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 for Year 12 (October 2015 to September 2016)

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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
PIT	passive integrated transponder
RPA	Reasonable and prudent alternative
USACE	U.S. Army Corps of Engineers

Summary

The goals of the Lower Columbia Estuary Partnership's Action Effectiveness Monitoring (AEM) program are to determine the impact of habitat restoration actions on salmon recovery at the site and landscape scale, identify how restoration techniques address limiting factors for juvenile salmonids, and improve restoration techniques to maximize the effect of restoration actions. To accomplish AEM program goals, the Estuary Partnership 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. In 2017 the objectives of the AEM program were to synthesize action effectiveness monitoring data collected from 2012 to 2016 and quantify ecological changes related to these restoration efforts. Additionally, annual monitoring objectives were to quantify changes in vegetation related to the lowering of marsh elevation, determine restoration impacts to existing wetlands within restoration sites, and determine post-restoration fish use at selected sites.

Action effectiveness monitoring (AEM) was conducted at twenty-one restoration sites in 2017. All monitoring was conducted following standardized protocols outlined in Roegner et al. (2009). Six restoration sites were selected for Level 2 monitoring and 15 restoration sites were scheduled for Level 3 monitoring. We also operated a PIT tag array at Horsetail Creek to determine type and residency time of salmonids at the site and address uncertainties related to fish passage through long culverts.
For the restoration site synthesis, data from 22 restoration sites were available and suitable for analysis.

Across all restoration sites monitored in 2017, we evaluated emergent wetland vegetation at the site scale and at a landscape scale using previously defined emergent wetland vegetation zones (1-5 following the estuarine tidal freshwater gradient; 1 being located closest to the river mouth and 5 being closest to Bonneville Dam). The presence of distinct emergent marsh vegetation zones provides a method to examine how restoration sites and reference sites at a larger ecosystem scale compare given inherent inter-annual variability.

In 2017 distinct vegetation zones were evident based on the collected vegetation data. Across the restoration sites, total vegetation cover was found to be negatively correlated with average marsh elevation, species richness, species diversity, and bare ground. Across restoration sites, higher marsh elevations had less bare ground than lower marsh elevations which is likely a result of the elevation lowering restoration actions. Vegetation species richness was lowest at pre-restoration sites and highest at the year three post-restoration sites.

AEM data from 2012 to 2016 shows the rate at which physical processes and habitats recover after restoration activities varies. For example, physical processes like water surface elevation, water temperature, and habitat opportunity change immediately after the wetland is reconnected and have shown a positive trend when compared to pre-restoration or reference conditions over a short period of time. Pairing post-restoration WSE data with main stem data as a reference, show all sites achieving a similar hydrology to their reference. Post-restoration water temperatures were also found to be similar to their reference and the main stem main stem Columbia River temperatures. Pairing WSE and water temperature together creates a meaningful a measure of salmonid habitat opportunity, habitat opportunity being defined by both suitable temperatures and water levels for salmonids. In all instances restoration sites showed increases in habitat opportunity during periods of time when upstream out migrating juvenile salmonids could be potentially be at restoration sites. Although physical processes change quickly, other aspects of the wetland recover more slowly. We found post-restoration changes in sediment accretion and channel variable in the short-term, however these geomorphic characteristics

are known to be dynamic and develop trends over a longer time scale. Plant communities showed clear trends towards native relative cover reference conditions at Dibblee Slough, North Unit Ruby Lake, Steamboat Slough, and Sandy River Dam, while trends towards reference conditions were not observed at Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire. Reed canarygrass levels, however, showed trends of increasing over the one to three-year post-restoration monitoring period for all sites except Dibblee Slough and Steamboat Slough, which showed trends of decreasing RCG cover.

In 2017, the PIT array at Horsetail Creek continued to detect upstream salmonid species. Hatchery Spring, Fall, and Summer Chinook visited the site between April and June. Hatchery Coho, steelhead, summer sockeye were also detected at the site. All detections at the site showed the fish occupied the area for less than one day.

AEM findings show restoration sites are achieving increases in connectivity and salmonid opportunity, however plant community recovery is more variable across sites. These findings indicate that re-establishment of natural physical processes to sites can be accomplished in a relative short period of time, but to understand how the site will respond ecologically will need take place over a longer period. Ultimately, continued monitoring will elucidate and improve our understanding of the connections between physical processes, habitat responses, and the resulting benefits to juvenile salmon.

