

Three vegetation plots were monitored within these high and low marsh groupings, paired with soil data collection and one sediment accretion bench monitoring area. This resulted in 9 vegetation and soil monitoring locations and 3 sediment accretion/erosion bench monitoring locations across the constructed high marsh zones and the adjacent low marsh zones for a total of 18 vegetation and soil monitoring locations and 6 sediment bench locations that were monitored annually between 2017-2021. A final (fifth year post-restoration) of monitoring across these high and low marsh zones will occur in 2022. It should be noted that the third monitoring area in the southern portion of the site has a low marsh zone located in a small pond excavated during construction. This presents a perched low marsh condition at a much higher elevation than the other "low marsh" zones, the designation as low marsh was retained as the area remains flooded (due to the perched nature of the pond) and exhibits similar soil and plant community development as the other low marsh zones.

Reference conditions are those monitored on the site's fringe wetlands- which are established on the river sides of the levee. Reference plots were also co-located with vegetation, soil, and sediment accretion monitoring. Sediment accretion monitoring at these locations was established in 2013; in 2018 vegetation and soil monitoring were added. This resulted in three high marsh and four low marsh reference plots.

Monitoring Results

The monitored parameters described above have been reported in a tableau dashboard that provides a detailed site trajectory and displays a dynamic site-wide habitat opportunity model. For detailed results, please click on this link: Wallooskee - Youngs Restoration Project Research Dashboard

La Center Wetlands

Basic Project Information

Project Description – Problem Statement, Goals, and Objectives

La Center Wetlands is a restoration site located in La Center, Washington, along the East Fork Lewis River (EFLR) (Columbia RM 88, Reach F). The wetlands are a collection of two sites – Site 43 (also named "La center West") and Site 43B (also named "La center East") (Figure 13). In 2013, LCEP performed a limiting factor analysis that identified the following constraints at the site:

- Impaired flow regime, hydrologic conditions, and impaired temperatures due to levees and historical agricultural land use.
- Impaired riparian function and low habitat complexity – the presence of levees, weirs and engineered channels at the sites had resulted in a change in vegetative composition to almost entirely Reed Canary grass and American Blackberry. The lack of maintenance of the weirs had resulted in steep channel banks, low channel widths, and no channel complexity for salmonids.
- Impaired fish passage – the sites did not provide adequate conditions for juvenile salmonid rearing and passage.

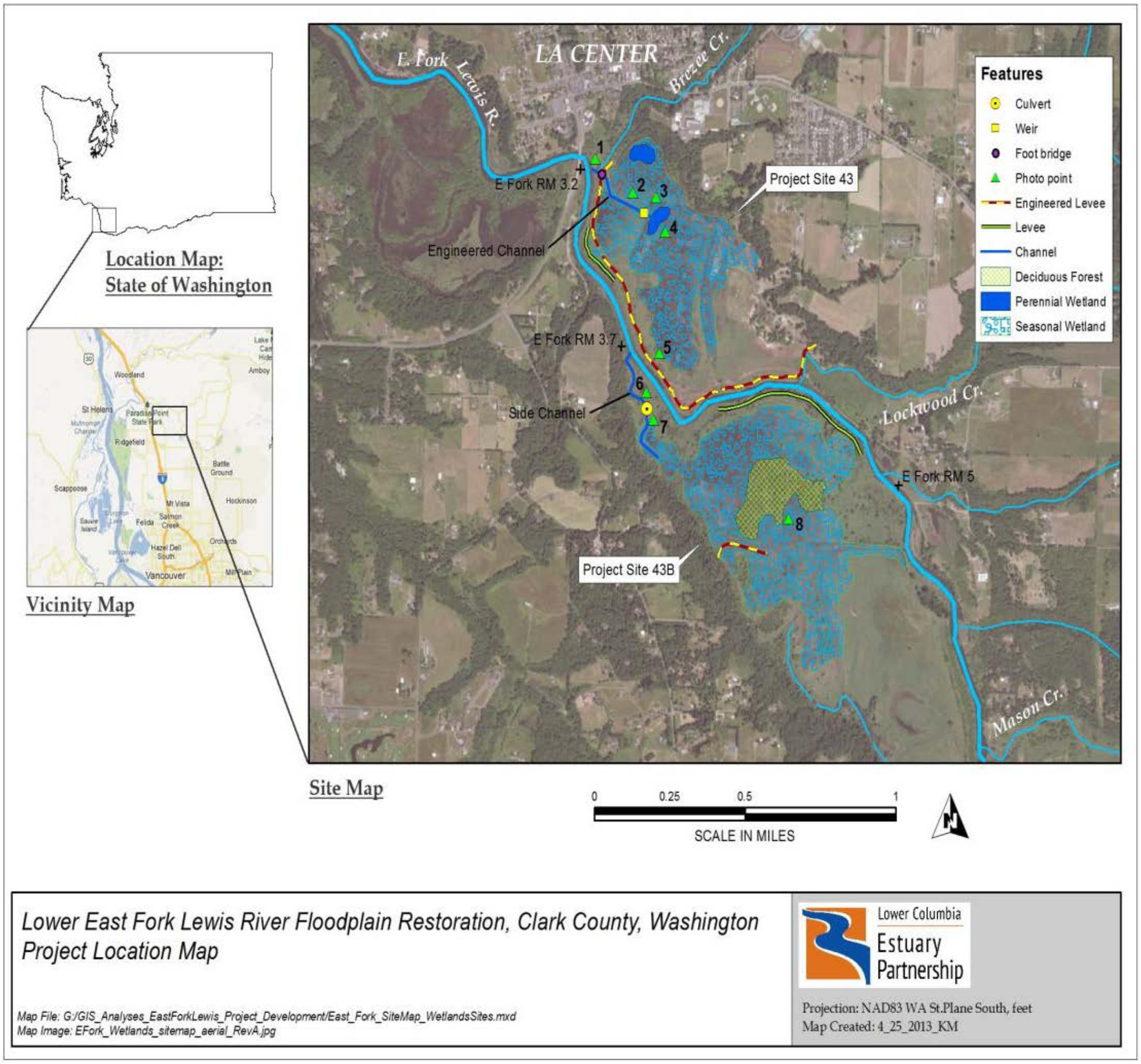

Figure 13: La center wetlands project construction actions map

The overall project goal was to restore hydrologic and geomorphic processes at the two sites. The following were the objectives:

1. Increase inundation frequency and develop a flow regime that mimics the EFLR on the site's seasonal wetlands and floodplains to provide seasonal fish access to 453 acres of emergent marsh habitat through four levee breaches.
2. Create riparian buffers at least 100 feet wide along the side channels by removing invasive species and planting native plants. The riparian buffers help reduce instream temperatures, increase inputs of woody material into the channels and increase food-web production.

3. Improve instream and off-channel habitat diversity and complexity by adding 200-300 pieces of Large Woody Debris (LWD) to the wetlands and newly created off-channel habitat.
4. Improve fish passage by removing the weir at Site 43 and removing the culvert at Site 43B. Removing these structures will ensure complete juvenile salmonid passage at all flows
5. Redesign the engineered side-channel to allow fish passage at all flows, reduce scour and erosion, and facilitate native plant establishment.

Project Construction – Construction Actions
Construction at these sites occurred in 2015, including levee breeches, weir and culvert removals and riparian revegetation.

- Levee Breaches increase the connectivity of the sites to mainstem EFLR, increasing periods of inundation and floodplain habitat available for salmonids and other species.
- Wier and Culvert removals enhance fish passage through the sites and restore hydrologic processes.
- Side channel and off-channel habitat enhancements through LWD placements increased habitat complexity and provided substrate for macroinvertebrates and organic matter input.

Monitoring Plan
Experimental Design, Monitored Indicators, and Monitoring locations
La Center Wetlands has received AEM Level 2 and Level 3 monitoring since 2015, with a nearby wetland being selected as an unimpacted “control” site (Figure 14). Vegetation grids at each location were set up, and hydrology was monitored since 2015. In accordance with the established BPA level 2 and 3 monitoring protocols, vegetation monitoring has occurred in years 0, 1, 3, and 5 post-restoration (Figure 15, Figure 16). UAV imagery was collected in 2020, providing full site digital terrain and vegetation models. Macroinvertebrate monitoring with fall-out traps has been conducted in years 0, 1, and 3 post-restoration, while neuston tows have been conducted in year 6 post-restoration. Additionally, a fishing check-in was performed by NOAA in year 6 (April 2021). Year 5 macroinvertebrate sampling and fish check-ins were delayed due to COVID-19 lockdowns.

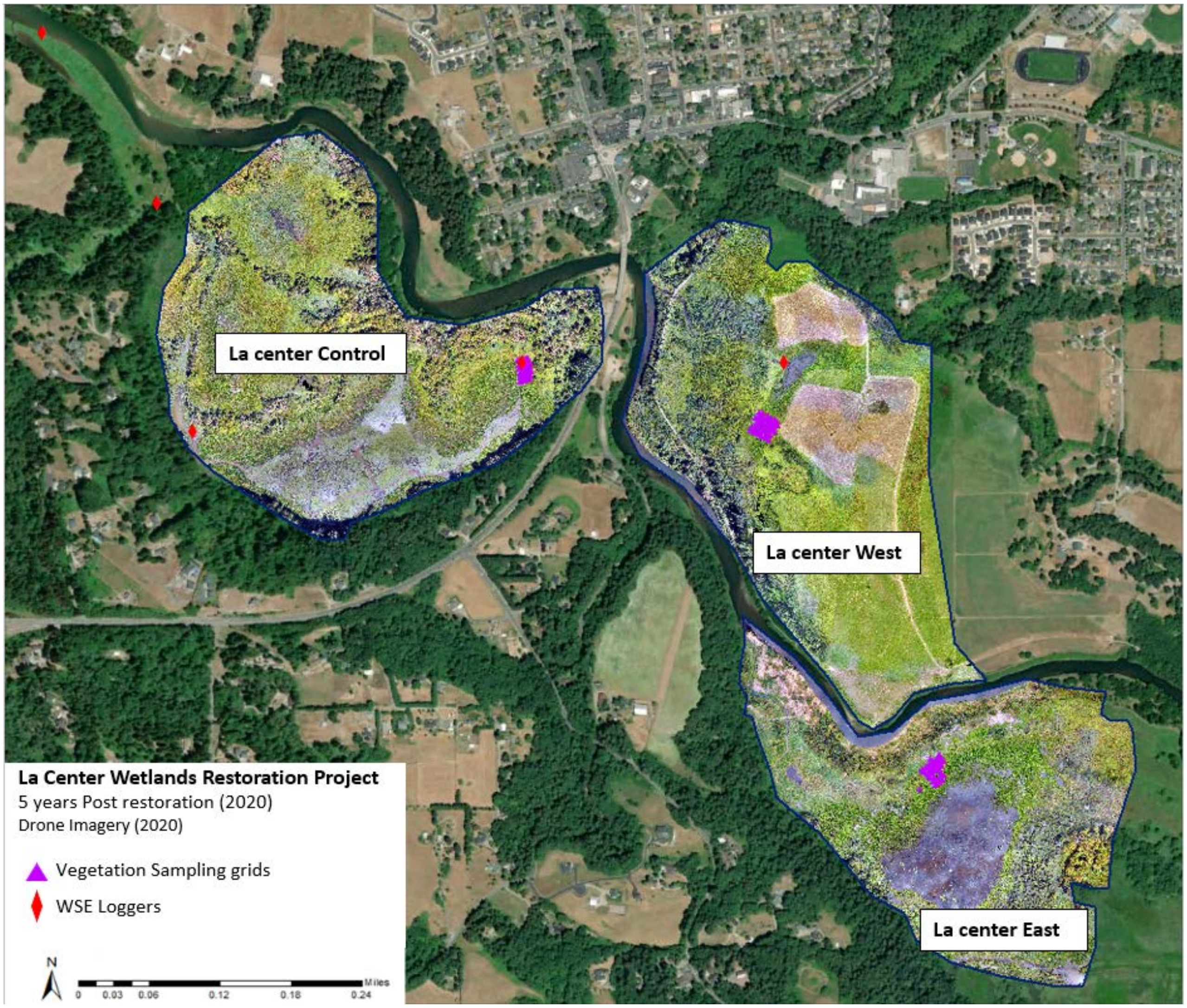

Figure 14: Overview Map of La Center Wetlands Restoration Project.

Figure 15: Map of plant community monitoring areas and the location of water surface elevation (WSE) data loggers at the La Center West Restoration Site.

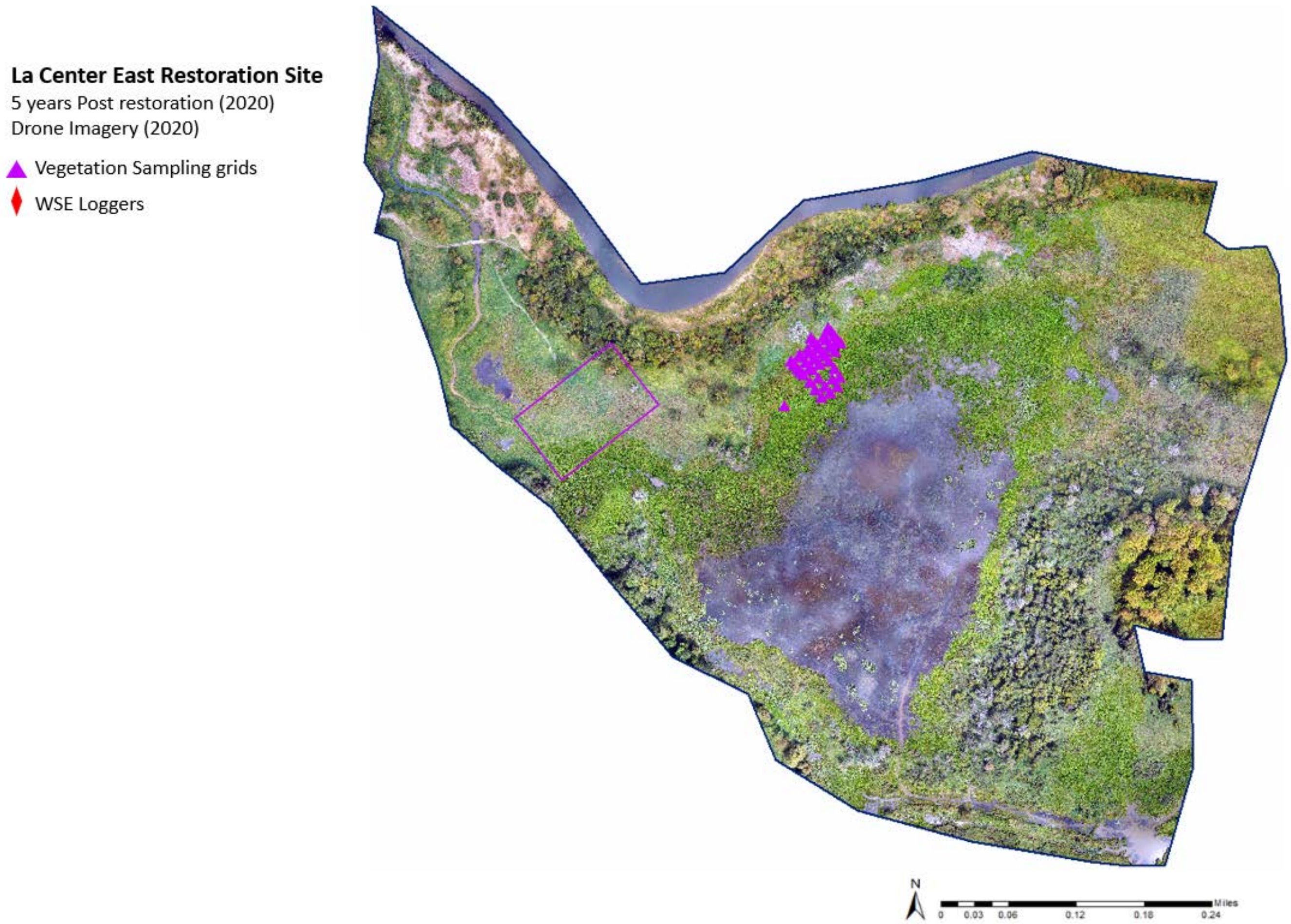

Figure 16: Map of plant community monitoring areas and the location of water surface elevation (WSE) data loggers at the La Center East Restoration Site.

Monitoring Results

The monitored parameters described above have been reported in a tableau dashboard that provides detailed site trajectory and displays a dynamic site-wide habitat opportunity model. For detailed results, please click on this link: La Center Wetlands Restoration Project Research Dashboard.

Flights End Wetlands

Basic Project Information

Project Description – Problem Statement, Goals, and Objectives

Flights End wetlands are located north of Crane Lake in Sauvie Island, OR (Figure 17). This restoration project, sponsored by CREST and funded by Bonneville Power Administration (BPA), was part of a landscape effort to restore the connectivity of Sauvie Island Wildlife Area to Multnomah Channel and the final phase of improving the hydrologic conditions of the Crane Lake System.

The site was formerly a ponded habitat with agricultural land management and vegetation to attract waterfowl. Culverts, water control structures and artificial berms prevented regular inundation and altered historic hydrologic and geomorphic processes that prevented the establishment of a native wetland vegetation mix, nutrient cycling, and restricted fish access. A vegetation survey undertaken in 2016 showed that wetted perimeters and historic prairie zones were dominated by reed canarygrass (*Phalaris arundinacea*). The National Marine Fisheries Service (NMFS) collected juvenile salmonid data along the mainstem channel of Reach F showing high levels of genetic stock diversity for juvenile Chinook.

The overall vision for Flights End wetlands was to increase connectivity to Crane Lake and the larger Multnomah Channel to create a network of habitats for salmonids and other species. This restoration project aimed to connect 42 acres of floodplain wetlands to the Columbia River. The objectives of the project were:

1. Reestablish hydrologic connectivity to Crane Lake and Multnomah Channel by removal of artificial berms and culverts and create a network of channels
2. Establish a native wetland vegetation community by selective marsh plain lowering and replanting these areas with a native emergent – wet prairie mix.
3. Retain recreational uses at the site

Project Construction – Construction Actions

Construction occurred in 2017, and construction actions included removal of two culverts, the artificial berm, and marsh plain lowering. Target elevations were achieved by using wetlands in the Crane Lake system and the larger Sauvie Island complex as design references. Specific actions included:

- Remove artificial earth berm and two additional undersized culverts that blocked the historical channel
- Creating two channel openings from Crane Slough into the wetlands
- Retention of water control structure to allow managers additional stewardship options for a late summer drawdown of water for moist soil management
- Lower marshplain surfaces to increase frequency, duration, and magnitude of water inundation
- Replant lowered marsh plain with native emergent species and wet prairie species
- Design beaver analog structures to prolong the duration of inundation

- Install channel-spanning light duty bridge in replacement of earth berm and culvert to retain recreational and hunting access at the site.

Monitoring Plan

Experimental Design, Monitored Indicators, and Monitoring locations

Monitoring in Flights End has occurred since 2017, with three transects in the site's North, South, and West areas (Figure 18). Sediment dynamics are measured by two pairs of sediment benches. Cunningham Lake was included in the study as the un-impacted reference site (Figure 17).

Figure 17: Overview map of Flights End Project and Reference Cunningham

The AEMR pre-restoration vegetation monitoring occurred in 2017. In accordance with the established BPA level 2 and 3 monitoring protocols water surface elevation and temperature monitoring has occurred continuously over since pre-construction (2017-2022), sediment accretion, and erosion monitoring has been conducted annually, and vegetation monitoring has occurred in years 0, 1, 3, and 5 (planned July 2022) post-restoration. UAV imagery was collected in 2020 (Year 3) and is planned in 2022 (Year 5) which has provided full site digital terrain and vegetation models.

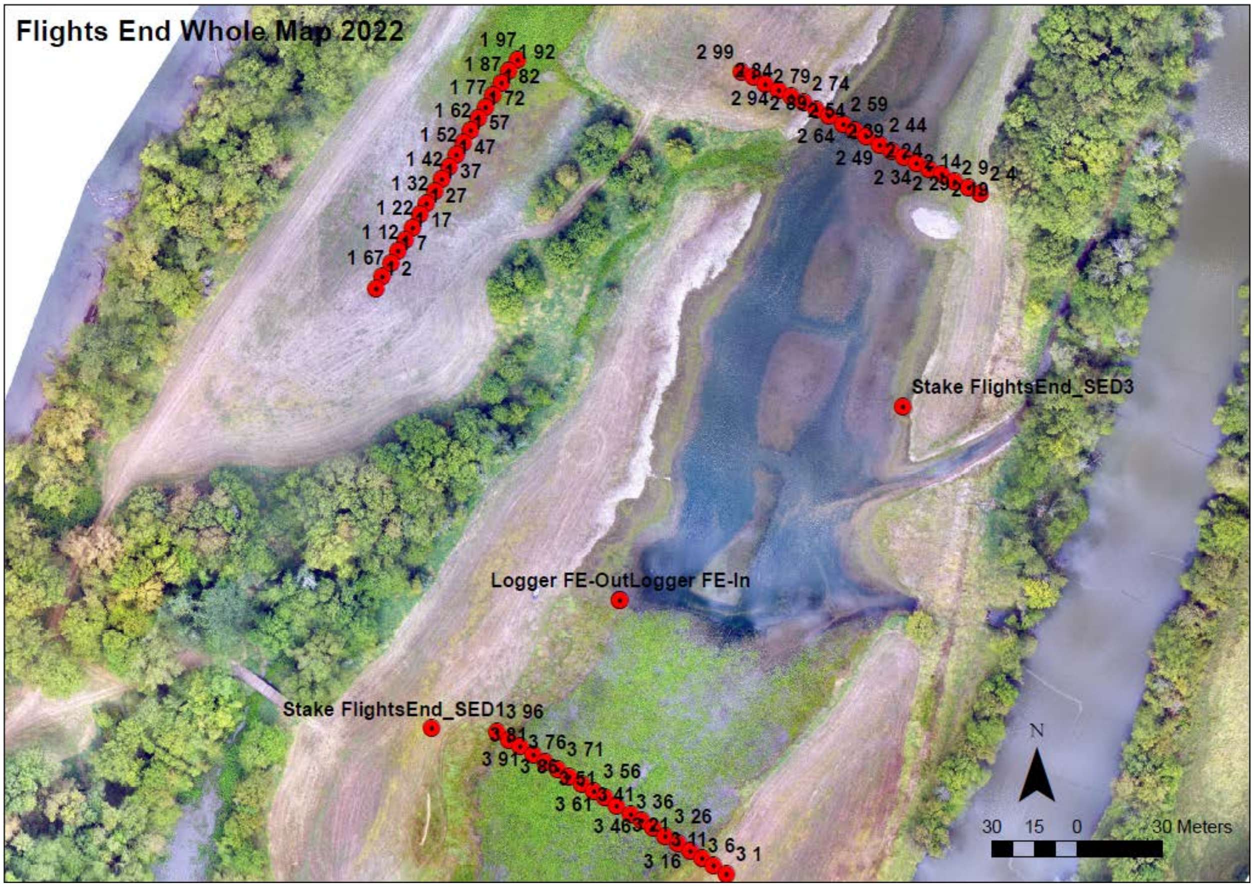

Figure 18: Flight's End Vegetation Survey Map.

Monitoring Results

The monitored parameters described above have been reported out in the form of a tableau dashboard that provides detailed site trajectory and displays a dynamic site-wide habitat opportunity model. For detailed results please click on this link: [Flights End Wetlands Restoration Project Research Dashboard].

Wallacut Slough

Basic Project Information

Project Description – Problem Statement, Goals and Objectives and Construction

Wallacut Slough is a restoration site located in Bakers Bay, near the City of Ilwaco in Washington.

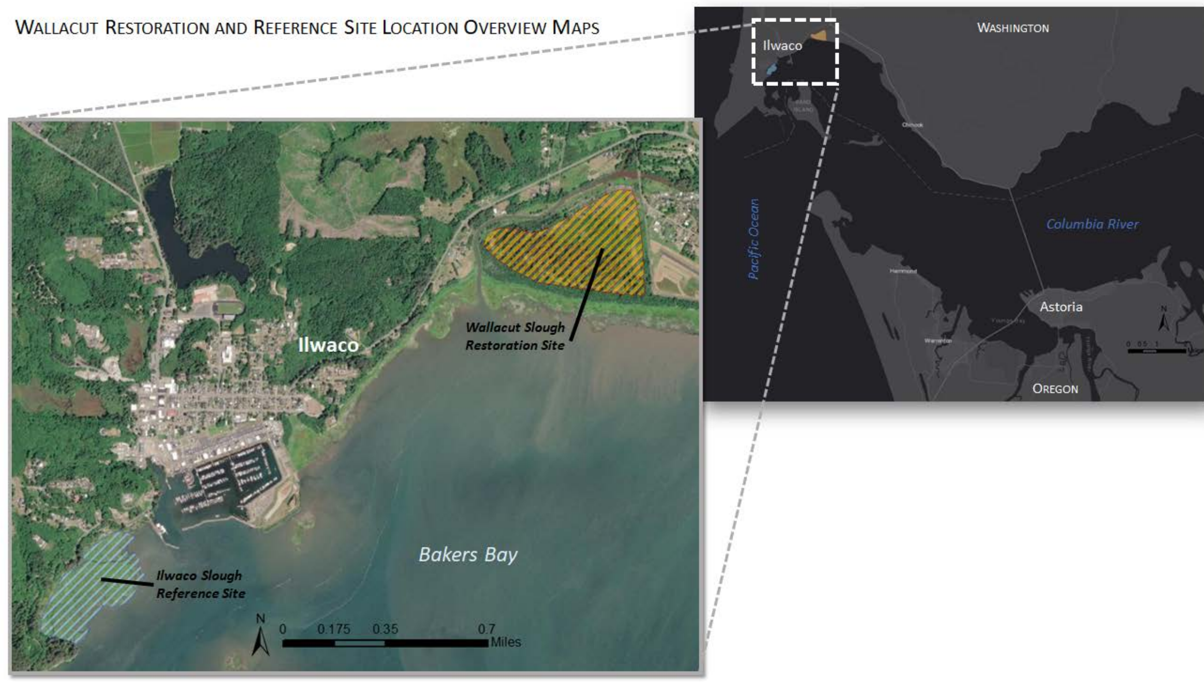

Figure 19: Overview map of Wallacut Slough Restoration Site Location and Ilwaco Slough Reference Site Location.

In 2016 tidal influence to the Wallacut Slough network was restored through the removal of barriers throughout the system (Table 2). Additional channel enhancements were conducted in areas to expand channel density and access to wetland habitat.

Project goals as defined in the SM2 (Johnson et al. 2018):

"Removing the levee and filling the borrow ditch will increase hydrologic connectivity during the tidal cycle and increase the spatial extent of inundation in the wetland. The restoration of a more natural tidal cycle will help restore ecosystem function by supporting a diverse native plant community, improving nutrient cycling, and increasing quantity and quality of off-channel habitat for aquatic species."

Monitoring Plan

Experimental Design, Monitored Indicators and Monitoring locations

Wallacut Slough has received AEM Level 2 and Level 3 monitoring since 2014. In addition to hydrology and sediment dynamics, two vegetation grids were set up - one area was located at the "Mouth" of the site near a channel re-connection and the other was located in an area in the "Upper" portion of the reconnected channel (Figure 20). Ilwaco Slough, a longterm EMP site, was chosen as a nearby reference site for ongoing monitoring and comparisons (Figure 19).

During the restoration, the area near the **Mouth** of the channel was heavily impacted by grading and removal of levee materials; after restoration, this area was also targeted for non-native herbicide treatments in the spring of 2019. The area monitored in the **Upper** portion of the restored channel received only minimal impacts during restoration and no herbicide treatments. Minimal impacts of herbicide treatments were observed in both vegetation grids in 2021.

In accordance with the established BPA level 2 and 3 monitoring protocols water surface elevation and temperature monitoring has occurred continuously over since pre-construction (2014-2021), sediment accretion, and erosion monitoring has been conducted annually, and vegetation monitoring has occurred in years 0, 1, 3, and 5 post-restoration. UAV imagery was collected in 2019 (Year 3) and 2021 (Year 5) which has provided full site digital terrain and vegetation models. Macroinvertebrate monitoring with fall out traps has been conducted in years 0 and 1 post-restoration, while neuston tows have been conducted in years 3, and 5 post-restoration. Additionally, a fishing check in has been performed by NOAA in year 5 (April 2021).

Figure 20: Map of plant community monitoring areas and the location of water surface elevation (WSE) data loggers at the Wallacut Slough Restoration Site.

Monitoring Results
The monitored parameters described above have been reported out in the form of a tableau dashboard that provides detailed site trajectory and displays a dynamic site-wide habitat opportunity model. For detailed results please click on this link: Wallacut Restoration Project Research Dashboard.

North Unit Phase 1 (Ruby Lake)
Basic Project Information
Project Description – Problem Statement, Goals and Objectives
North Unit Phase 1 – Ruby Lake is a restoration site located in the northern portion of Sauvie Island, Oregon (Columbia RM 89, Reach F). This restoration project sponsored by CREST and funded by Bonneville Power Administration (BPA), was the first of three planned phases in the Sauvie Island Wildlife Refuge area with the goal of reestablishing juvenile salmonid access to 292 acres of historical wetland habitat (all 3 phases combined).

Water-control structures placed in channels connecting Ruby Lake to Cunningham Slough were outdated, restricting fish and degrading water quality. These structures also reduced channel velocities, altering sediment transport throughout the wetland. The lack of prolonged inundation also allowed Reed canarygrass to out-compete native wetland vegetation.

The overall goal for this restoration project is to create a mosaic of wetland habitats that support juvenile salmonids by increasing tidal connection, reestablishing historical hydrology an increasing habitat complexity. The project specific objectives are listed below:

1. Improve habitat quality and opportunity by improving access to Cunningham Slough and reducing non-native vegetation to allow establishment of native wetland mix.
2. Use Adaptive management practices to maintain habitat quality

Project Construction – Construction Actions
Ruby Lake restoration occurred in 2013, and construction actions included removing water control structure, channel enhancements, strategic marsh plain lowering and implementation of a vegetation enhancement plan. These techniques were aimed at increasing habitat opportunity at the site.