Introduction

The goals of the Lower Columbia Estuary Partnership's Action Effectiveness Monitoring (AEM) program are to determine the impact of habitat restoration actions. The AEM Program, part of the Columbia Estuary Ecosystem Restoration Program (CEERP), provides the Bonneville Power Administration (BPA), the Lower Columbia Estuary Partnership (Estuary Partnership), restoration partners (e.g., USACE and CREST), the Environmental Protection Agency, and others with information useful for evaluating the success of restoration projects. On-the-ground AEM efforts collect the data needed to assess the performance and functional benefits of restoration actions in the lower Columbia River and estuary and addresses RPA 60 of the 2008 Draft Biological Opinion (NMFS 2008).

The goals of the AEM Program are to:

- Determine the impact of restoration actions on salmon recovery at the site, landscape, and ecosystem scale
- Improve restoration techniques to maximize benefits of habitat restoration actions and better track long term project success
- Use the results of intensive AEM to focus extensive AEM efforts to link fish presence through a lines of evidence approach

In 2008, during the pilot phase of the program, 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:

Level 3 – includes “standard” monitoring metrics: water surface elevation, water temperature, sediment accretion, and photo points that are considered essential for evaluating effectiveness of hydrologic reconnection restoration. This monitoring is done at all restoration sites within the CEERP.

Level 2 – includes the Level 3 metrics and metrics that can be used to evaluate the capacity of the site 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 and is intended to provide a means of monitoring an “extensive” area.

Level 1 – includes Level 2 and 3 metrics and more “intensive” monitoring of realized function at restoration sites, such as fish use, genetics, and diet. Since this monitoring is more expensive, it is conducted at fewer sites with the goal of relating the Level 1 results to the findings of the Level 2 and Level 3 monitoring.

To meet AEM program goals, the Estuary Partnership is engaged in the following tasks:

- 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
- Developing long-term datasets for restoration projects and associated reference sites
- Coordinating between stakeholders to improve AEM data collection efficiency
- Supporting a regional cooperative effort by all agencies and organizations participating in restoration monitoring activities to create a central database to house monitoring data
- Capturing and disseminating data and results to facilitate improvements in regional restoration strategies

In 2017 the objectives of the AEM program were to synthesize action effectiveness monitoring data collected from 2012 to 2016 to quantify ecological changes related to restoration efforts. Additionally, annual monitoring objectives were to quantify changes to vegetation related to the lowering of marsh elevation, determine impacts to existing wetlands within restoration sites, and determine fish use at selected sites. To put ecological changes at restoration sites into context, the Estuary Partnership’s AEM Program incorporated data from the Ecosystem Monitoring Program (EMP). The EMP implements monitoring activities to characterize status and trends of relatively undisturbed emergent wetlands and assess juvenile salmonid usage of those habitats.

Methods

Site Selection 2017

Twenty-one restoration sites received action effectiveness monitoring in 2017 (Table 1 and Table 2). Six restoration sites were selected for Level 2 monitoring (Table 1) using the prioritization criteria outlined in Johnson et al. (2016). Four 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 1). Fifteen restoration sites were scheduled for Level 3 monitoring.

Horsetail Creek was selected for fish monitoring to determine residency time of salmonids in streams in upper reaches of the lower Columbia River and address uncertainty related to fish passage through long culverts. The site was selected for fish monitoring prior to the establishment of AEM prioritization process (Figure 2).

Table 1. Restoration sites and associated reference sites selected for Level 2 monitoring in 2017

Restoration Site	Location	Pre-Restoration Monitoring Date	Post-Restoration Monitoring Date	Reference Site and Monitoring Dates
Wallacut	Rkm 6	23-24 June 2014	2 August 2017	Illwaco 27 June 2014 July 2017
Steamboat Slough	Rkm 56	18-19 July 2013	15-16 June 2015 31 July - 1 August 2017	Welch Island 23 July 2013 31 July 2015
Dibblee Slough	Rkm 103		6-7 August 2013 17-18 July 2015 10 July 2017	Dibblee Reference 8 August 2013 18 June 2015
North Unit Sauvie Phase 2 Deep/Widgeon	Rkm 143	17 July 2014	14-15 July 2017 6 July 2017	Cunningham Lake 18 July 2014 28 July 2015 Campbell Slough 18 July 2014 29 July 2015
North Unit Sauvie Phase 2 Millionaire	Rkm 143	16 July 2014	13-14 July 2015 5 July 2017	
North Unit Flight's End	Rkm 148	14 August 2017		