- Removal of water control structure and channel enhancements will restore tidal connectivity to the site, increasing periods and levels of inundation at the site.
- Marsh plain lowering to target elevations based on reference wetlands like Cunningham Lake and riparian revegetation assists in establishment of a native vegetation community, while staying inundated for longer, which reduces the chances of reed canarygrass germination and survival.

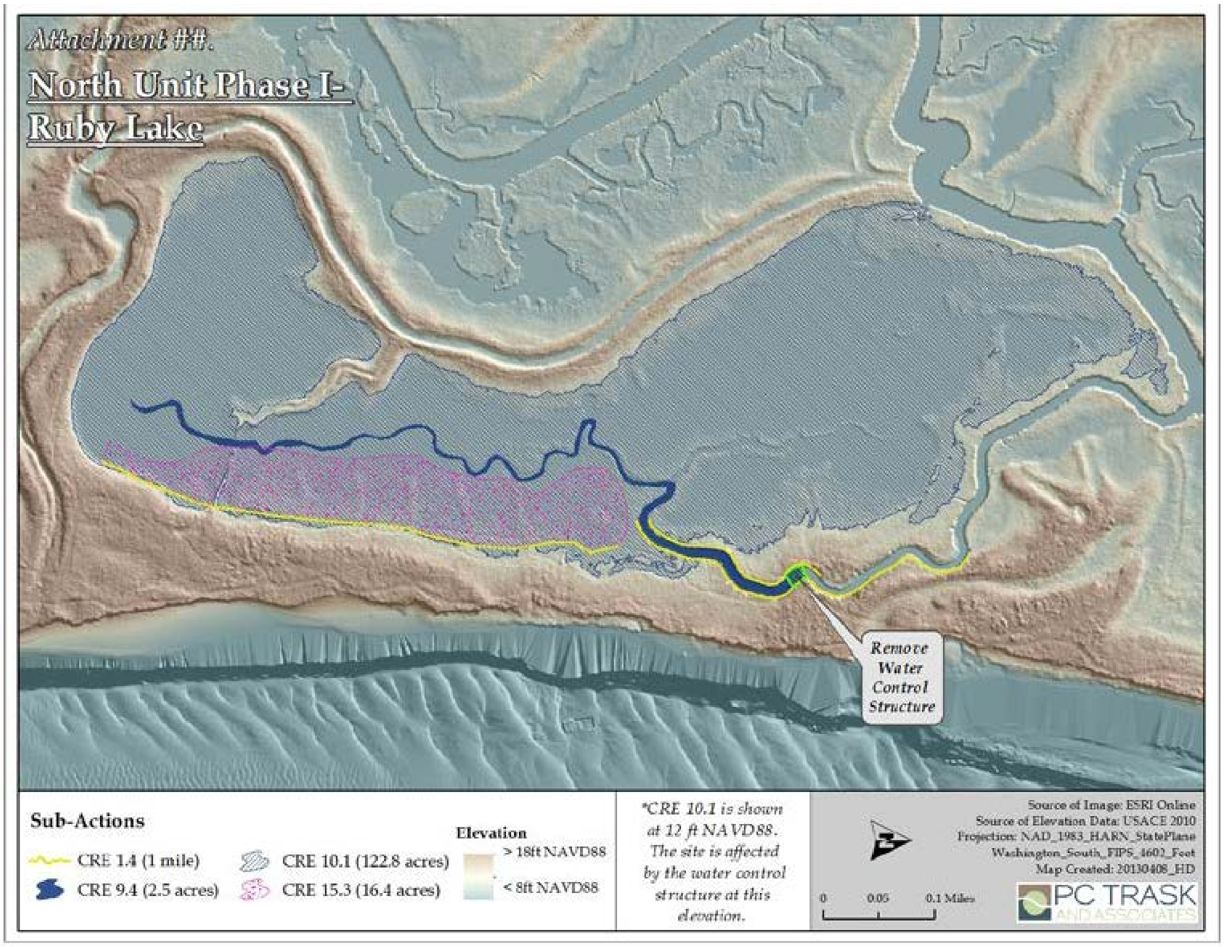

Figure 21: Construction design overview for planned restoration activities at North Unit Phase 1

Monitoring Plan

Experimental Design, Monitored Indicators and Monitoring locations

Ruby Lake has received AEM Level 2 and Level 3 monitoring since 2013. During Year 5 post-restoration, the low marsh community was not developed enough to draw adequate conclusions about the restoration of site. Hence, it was included as a Year 8 AEM Monitoring site. In addition to hydrology and sediment dynamics, two vegetation grids were set up – the “North” vegetation grid is located in a scrape down area, while the “South” vegetation grid is located adjacent to an existing channel (Figure 23). Cunningham Lake, located south of the restoration site, was chosen as a “reference” or unimpacted site for monitoring (Figure 22)

North Unit Ph 1 Ruby Project Overview Map

Figure 22: Overview map of Ruby Lake Project and Reference Cunningham

In accordance with the established BPA level 2 and 3 monitoring protocols water surface elevation and temperature monitoring has occurred continuously over since pre-construction (2013-2021), sediment accretion, and erosion monitoring has been conducted annually, and vegetation monitoring has occurred in years 0, 1, 3, and 5 post-restoration. UAV imagery was collected in 2021 (Year 8) which has provided full site digital terrain and vegetation models. Macroinvertebrate monitoring with fall out traps has been conducted in years 0, 1, 3, and 5 post-restoration by placing traps in established vegetation grids in the North and South, and neuston tows were conducted in year 8post-restoration. The site is planned for Year 10 post-restoration monitoring in 2023.

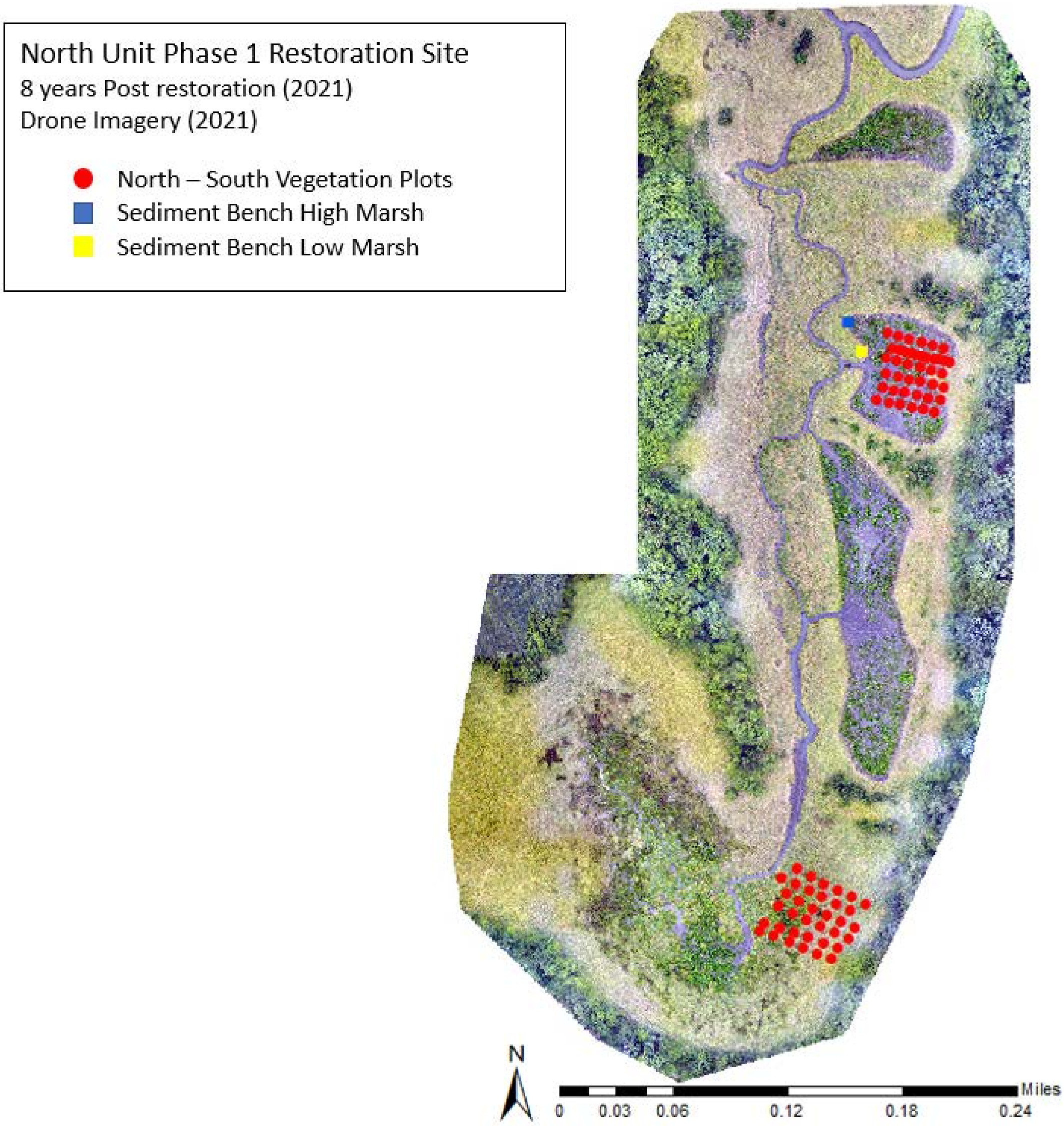

Figure 23: Map of plant community monitoring areas and the location of sediment benches at the Ruby Lake Restoration Site.

Monitoring Results

The monitored parameters described above have been reported out in the form of a tableau dashboard that provides detailed site trajectory and displays a dynamic site-wide habitat opportunity model. For detailed results please click on this link: Sauvie Island North Unit Phase 1 (Ruby Lake) Restoration Project Research Dashboard.

Horsetail Creek PIT Array
From 2014 – 2019, Salmon originating from throughout the Columbia River Basin were detected at the Horsetail array (Figure 24). Species originating from the mid-Columbia Basin included Chinook, coho, and steelhead. Species originating from the upper Columbia Basin included Chinook, coho, sockeye, and steelhead. Coho was the only species originating from the Yakima Basin, and Chinook, coho, sockeye, and steelhead from the Snake River Basin were detected.

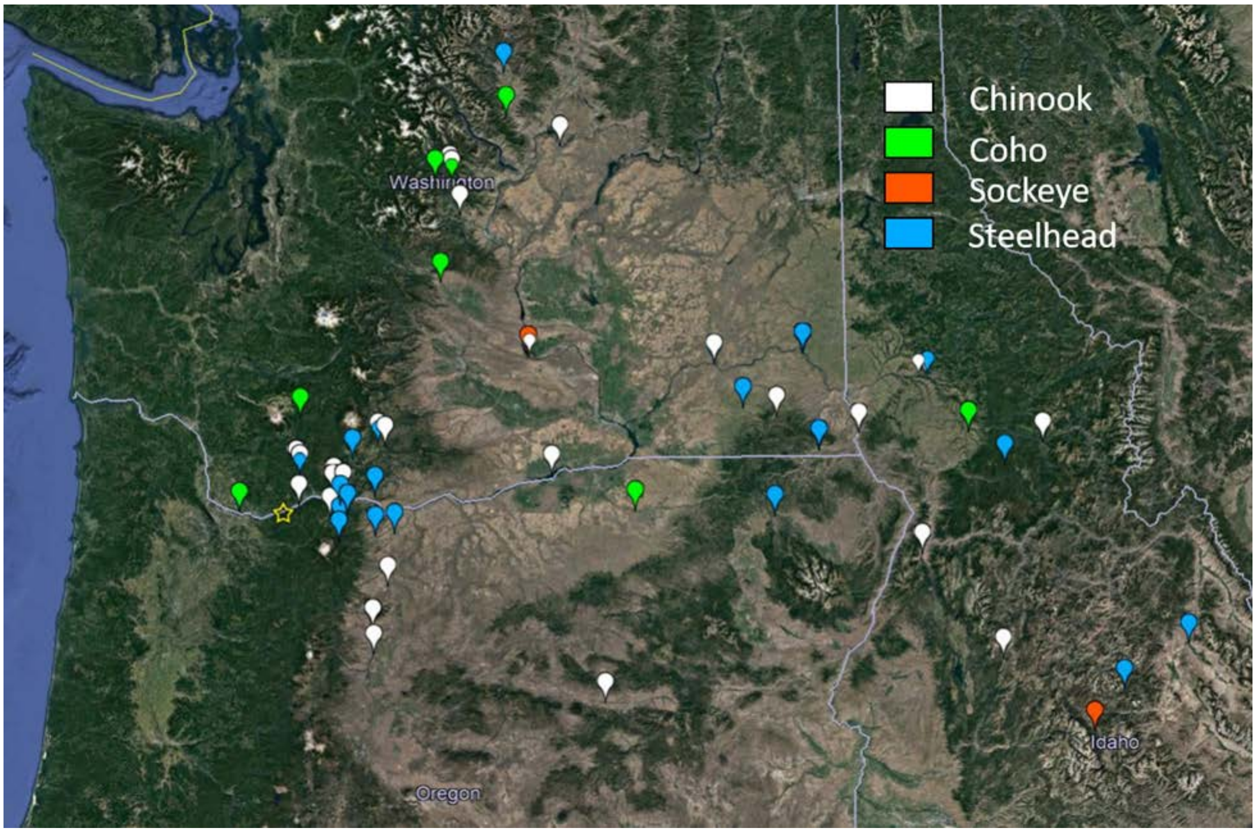

Figure 24: Map of origins of salmon detected at Horsetail array, 2014-2019.

Four species of salmonids were detected at the Horsetail array throughout the monitoring period: coho, Chinook, sockeye, and steelhead. A combination of juvenile and adult/jack coho, Chinook, and steelhead were detected (Table 6). 23% of Array detections were of adults or jacks that were migrating upstream (i.e., detected at Bonneville fish ladders soon after detection at Horsetail array). Of the adults/jacks, 16 coho and one steelhead were tagged as adults in the lower Columbia River. The remaining adult/jacks were a combination of Chinook (N=4), steelhead (N=7), and coho (N=4) that were tagged as juveniles. In addition to salmon, eight northern pikeminnow were detected from 2014-2019 and there were 41 tags detected for which no information could be found in the PTAGIS data repository.

Between 2014 – 2019, Seventy-seven percent of salmon detections at Horsetail were of juvenile fish. Within juvenile salmon, spring/summer Chinook as well as fall Chinook each comprised 34%, steelhead comprised 23%, coho comprised 5%, and sockeye comprised 4% of the juvenile salmon detections.

Table 6: Number of juvenile and adult/jack salmon detected at Horsetail array by species, basin of origin, and year, 2014 – 2019

Year	Basin	Species	Juvenile	Adult/Jack
2014	Lower Columbia	Coho	1	15
	Mid-Columbia	--	--	--
	Snake River	Coho		1
		Steelhead	1	1
	Upper Columbia	Chinook	1	
		Coho		1
	Yakima River	Coho		1
2015	Lower Columbia	Chinook	1	
	Mid-Columbia	Chinook	7	1
		Coho	1	
		Steelhead	5	1
	Snake River	Chinook	4	
		Steelhead	7	1
		Sockeye	2	
	Upper Columbia	Chinook	2	
		Coho		1
		Steelhead	1	
		Sockeye	1	
2016	Lower Columbia	--	--	--
	Mid-Columbia	Chinook	11	
		Steelhead		1
	Snake River	Chinook	1	
		Sockeye	1	
	Upper Columbia	Coho	1	
2017	Lower Columbia	Coho		2
	Mid-Columbia	Chinook	10	1
		Steelhead	3	
	Snake River	Chinook	2	2
		Steelhead	4	
2018	Lower Columbia	--	--	--
	Mid-Columbia	Chinook	23	
		Steelhead	1	3
	Snake River	Chinook	2	
		Coho	1	
		Steelhead	4	1
2019	Lower Columbia	--	--	--
	Mid-Columbia	Chinook	9	
	Snake River	Chinook	2	
	Upper Columbia	Coho	1	

Juvenile salmon residence times at the site ranged from a single detection to 115 days (Figure 25). Majority of salmon were detected for less than one minute. Steelhead had the longest residence time with one individual residing for 115 days. A second steelhead had a residence time of 67 days, after which it was detected on the Bonneville ladder, indicating that it had used Horsetail to rear until it was ready to return upriver. Spring/summer Chinook and fall run Chinook had similar residency times, ranging from less than a minute to 19 days. Juvenile coho and sockeye had the shortest residence times of one day or less for coho and one hour or less for sockeye.

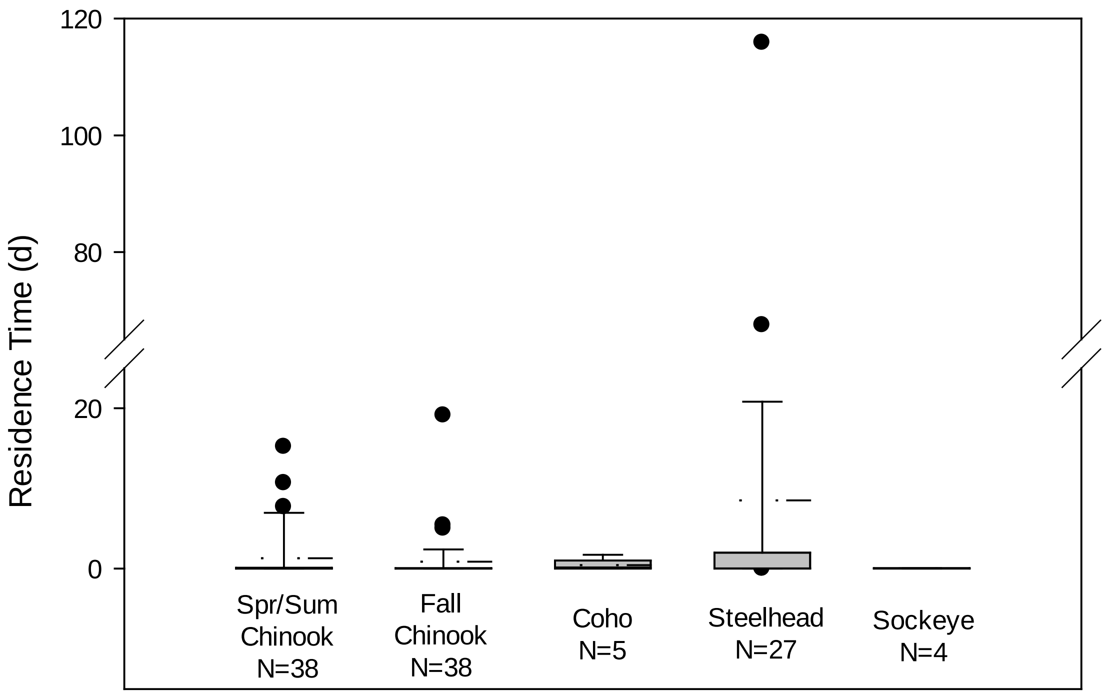

Figure 25: Box plots of residence times for juvenile spring/summer Chinook, fall Chinook, coho, steelhead, and sockeye. Box boundaries indicate 25th and 75th percentiles, error bars represent 10th and 90th percentiles, and dots are outliers. The solid line is the median (not always visible) and dashed line is the mean.

Between 2014 – 2019, adult salmon residence times ranged from a single detection to 18 days (Figure 26). Adult coho were the most numerous adults detected at Horsetail, likely as a result of an adult tagging study in the lower Columbia River. Coho also exhibited the longest adult residence time of 18 days. Steelhead were the second most numerous species of adult salmonid detected and exhibited the residence time of 12 days. Spring/summer run and fall run adult Chinook were detected in low numbers. These stocks also exhibited the shortest residence times with the sole fall Chinook residing 1.8 days and the spring/summer Chinook residing an hour or less.

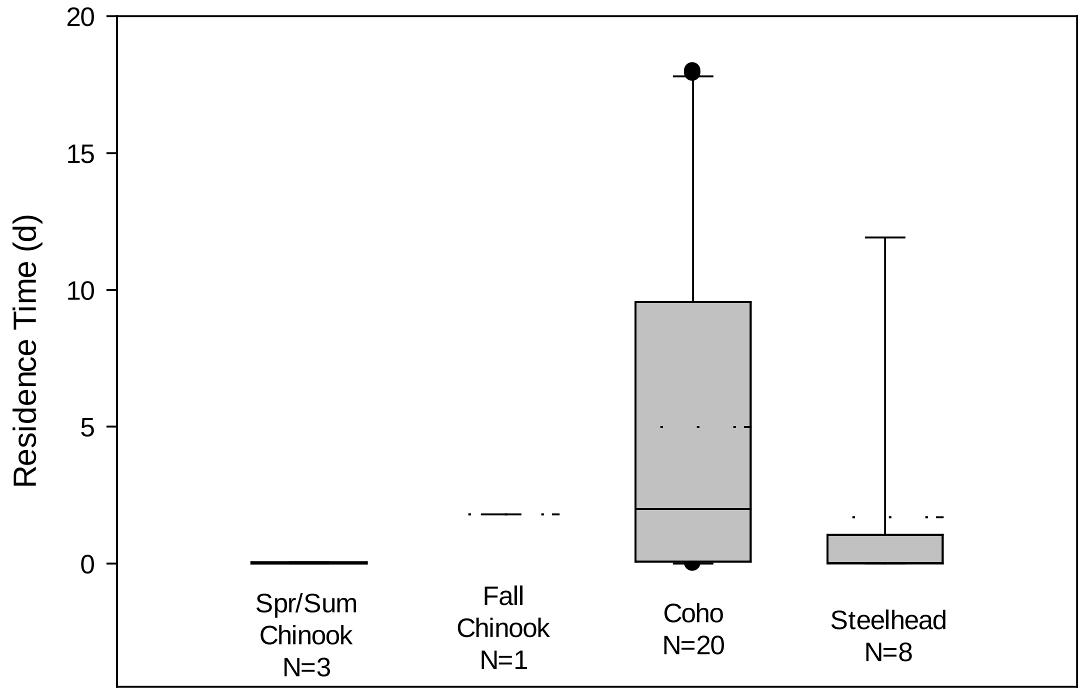

Figure 26: Box plots of residence times for adult spring/summer Chinook, fall Chinook, coho, and steelhead. Box boundaries indicate 25th and 75th percentiles, error bars represent 10th and 90th percentiles, and dots are outliers. The solid line is the median (not always visible) and dashed line is the mean.

The installation of antennas on both sides of the culvert provided the opportunity to determine when a fish had passed through the culvert to the Horsetail/Oneonta Creeks side. These estimates are not complete as there were instances when some antennas were not fully-functional thus, PIT tagged fish could have passed through the culvert undetected. Thirty-six (25%) salmon that were detected on the Horsetail array were detected on both sides of the culvert, indicating that the individuals managed to access the site between 2014 – 2019 (Table 7). Of those 36, 14 were adults/jacks and 22 were juveniles. Twelve adult coho, one adult steelhead, and one adult fall Chinook salmon potentially accessed the restoration areas. In terms of juvenile salmon, twelve steelhead, six spring/summer Chinook, two coho, and one each of fall Chinook and sockeye salmon potentially access the restoration areas. Two of the eight northern pikeminnow also traversed the culvert.

Table 7: Summary of juvenile and adult/jack salmon site access between 2014 – 2019.

Basin	Species	Juvenile	Adult/Jack
Lower Columbia	Coho		12
Mid-Columbia	Chinook	5	1
	Steelhead	1	1
Snake River	Chinook	1	
	Coho	1	
	Steelhead	11	
	Sockeye	1	
Upper Columbia	Chinook	1	
	Coho	1	

CONCLUSION

The final goal of AEM restoration efforts is the establishment of functional wetland processes and habitat that support juvenile salmonids. Action effectiveness monitoring tracks the ecological impact of restoration work and provide valuable information to manage restoration sites adaptively. Furthermore, AEM shows that the rate at which physical processes and habitats recover after restoration activities vary, depending on location in the estuary, degree of tidal reconnection, and pre-existing site conditions. For example, physical processes in a wetland like water surface elevation (duration, frequency, depth, and timing of flooding), water temperature, and overall habitat opportunity change rapidly after reconnection and become closer to conditions in reference sites. Other aspects of wetlands recover over a longer period, such as changes in the vegetation community and soil conditions. The trend for sites five years post-restoration indicates that they have slightly less native cover and a similar amount of reed canarygrass as reference sites. Limited fish monitoring shows that juvenile salmonids are present in restoration sites after tidal reconnection, but, without intensive monitoring efforts, the number of fish using the site can be difficult to ascertain. Furthermore, it is not known if the number of fish accessing a site increases as the habitat moves toward a reference state. A better understanding of how physical processes influence habitat conditions and how these resulting habitat conditions support juvenile salmonids are key to quantifying the overall impact of restoration efforts.

MANAGEMENT IMPLICATIONS

Action effectiveness monitoring measures changes to physical and ecological processes that influence the ability of restoration sites to support juvenile salmonids. In addition, AEM data provides project managers with vital information to determine if project design elements are meeting goals or if adaptive management is required.

At the site-scale, restoration projects are leading to the reestablishment of natural physical processes that support juvenile salmonids. Data has shown that site water levels respond immediately to hydrologic reconnection. Water temperatures at the restoration sites are generally warmer than nearby main stem waters but were generally suitable during the spring and early summer juvenile outmigration periods. The higher temperature at restoration sites can be attributed to shallower water depths, and this trend is mirrored in results seen at Ecosystem Monitoring Program (EMP) sites (Kidd et al. 2019).

As the goals of restoration activities include improving fish access to historic floodplain habitats and the quality of those habitats, we wanted to verify that fish are using restored sites. We chose to employ a "status check" of fish use at five years post-restoration. We collected fish occurrence data at Wallacut River and La center Wetlands and found juvenile salmonids at all locations. The presence of juvenile salmonid indicates that restoration benefits fish. The PIT array at Horsetail Creek detected out migrating upriver juvenile and adult salmonid species visiting the site for periods ranging from a few hours to a number of days.

AEM research shows that restoration sites are achieving increases in hydrologic connectivity and salmonid opportunity; however, plant community recovery is more variable across sites. Given the inherent inter-annual climate variability, it is difficult to predict specific restoration outcomes on a year-to-year basis. However, clear trends in plant community recovery across restoration sites persist, with high marsh elevations retaining reed canarygrass and other non-native species at year 3 and 5 post restoration. The lack of high marsh plant community recovery is also echoed in the soil conditions identified in these locations, which retain lower soil salinity, pH, and greater ORP levels than found at reference sites. Additionally, areas within restoration sites that have undergone heavy construction impacts and grading have also been shown to recover on a slower timeline. Alternatively, we have observed that both soil and dominant native plant communities recover quickly (within 5 years post-restoration) in areas that are found at moderately low to mid wetland elevations. Across all these findings, wetland elevation is used as a proxy for restored wetland hydrology which, in combination with soil conditions, is the ultimate mechanism driving restoration outcomes throughout the estuary (e.g., Bledsoe and Shear 2000, Neckles et al. 2002, Davy et al. 2011, Mossman et al. 2012, Gerla et al. 2013, Kidd 2017). Through our AEM research we have found that the re-establishment of natural physical and hydrological processes to sites can be accomplished in a short period of time but understanding how these wetland sites respond ecologically will require longterm monitoring. Ultimately, this continued monitoring will elucidate longterm trends and improve our understanding of the connections between physical processes, habitat responses, and the resulting benefits to juvenile salmon.

AEMR Program Recommendations

Suggestions for Project Design

- Both restoration design and evaluation would benefit from the use of predictive modeling to determine the restoration of aquatic, marsh, and shrub-scrub plant communities. This type of modeling can be easily accomplished by incorporating anticipated restored hydrology and site elevations and comparable reference site conditions (Hickey et al. 2015).

These data can also provide a platform for evaluating different restoration scenarios, such as considering different levels of hydrologic reconnection and/or marsh plain lowering and the impacts of this for multispecies and plant community habitat recovery (Hickey et al. 2015)[4].

- o Across multiple restoration projects we have seen very high and very low marsh elevations struggle to recover native plant cover within a 5-year timeline. Moving forward predictive modeling could aid in restoration design (and adaptive management efforts) to maximize the restoration of the mid to moderately low marsh elevations which have been shown to recover native plant habitat and soil conditions quickly post-restoration (throughout the Estuary).
- o In addition, this will also aid project planning for determining seeding and planting zones in target high marsh areas for non-native species control and shrub-scrub development.
- o Assess restoration success and goal-reaching post-restoration would also be easier given predictive maps and data could be compared to conditions observed post-restoration.

SUGGESTIONS FOR PROJECT MONITORING

SITE TOPOGRAPHY AND REFERENCE SITES

- Accessibility to ground survey technology such as RTK GPS systems has increased dramatically over the last five years and these systems allow us to easily map the overall topography of wetlands and their plant communities and channels. With this technology, we can assess the compatibility of reference and restoration wetland sites. Similar elevation gradients (and hydrology) should be sampled within reference and restoration sites for meaningful comparisons to be made post-restoration (and to aid in project design). In this report we have highlighted that the reference site elevations have generally been a poor match with each restoration site's restored elevations, moving forward we will aim to alter monitoring plans to sample more overlapping elevation gradients between the restoration and reference sites to correct these issues. Additionally, upon choosing reference sites to inform project design and post-restoration project success elevations and (anticipated) hydrology should be compared to ensure the use of reference elevation data is an appropriate proxy for hydrologic conditions.

HYDROLOGY

- Hydrology is a critical component to all wetland restoration efforts and should be monitored for project planning, design, and to assess project success. During project design clear hypotheses should be developed to define hydrologic changes anticipated from restoration efforts. For monitoring data loggers need to be in placed areas that are

[4] We are currently using this Ecosystem Modeling Approach (Hickey et al. 2015) at Steigerwald National Wildlife Refuge and Multnomah Channel Natural Area to evaluate and design for desired restoration outcomes.

anticipated to experience these hydrologic changes post-restoration and remain in the same location pre- and post-restoration. Given the number of issues we have experienced through the years with data loggers we recommend having at least one redundant logger be placed within the site (nearby or at the same location), that can provide additional data in case of equipment failure (which is common). Loggers need to be maintained at least every six months and we recommend all deployment and retrievals follow the new and more detailed monitoring protocols to avoid data loss (Kidd et al. 2018).

SEDIMENT ACCRETION AND EROSION, CHANNEL CROSS-SECTIONS

- Understanding sediment accretion and erosion dynamics across the floodplain of newly restored wetlands is critical for tracking wetland and channel development and longterm topographic trajectories. Sediment dynamics across restoration sites can be extremely variable making it difficult to track meaningful change without intensive and extensive monitoring efforts. We recommend shifting our current approach of sediment monitoring (one or two sediment benches placed within a site) to a more targeted application of these methods. Before restoration occurs specific areas of interest should be selected, and multiple sediment monitoring benches (minimum of 6) should be installed along the elevation gradient and within these targeted areas. Within the sediment bench monitoring area (between the pins), we also recommend tracking dominant plant community development and soil characteristics to aid data interpretation. Channel cross-section monitoring should be similarly focused, and extreme care should be taken to resurvey the exact location of the cross-section for meaningful results to be obtained. Both channel cross-section and sediment benches need to be resurveyed using RTK GPS technology to provide topographic context and increase data usability. Updated monitoring protocols are currently in development for these methods (Kidd and Rao 2019).

WETLAND PLANT COMMUNITY

- Native wetland plant communities provide a critical base of the salmonid food web and are essential for determining wetland restoration success (Rao et al. 2020). We have found monitoring a randomized selection of vegetation plots each year creates a great amount of variability in the data and makes determining what change has been caused by the restoration and what change is due to the new randomized sampling difficult to determine. There are two approaches to addressing this issue, one would be to 1) continue to randomize the plots annually but significantly increase the overall total number of plots surveyed or 2) to only randomize the plots the first year of monitoring and re-visit these same plots year after year. We recommend (#2) re-visiting the same plots year after year, which provides a clear path to assessing plant community changes overtime and does not increase the overall amount of time required to conduct sampling. Additionally, as shown in this report, the collection of soil data, alongside of plant community data, can be very informative when evaluating wetland development and restoration. We recommend integrating soil data collection as an essential metric for Level 2 monitoring across sites. Further vegetation and soil monitoring recommendations are forthcoming, as we work on a comprehensive update to the *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary* (Roegner et al. 2008).

UTILIZING UAV TECHNOLOGY: SITE TOPOGRAPHY, PLANT COMMUNITY MAPPING

- The accessibility and applicability of Unmanned aerial vehicles (UAV) and associated sensor technology have made significant strides in the last several years. Using some of the most affordable equipment and software available we have shown that large scale site wetland plant community and topographic mapping is possible and accurate (Kidd et al. 2020). Mapping dominant native and non-native plant communities across large portions of restoration sites can aid evaluation of project success post-restoration, and guide both active restoration project design and post-restoration project adaptive management efforts. Moving forward we are working to refine our UAV monitoring methods to include tracking channel and floodplain topographic development into our analysis and reporting. We are also exploring methods of evaluating biomass and carbon stores across reference and restored wetlands using our UAV and sensor technologies. Further UAV vegetation monitoring methods and recommendations will be included in the comprehensive update to the *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary* (Roegner et al. 2008).

FREQUENCY OF MONITORING

- Currently, Level 3 monitoring is conducted pre- through year 5 post-restoration and Level 2 monitoring is conducted pre, 1, 3, and 5 years post restoration. Results from the last 6 years of the AEMR level 2 and 3 monitoring indicate that restoration outcomes can be slow and variable, with sites not achieving reference level native plant community conditions by year 5 post-restoration (Johnson et al. 2018, and this report). Given these observations, we recommend level 3 monitoring continue to occur pre through 5, 8, and 10 years post-restoration and that Level 2 monitoring should also be conducted at year 8 and year 10 post-restoration. Adding year 8 and 10 to monitoring for all level 2 and 3 metrics will aid in understanding the longterm impacts of our restoration efforts and allow for monitoring to occur over a wider spectrum of annual climate conditions. Additionally, we recommend UAV plant community mapping occur across all Level 2 and 3 sites pre-restoration, and 3, 5, 8, and 10 years post-restoration. These additional data and longer-term monitoring windows will provide greater context to assess restoration actions and outcomes and help us test ongoing hypotheses about how shifts in climate and river discharge conditions impact restoration outcomes. Adding synthesis reports of site conditions at year 8 and 10 post-restoration will also provide meaningful insight for ongoing adaptive management and restoration efforts.

FISH AND MACROINVERTEBRATE MONITORING

- AEMR Level 2 monitoring does not encompass comprehensive fish or macroinvertebrate monitoring as part of the standard habitat monitoring protocol. Level 2 monitoring includes limited macroinvertebrate monitoring (one or two neuston tows a year following the Level 2 monitoring schedule) and a one-time fish sampling event at year five post-restoration.

Given the spatial and temporal variability of both fish and macroinvertebrate populations seen across the longterm EMP reference sites (Rao et al. 2020), we have concluded a more comprehensive macroinvertebrate and salmonid sampling effort is required, for meaningful post-restoration food web conditions to be evaluated. Limited fish monitoring shows that juvenile salmonids are present in restoration sites after tidal reconnection, but, without intensive monitoring efforts, the number of fish using the site can be difficult to ascertain. Furthermore, it is not known if the number of fish accessing a site increases as the habitat moves toward a reference state. A better understanding of how physical processes influence habitat conditions and how these resulting habitat conditions support juvenile salmonids are key to quantifying the overall impact of restoration efforts. The addition of longterm ecosystem monitoring at a select number of restoration sites would allow for these sites to be tracked alongside the Ecosystem Monitoring Program. The EMP sites have years of accumulated status and trends fish, macroinvertebrate, water quality, and habitat data which could be used for ongoing comparative analysis and evaluation. Selecting focal restoration sites of interest and conducting intensive fish and macroinvertebrate monitoring efforts at these sites, similar to the level of monitoring conducted across EMP sites (Rao et al. 2020), would allow for the recovery of fish use and macroinvertebrate communities to be assessed over the longterm and aid in the interpretation of how physical changes to habitat directly influence the salmonid food web.

Synthesizing Restoration Results

- The most meaningful analysis of restoration success would be one that incorporates all habitat level monitoring metrics across a site to identify recovery of salmonid habitat overtime. We have developed a site wide assessment of habitat opportunity that extends across the wetland's active floodplain (Johnson et al. 2018). This incorporates floodplain topography, water surface elevation (water depth), water temperatures, and dominate plant communities to highlight salmonid habitat conditions across the active floodplain of restoration and reference sites. See this tableau link for the habitat opportunity assessment of Wallooskee – Youngs Project. This active floodplain mapping approach could also be used as a tool to evaluate the impacts of climate change and shifting river discharge on wetland habitat conditions throughout the Columbia Estuary.

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Appendix

Appendix A: Site Sampling Reports

The summaries are presented in order starting from the mouth of the estuary to up-river. Additional background information about the sites sampled in the AEMR Program is often available in restoration project planning documents and reports, or in previous monitoring reports. To the extent possible, these are cited in the descriptions of each site.

Equipment

Equipment for each of the metrics sampled is outlined below.

- *Vegetation*: 100-m tapes for the baseline and transects, a compass for determining the baseline and transects azimuth, 1-m quadrat, data sheets, and plant books for species identification. GPS to identify location of base stakes and quadrats.
- *Sediment Accretion Rate*: 2 gray 1-inch PVC conduit pipes, at least 1.5m long, construction level, meter stick. GPS to identify location of stakes.
- *Neuston Tows:* To assess the availability of salmon prey at 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). Samples were preserved in 95% ethanol.
- *Photo Points:* camera, stake for including in photo, previous photos at location for reference, GPS to identify location of point.
- *Elevation*: Topcon GPS with real-time kinematic (RTK) correction. Other survey equipment in case GPS equipment is non-functional, including an auto-level, tripod, and stadia rod.

Survey Dates 2020

Wallooskee – July 21 – July 22, 2020
Dagget Point – July 23, 2020
Flights End – August 10, 2020
La Center Wetlands and Reference – August 11 – August 12, 2020
Cunningham Lake – August 21, 2020

Survey Dates 2021

Ilwaco Slough – July 26, 2021
Wallacut Slough –July 27, 2021
Cunningham – August 17, 2021
North Unit Phase 1 – August 18, 2021

Wallooskee-Youngs

2020 Notes

- Wallooskee is owned by Cowlitz Tribe, Access has a locked gate, Site Contact is Rudy Salakory, Habitat Restoration and Conservation Program Manager, rsalakory@cowlitz.org
- Dagget Slough, State of Oregon, no permits needed for access
- Tides follow Astoria NOAA gage
- **KML of all sampling locations**, sed benches, WSE, etc: https://www.dropbox.com/s/4qaj2jpxy6pmfts/WY_Dagget_2020_Monitoring.kmz?dl=0
  - o Some old data logger housings remain on the site but have been retired (no longer have loggers in them), I have only included active logger locations in this KML (2020).
  - o All data points should be re-surveyed with the RTK
  - o As time allows, soil data and vegetation notes should be collected at Sed Bench Locations
  - o As time allows, soil data should be collected at all Veg survey locations
  - o **Wallooskee Maps (PDF)** https://www.dropbox.com/sh/je5bme1fr6t7u9x/AADG388ZdeRvK6FLyJnl3iuXa?dl=0
  - o **Dagget Map (PDF)** https://www.dropbox.com/sh/je5bme1fr6t7u9x/AADG388ZdeRvK6FLyJnl3iuXa?dl=0
- **AEMR Species Lists:** https://www.dropbox.com/s/ap0tp279ank1fnf/WYDagget_SpeciesListandData_2020.xlsx?dl=0
- **Additional Monitoring – Mound Study:** Two sed benches and three veg quadrants have been set up at paired high and low marsh elevations across three locations at the Wallooskee site (total of 6 veg quads and 2 sed benches at each location, split between high and low marsh elevations). Veg data (% cover) is collected at 1m2 quads at the location of the Sed Benches and then 1-meter offset to either side of the Sed Bench locations. The exact sed bench and veg monitoring areas can be found in the KML above. Soil ORP, pH, Con, Sal, and Temp should also be recorded at each mound study veg quad location.

General Site Location
The site is located approximately 6 Km on the Young's River, which empties into Young's Bay, at approximately Columbia River Km 19.

Ecosystem Type
Diked, planned restoration site

Dates of Sampling in 2020
July 21 – July 22, 2020

Types of Sampling in 2020

• Vegetation: Herbaceous cover (2 sample areas of 36 quadrats each, 72 quadrats total)
• Elevation: collected elevation at all vegetation quadrats

Vegetation Sampling Design
2 sampling areas were set up. New vegetation sample areas were established to capture the current condition and potential change that would occur as follows:

*North Veg Sample area (*Figure 27*)*
• Located in area near channel and tide gate removal on Young's River
• 60 m x 80 m, with 36 quadrat locations
• Baseline azimuth: 188° magnetic
• Transect azimuth: 278° magnetic
• Transect spacing: 10 m, random start: 3
• Quadrat spacing: 13 m, random starts: 7, 3, 4, 5, 6, 0

*South Veg Sample area (*Figure 27*)*
• Located in area between the culvert removal and dike breach
• 60 m x 60 m, with 36 quadrat locations
• Baseline azimuth: 29° magnetic
• Transect azimuth: 119° magnetic
• Transect spacing: 10 m, random start: 1
• Quadrat spacing: 10 m, random starts: 8, 6, 1, 3, 9, 6

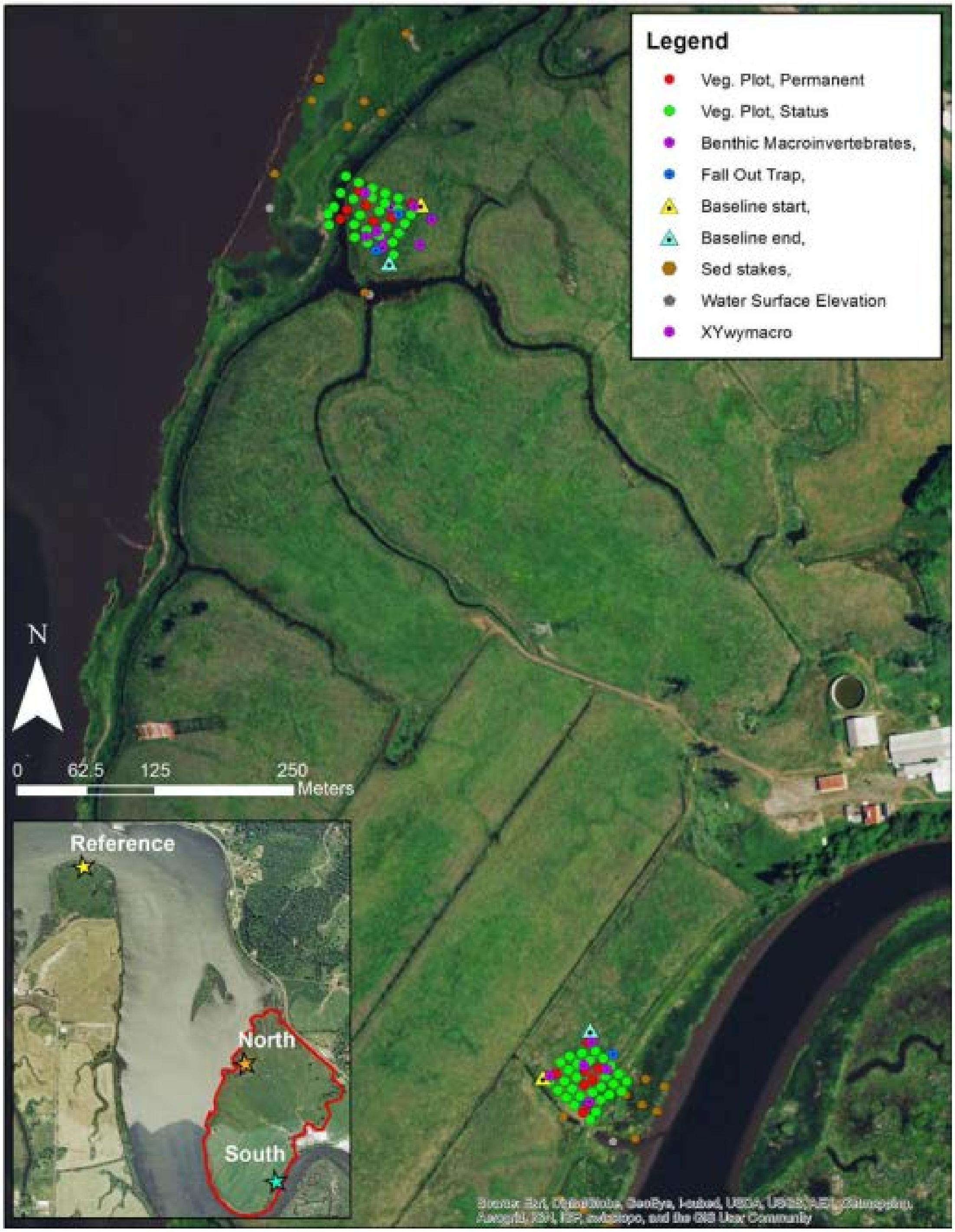

Figure 27: Vegetation and macroinvertebrate sampling locations at the Wallooskee-Youngs Restoration site (Fallout traps from 2015 – 2018, Neuston Tows in 2020).

Markers Left on Site

All marking stakes are white ¾ inch PVC. We marked the following locations:

• Start and End stakes of the baseline for the vegetation sample areas.

Macroinvertebrate Sampling
To assess the availability of salmon prey at 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). Samples were preserved in 95% ethanol.

Wallooskee-Youngs Reference (Dagget Point)
General Site Location
The site is located approximately 1.5 km up the Young's River, which empties into Young's Bay at Columbia River km 19.

Dates of Sampling in 2020
23 July 2020

Types of Sampling in 2020
• Vegetation: Herbaceous cover (1 sample areas, 36 quadrats total). Drone and Veg monitoring by LCEP
• Sediment Accretion Rate: measured one previously installed pair of stakes
• Elevation: collected elevation at all vegetation quadrats

Vegetation Sampling Design
1 sampling area was set up. New vegetation sample areas were established to capture the current condition and potential change that would occur as follows:

*Veg Sample area (*Figure 28*)*
• 60 m x 70 m, with 36 quadrat locations
• Baseline azimuth: 81° magnetic
• Transect azimuth: 351° magnetic
• Transect spacing: 10m, random start: 4
• Quadrat spacing: 10 m, random starts: 2, 2, 4, 6, 7, 1

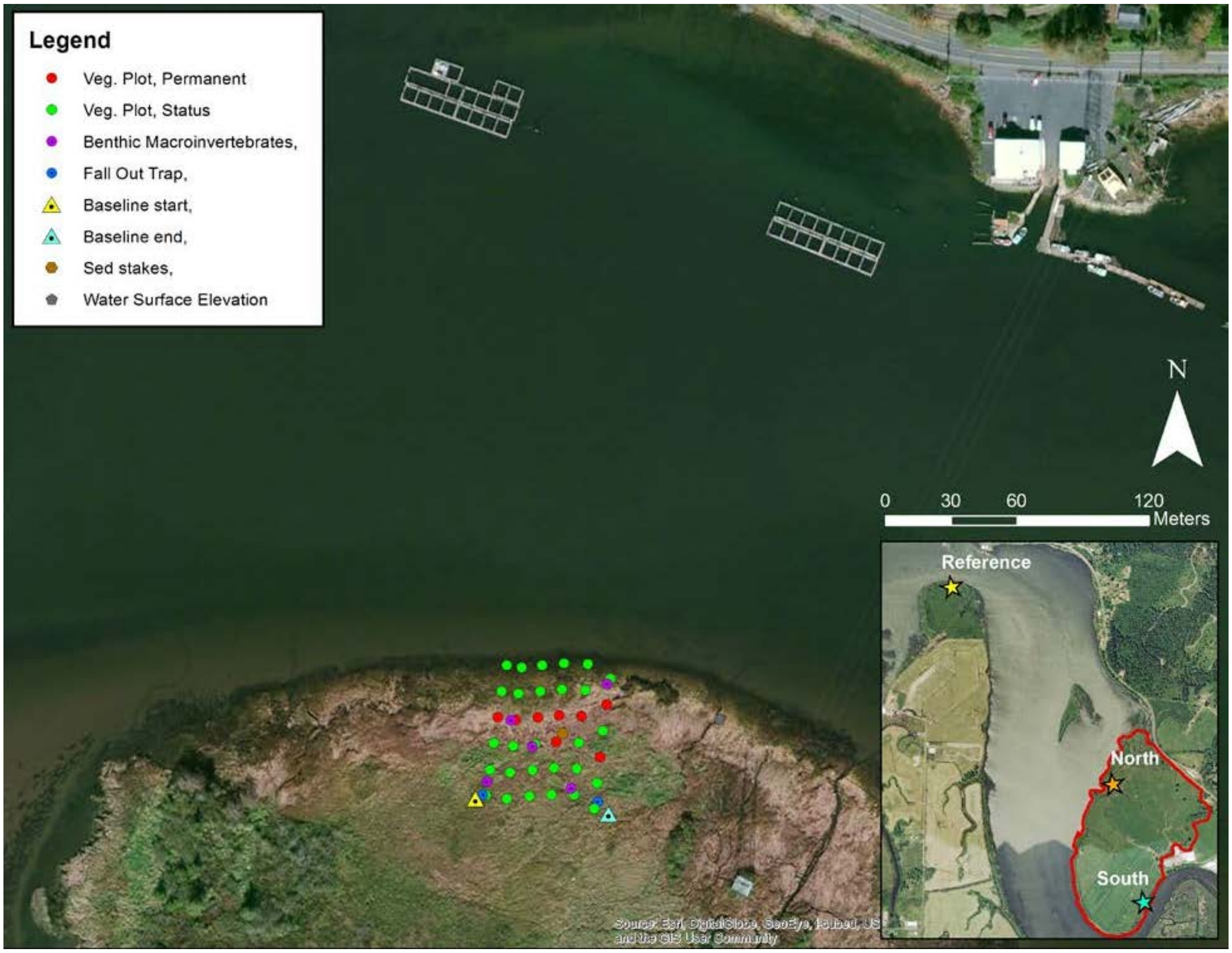

Figure 28: Vegetation and macroinvertebrate sampling locations at the Wallooskee-Youngs reference site

Markers Left on Site

All marking stakes are white ¾ inch PVC. We marked the following locations:

- Start and End stakes of the baseline for the vegetation sample areas.
- Permanent quadrat stakes; 2 stakes per location in the diagonal corners.

Macroinvertebrate Sampling

To assess the availability of salmon prey at 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). Samples were preserved in 95% ethanol.

Flights End

Monitoring Data 2020

- Water levels follow St. Helens gage
- Species Lists: https://www.dropbox.com/s/wogp88mx86k5hi6/FlightsEnd_SpeciesListandData_2018.xlsx?dl=0
- Maps: https://www.dropbox.com/s/bjwwbfjjcow0c42/FlightsEnd_MapAll.pdf?dl=0
- KML: https://www.dropbox.com/s/y9fumpikwgxj3et/Flights_Veg_Tran2018.kmz?dl=0
- Permits: Permissions provided through CREST (project manager)
- Reference Site – Cunnignham Lake
- Drone and Veg Monitoring by LCEP
- SED/WSE/Temp - CREST

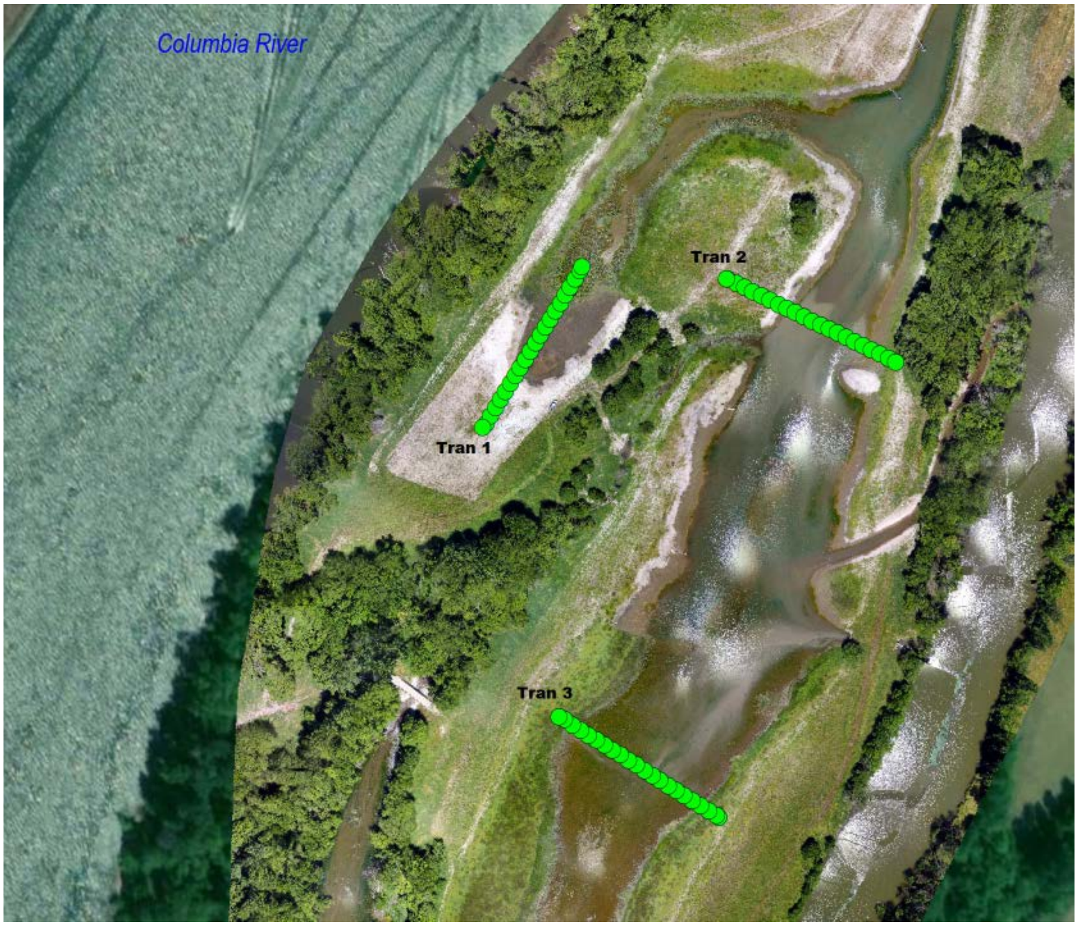

Figure 29: Vegetation sampling locations at the Flights End restoration site

General Site Locations
North End of Sauvie Island on the Oregon side of the river at rkm 143

Ecosystem Type
Post-restoration, emergent tidal wetland

Types of Sampling in 2020

- *Vegetation*: Herbaceous cover (3 sample transects of 20 quadrats, 60 quadrats total)
- *Elevation*: collected elevation at all vegetation quadrats
- *Sed Benches*: One pair of sed stakes (Flights_End_SED_1) was measured. SED_2 was not found in 2018. A third set was installed for 5-year post. Usually surveyed by CREST.

Vegetation Sampling Design

North Veg Sample Transect

- Veg sample area spanned elevation gradient which contained reed canarygrass to bare ground.
- 100 m transect, with 50 quadrat locations
- Transect azimuth: 278° magnetic
- Quadrat spacing: 5 m, random start: 4

South Veg Sample Transect

- Veg sample area spanned elevation gradient which contained reed canarygrass to bare ground.
- 100 m transect, with 50 quadrat locations
- Transect azimuth: 282° magnetic
- Quadrat spacing: 5 m, random start: 1

West Veg Sample Transect

- Veg sample area spanned elevation gradient which contained was dominated with reed canarygrass and would be scraped down to an elevation to promote wet prairie grass and prevent recolonization of reed canarygrass.
- 100 m transect, with 50 quadrat locations
- Transect azimuth: 31° magnetic
- Quadrat spacing: 5 m, random start: 2

Macroinvertebrate Sampling
Two macroinvertebrate neuston tows were collected in the Flights End vegetation sampling areas.

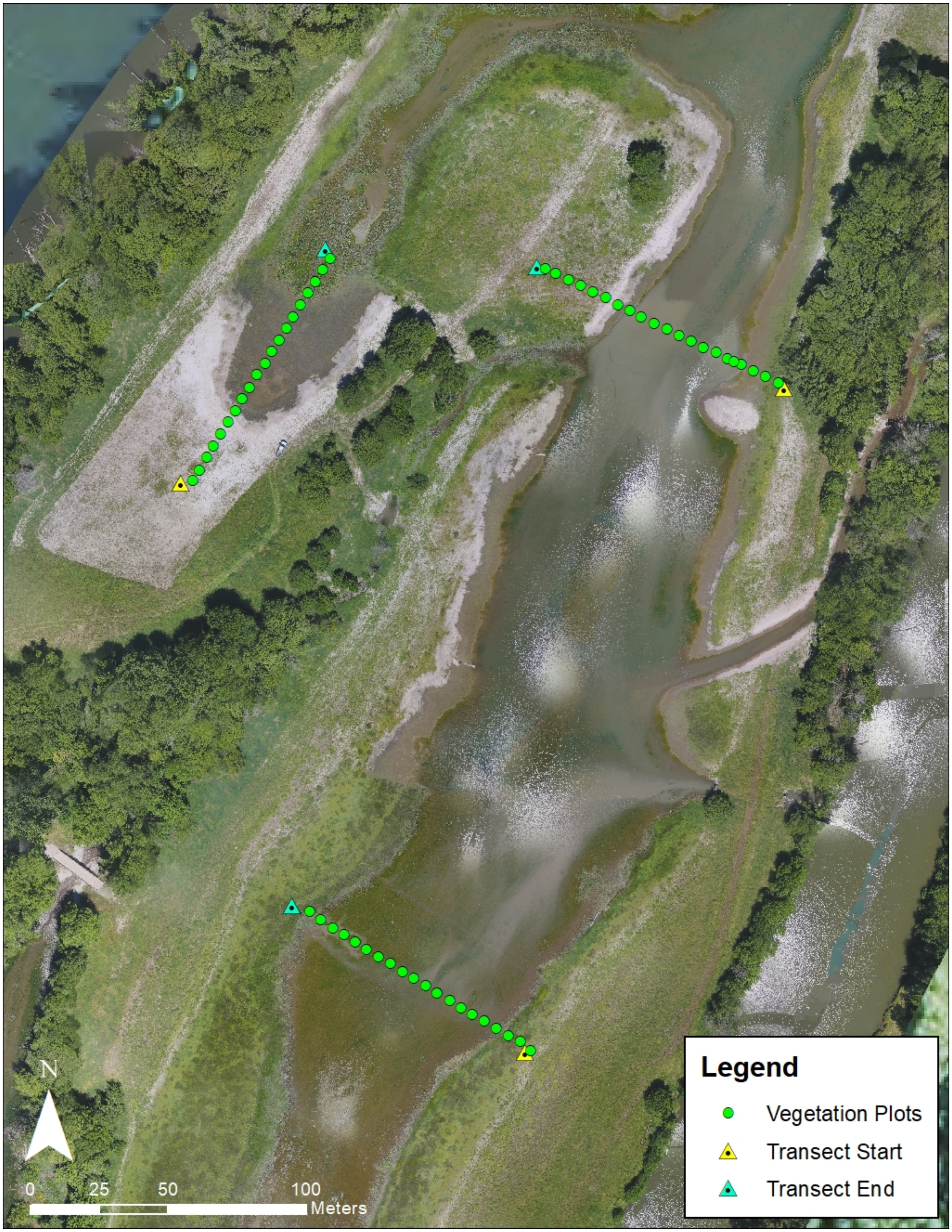

Figure 30. Sauvie Island Flights End vegetation sampling locations

La Center Wetlands Phase 1 and Phase 2 control

Monitoring Data 2020

- Parking
  - La Center 1- North-West: park at the Water Treatment Plant and walk down a trail across Breezy Creek. Here's a pin of the parking: https://goo.gl/maps/3vwiwCypRBps3oyGA
  - La Center 1- South-East: he entrance drive to this area is here: https://goo.gl/maps/j8jDPeP5o5ff9XsRA
  - La Center 2 – Control: https://goo.gl/maps/8GrkqX8wrx3ytvuM6
- Water levels (not tidal) follow East Fork Lewis River
- Species Lists: https://www.dropbox.com/s/udor00zdoa1ndos/LaCenterSpeciesListandData_2018.xlsx?dl=0
- Maps: https://www.dropbox.com/s/tmzrgcvf5f5tpdi/AllLaCenterMaps.pdf?dl=0
- KML: https://www.dropbox.com/s/y7mif2kowytalq4/LaCenterPhase1and2.kmz?dl=0
- Permits: Landowners need to be contacted prior to site access.
- La Center Phase 1 restored in 2015 will be used as a control site for restoration work done on the La Center Phase 2 (pending restoration action in 2021)

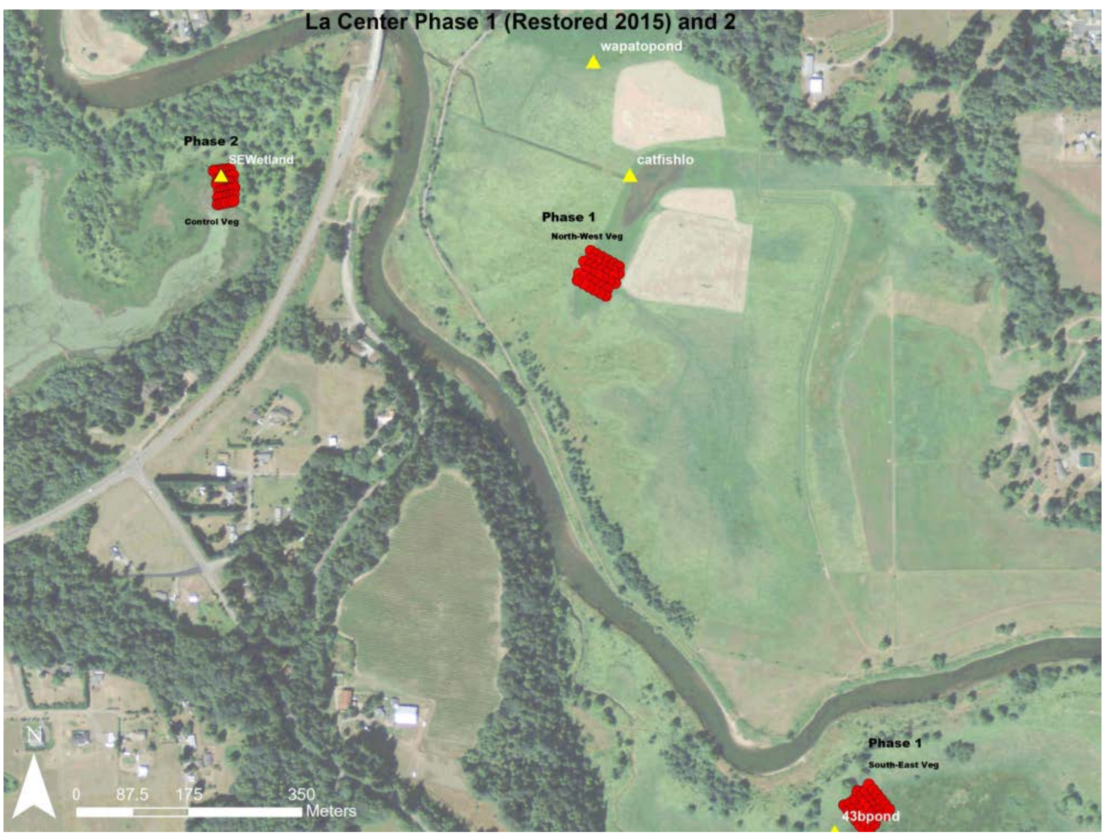

Figure 31: Layout of sampling locations at La center

General Site Location
The site is located approximately 7.5 Km on the East Fork Lewis River, which empties into the Lewis River rkm 8.5. The Lewis River enters the Columbia at rkm 140.

Ecosystem Type
Diked, planned restoration site

Dates of Sampling in 2020
August 11-12

Types of Sampling in 2020
- *Vegetation*: Herbaceous cover (2 sample areas of 36 quadrats each, 72 quadrats total)
- *Elevation*: collected elevation at all vegetation quadrats

Vegetation Sampling Design
*West Vegetation Sample Area (*Figure 32*)*
- Located on the north side of the East Fork Lewis River.
- 60m x 60m, with 36 quadrat location
- Baseline azimuth: 190° magnetic
- Transect azimuth: 100° magnetic
- Transect spacing: 10 m, random start: 4
- Quadrat spacing: 10m, random starts: 3, 8, 1, 9, 2, 5

*East Vegetation Sample Area (*Figure 32*)*
- Located on the south side of the East Fork Lewis River.
- 60m x 60m, with 36 quadrat location
- Baseline azimuth: 39° magnetic
- Transect azimuth: 129° magnetic
- Transect spacing: 10 m, random start: 7
- Quadrat spacing: 10m, random starts: 5, 8, 7, 0, 6, 2

Figure 32: Vegetation and macroinvertebrate sampling locations at the La Center Wetlands restoration site. (Macroinvertebrate sampling locations for 2015, 2016, 2018. Neuston tows collected in 2021)

Markers Left on Site

All marking stakes are white ¾ inch PVC. Marks left:

- Start and End stakes at each of the transects in the vegetation sample area.

Macroinvertebrate Sampling
Two macroinvertebrate neuston tows were collected in the La Center West vegetation sampling area.

La Center Reference (Phase 2 Control)

General Site Location
The site is located approximately 7.5 Km on the East Fork Lewis River, which empties into the Lewis River rkm 8.5. The Lewis River enters the Columbia at rkm 140.

Ecosystem Type
Emergent Wetland

Dates of Sampling in 2020
11 August

Types of Sampling in 2020
- *Vegetation*: Herbaceous cover (1 sample area, 36 quadrats total)
- *Elevation*: collected elevation at all vegetation quadrats

Vegetation Sampling Design
Veg Sample area (Figure 33)
- Located on the west side of East Fork Lewis
- 60 m x 30 m, with 36 quadrat locations
- Baseline azimuth: 334° magnetic
- Transect azimuth: 244° magnetic
- Transect spacing: 10 m, random start: 4
- Quadrat spacing: 5 m, random starts: 4, 3, 0, 2, 0, 4

Figure 33. 2016 vegetation and macroinvertebrate sampling locations at La Center Control.

Markers Left on Site
All marking stakes are white ¾ inch PVC. Marks left:

- Start and End stakes of the baseline for the vegetation sample areas.

Macroinvertebrate Sampling
Two macroinvertebrate neuston tows were collected in the vegetation sampling area.

Wallacut Restoration

General Site Location
The site is located near the mouth of the Wallacut River, which empties into Baker Bay, at approximately rkm 7.

Ecosystem Type
Diked, planned restoration site

Current Role of Site in the CEERP
The Wallacut site is owned by the Columbia Land Trust. The site is slated for hydrologic

reconnection through the removal of three culverts, removal of a low levee, ditch filling, and tidal channel creation. In addition, invasive species removal of gorse (*Ulex europaeus* L.) has been implemented to increase native species colonization.

Dates of Sampling in 2021
27 July

Types of Sampling in 2019

- Vegetation: Herbaceous cover (2 sample areas of 36 quadrats each, 72 quadrats total)
- Insect Neuston Tows
- Photo Points: 2
    - Top of dike near the location of the lower vegetation monitoring plot
- Elevation: collected elevation at all vegetation quadrats

Vegetation Sampling Design (Figure 34)
2 sampling areas were set up. New vegetation sample areas were established to capture the current condition and potential change that would occur as follows:

Mouth Veg Sample area (Wallacut North)

- Located in area near the mouth of the channel
- 60 m x 30 m, with 36 quadrat locations
- Baseline azimuth: 60° magnetic
- Transect azimuth: 105° magnetic
- Transect spacing: 10 m, random start: 5
- Quadrat spacing: 5 m, random starts: 2, 1, 2, 2, 3, 2
- 8 permanent quadrats, randomly selected, systematically to ensure coverage on all transects

Upper Veg Sample area (Wallacut South)

- Located in area that will be affected by the dike removal, but away from the channel excavation.
- 60 m x 30 m, with 36 quadrat locations
- Baseline azimuth: 185° magnetic
- Transect azimuth: 95° magnetic
- Transect spacing: 10 m, random start: 9
- Quadrat spacing: 10 m, random starts: 2, 2, 4, 2, 3, 2
- 8 permanent quadrats, randomly selected, systematically to ensure coverage on all transects

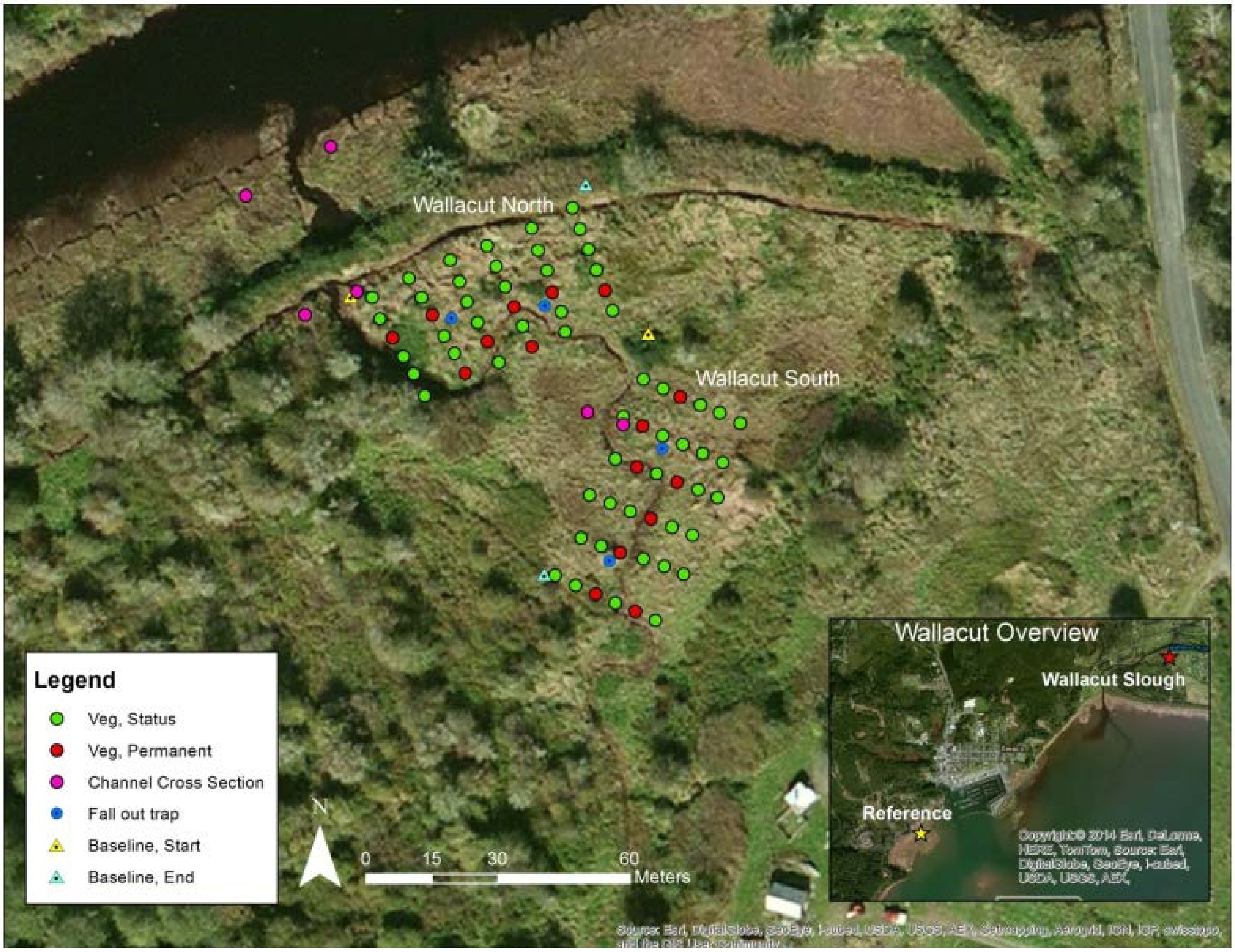

Figure 34. 2021 vegetation and macroinvertebrate sampling locations at Wallacut restoration site.

Markers Left on Site
All marking stakes are white ¾ inch PVC. We marked the following locations:

- End stakes of the baseline for the vegetation sample areas.
- Permanent quadrat stakes; 2 stakes per location in the diagonal corners (SW and NE).

Macroinvertebrate Sampling
Two macroinvertebrate neuston tows were collected in the Wallacut Slough vegetation sampling areas.

Ilwaco Reference

General Site Location

Northwest side of Baker Bay west of Ilwaco marina.

Ecosystem Type

Tidal brackish emergent wetland

Sampling History in CEERP

This longterm monitoring site has been surveyed annually since 2011 site as part of LCEP's Ecosystem Monitoring Program.

Current Role of Site in the CEERP

Ilwaco is being sampled as a reference site for baseline monitoring for the restoration actions being conducted in 2019 at Wallacut Restoration site.

Dates of Sampling in 2021

26 July

Types of Sampling in 2021

See map below for sampling locations (Figure 69).

- Vegetation: Herbaceous cover (1 sample area of 40 quadrats)
- Insect Neuston Tows
- Photo Points:
    - 360° from 2 m east of the 0 m baseline stake
- Sediment Accretion Rate: measured one previously installed pair of stakes
- Elevation: collected elevation at all vegetation quadrats

Vegetation Sampling Design

Status Sampling. The sampling design implemented for the EMP was used for monitoring. This sampling design is similar to that used for the AEMR sampling except that the same quadrats are
sampled from year to year to evaluate trends.

Vegetation Sample Area

- Veg sample area covered the mid-marsh elevation gradient which contained primarily
- *Agrostis stolinifera* and *Carex lyngbyei*.
- 200 m x 100 m, with 40 quadrat locations
- Baseline azimuth: 240° magnetic
- Transect azimuth: 330° magnetic
- Transect spacing: 50m, random start: 16

- Quadrat spacing: 10 m, random starts: 4, 7, 2, 6
- Trends Sampling. No permanent plots were placed at this site. Future trends monitoring will
  be conducted according to the EMP sample design.

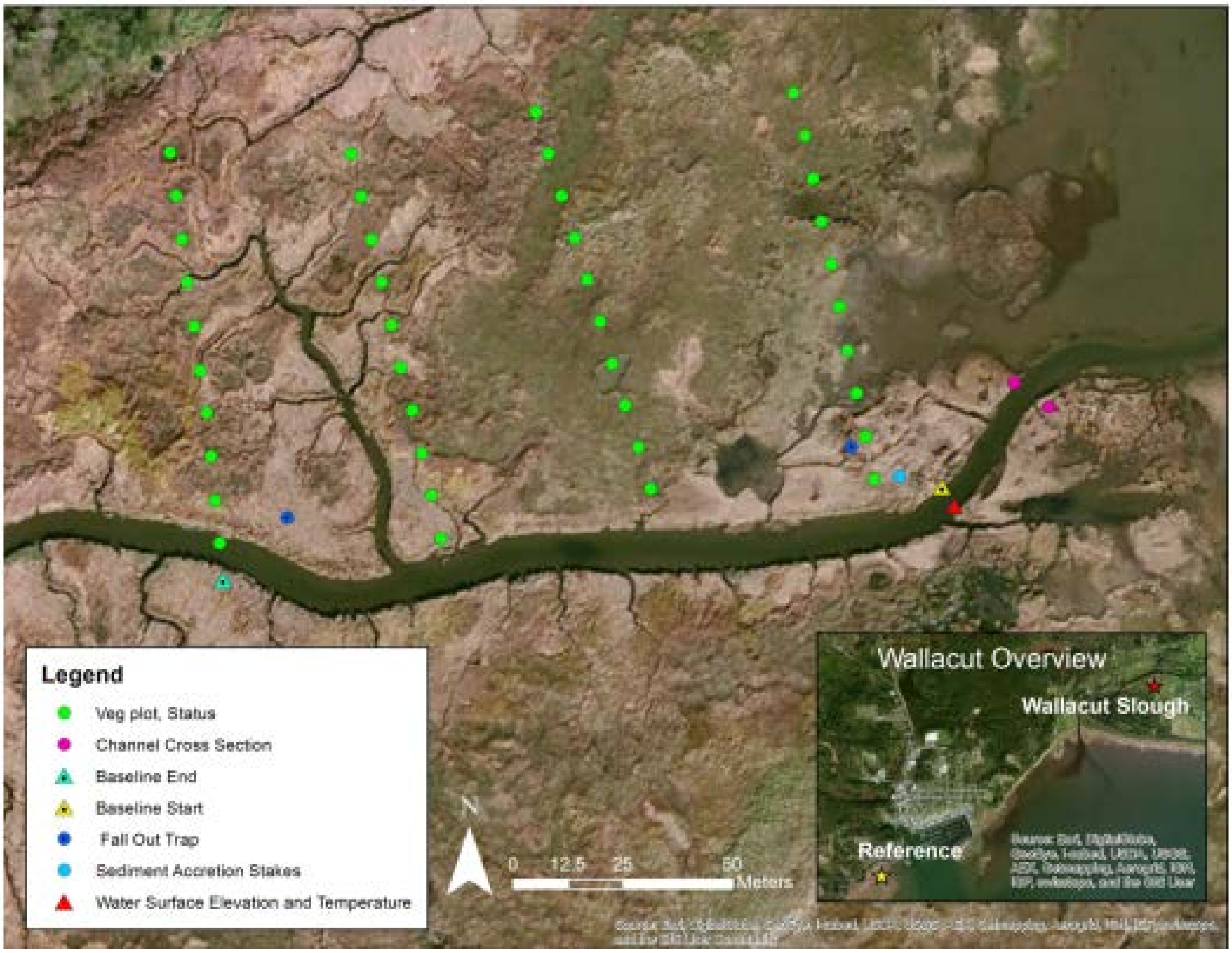

Figure 35. 2021 vegetation and macroinvertebrate sampling locations at Ilwaco marsh. (Fall out traps collected in 2014, neuston tows collected in 2021)

Markers Left on Site
All marking stakes are white ¾ inch PVC. Marks left:

- End stakes at each of the transects in the vegetation sample area.
- In addition, 2 1" gray pvc sediment accretion stakes are located on the site and a depth sensor is located inside 1 ½" PVC on a t-post in the channel.

Macroinvertebrate Sampling
Two macroinvertebrate neuston tows were collected in the vegetation sampling area.

Sauvie Island North Unit Phase 1

General Site Location
North End of Sauvie Island on the Oregon Side of the River at rkm 144.

Ecosystem Type
Post-restoration, emergent tidal wetland

Dates of Sampling in 2021
18 August

Types of Sampling in 2021
- *Vegetation*: Herbaceous cover (2 sample areas of 36 quadrats, 72 quadrats total)
- *Insect Neuston Tows*
- *Photo Points:*
    - 1 photo point at the North Veg Sample area - 360° from 2 m north of the 0m baseline stake
    - 2 photo points at the South Veg Sample area
        - 180° from permanent plot 47-59, looking south
        - 360° from 2 m northwest of the 0m baseline stake
- *Elevation*: collected elevation at all vegetation quadrats

Vegetation Sampling Design
*North Veg Sample area (*Figure 36*)*
- Located at north end of the southern part of the site. Veg sample area spanned elevation gradient which contained only reed canarygrass and would be scraped down to an elevation to prevent recolonization of reed canarygrass.
- 70 m x 60 m, with 36 quadrat locations
- Baseline azimuth: 180° magnetic Transect azimuth: 270° magnetic
- Transect spacing: 11m, random start: 2
- Quadrat spacing: 10 m, random starts: 9, 1, 5, 2, 3, 5

*South Veg Sample area (*Figure 36*)*
- Located at the southern end of the southern part of the site. Veg sample area spanned elevation gradient from lowest elevation SAV and bare mud through low marsh up to an elevation dominated by reed canarygrass.
- 70 m x 80 m, with 36 quadrat locations
- Baseline azimuth: 191° magnetic
- Transect azimuth: 281° magnetic
- Transect spacing: 11m, random start: 3
- Quadrat spacing: 13 m, random starts: 0, 10, 1, 2, 7, 8

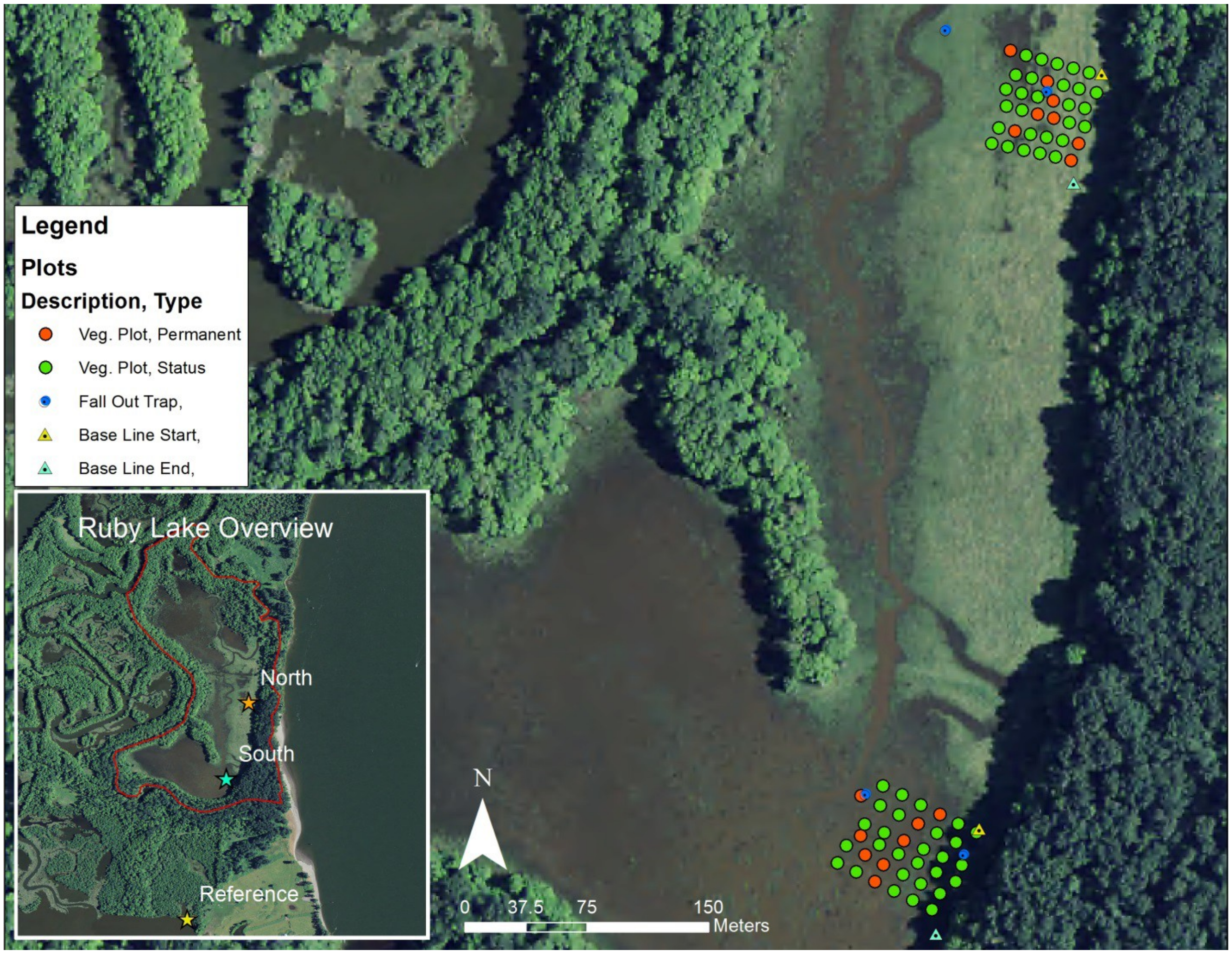

Figure 36. 2021 vegetation sampling locations at the North Unit Phase 1 (Ruby Lake) restoration site.

Markers Left on Site

All marking stakes are white ¾ inch PVC with orange duct tape or flagging at the top were left on site from previous year's marking. Marks left:

- End stakes of the baseline for the vegetation sample areas.
- Permanent quadrat stakes; 2 stakes per location in the diagonal corners (SW and NE).

Macroinvertebrate Sampling

Two macroinvertebrate neuston tows were collected in the vegetation sampling area.

Sauvie Island North Unit Reference (Cunningham Lake)

General Site Location

Cunningham Lake is a floodplain lake located at rkm 145 on Sauvie Island in the Oregon DFW Wildlife Area. The mouth of the Slough is located between rkm 142 and 143 close to where Multnomah Channel meets the Columbia River. The end of Cunningham Slough is approximately 8.7 km from Multnomah Channel.

Ecosystem Type

Reference Site, Fringing Emergent Marsh at the upper extent of the extremely shallow "lake"

Dates of Sampling in 2021

17 August

Types of Sampling in 2021

See map below for sampling locations

- *Vegetation*: Herbaceous cover (70 quadrats total)
- *Insect Neuston Tows*
- *Photo Points:* 1 photo point
    - 360° panorama taken at location near south end of vegetation sample area.
- *Elevation*: collected elevation at all vegetation quadrats

Vegetation Sampling Design

Veg Sample area (Figure 37)

- Located along the fringe of the very shallow Cunningham Lake. Vegetation sample area spanned elevation gradient from unvegetated flats to the shrub/tree zone.
- 70 m x 25 m, with 36 quadrat locations
- Transect spacing: 2m, random start: 0
- Quadrat spacing: 2 m
- 8 permanent quadrats established for AEMR were monitored

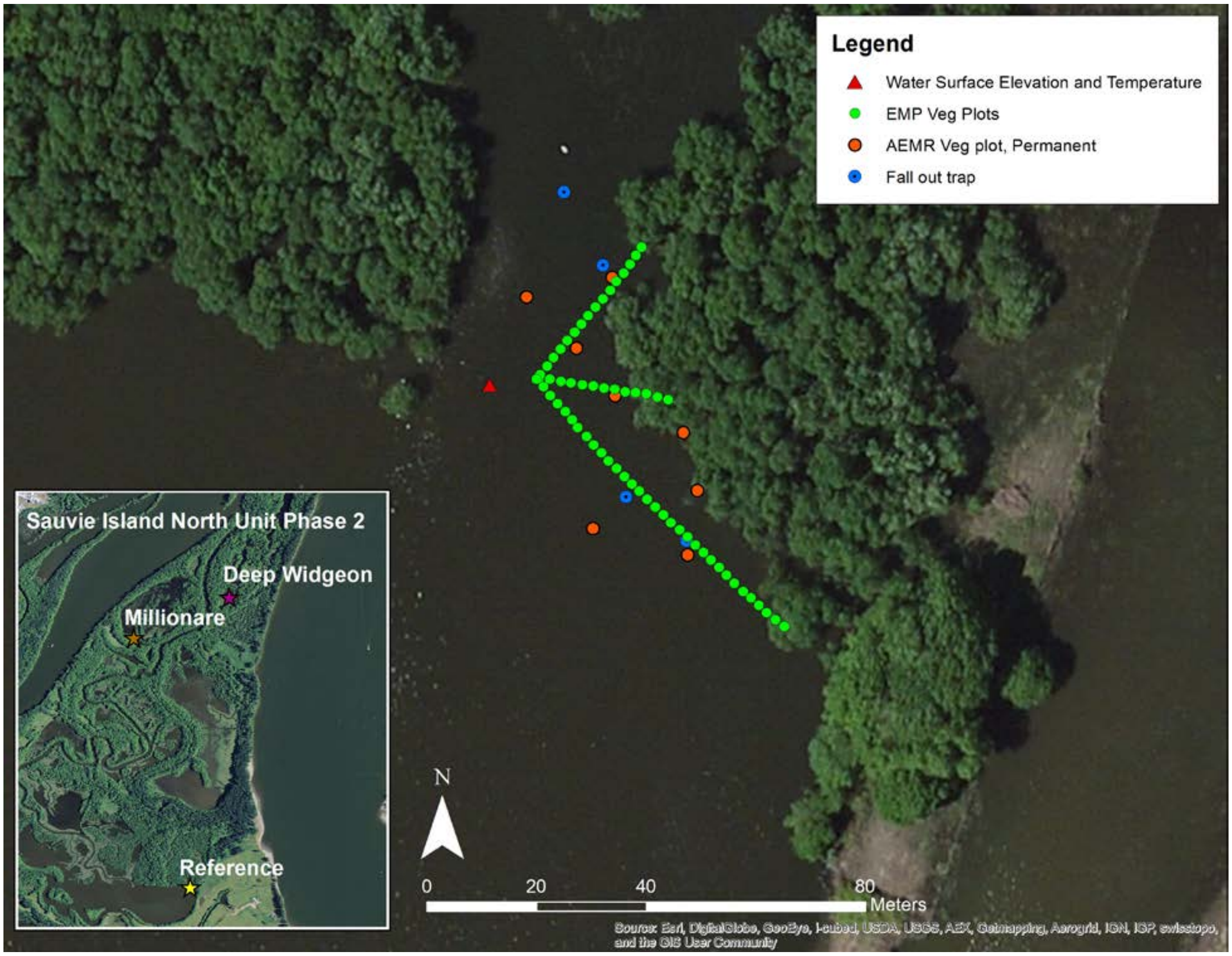

Figure 37. Vegetation and macroinvertebrate sampling locations at the Cunningham Lake reference site. (Fall out traps collected in 2015, neuston tows collected in 2019).

Markers Left on Site

All marking stakes are white ¾ inch PVC with orange duct tape or flagging at the top. We marked the following locations:

- End stakes of the baseline for the vegetation sample areas.
- Permanent quadrat stakes; 2 stakes per location in the diagonal corners (SW and NE).

In addition, 2 1” gray pvc sediment accretion stakes are located on the site and a depth sensor is located inside 1 ½” PVC on a t-post in the channel.

Macroinvertebrate Sampling

Two macroinvertebrate neuston tows were collected in the Cunningham Lake vegetation sampling areas.