Table 2. Restoration sites receiving Level 3 monitoring in 2017

Restoration Site	Location	Pre-Restoration Monitoring Year	Post-Restoration Monitoring Year
Wallacut River	RKm 5	2014	2017
Chinook River Estuary	RKm 10	2014	2015, 2016, 2017
Kandoll Farm	Rkm 37	2013	2014, 2015, 2016
Karlson Island	RKm 42	2015	2016, 2017
Steamboat Slough	RKm 56	2015	2017
Elochoman	Rkm 60	2015	2016, 2017
Elochoman Slough	Rkm 60	2016	
Kerry Island	Rkm 72	2015	2016, 2017
Batwater	Rkm 91	2015	2016, 2017
Dibblee	Rkm 92	2012	2013, 2015, 2017
La Center Wetlands	Rkm 140	2015	2016, 2017
Crane-Domeyer	Rkm 142	2016	2017
Flights End	RKm 148	2017	
Willow Bar	Rkm 154	2016	2017
Buckmire Phase 1	Rkm 158	2015	2016, 2017

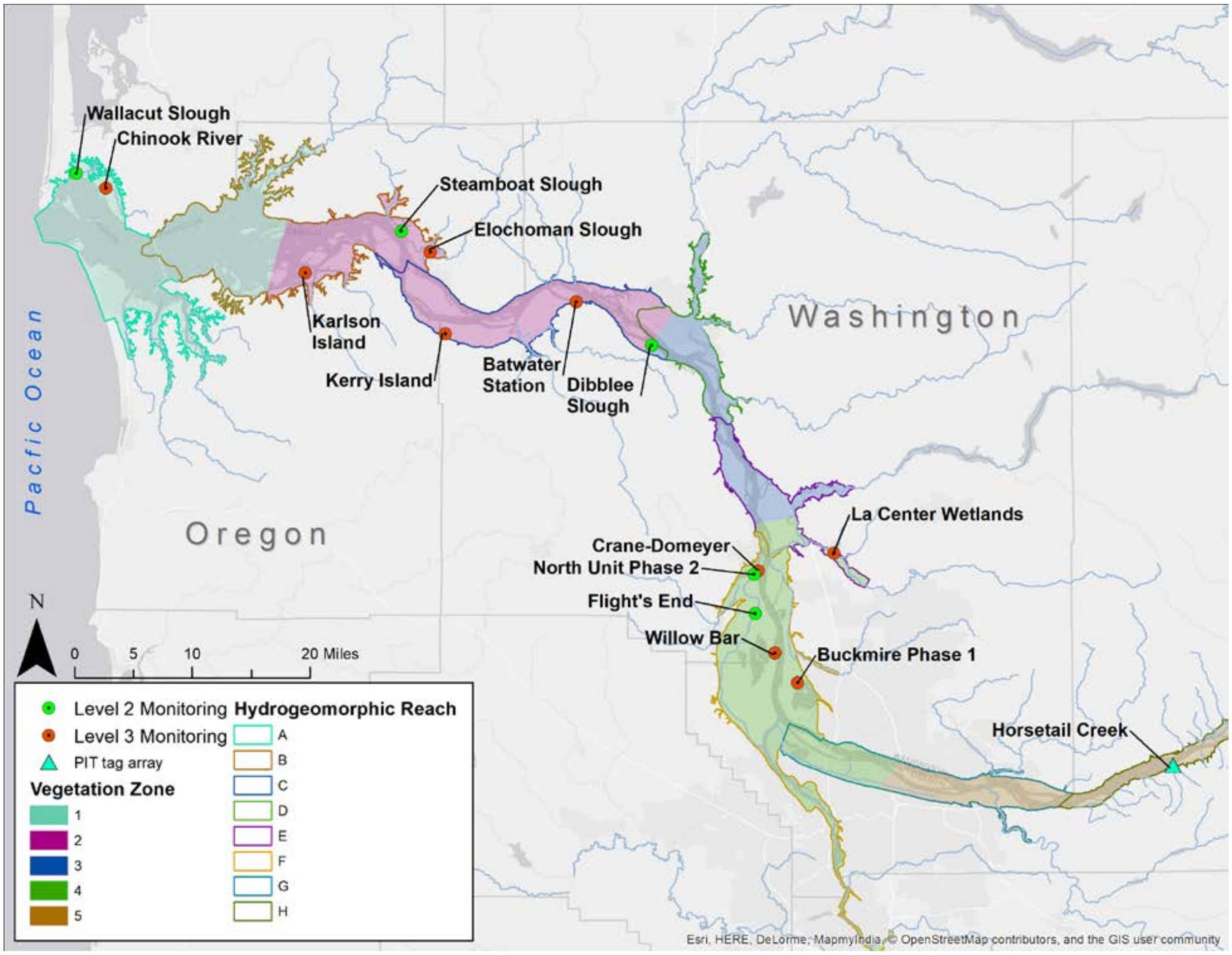


Figure 1. 2017 Level 2 and Level 3 AEM sites

Site Selection AEM Synthesis

From 2004 to 2016, AEM has been conducted at 35 of the 58 restoration projects. AEM included before/after monitoring at 27 of the 35 projects; 10 of the 27 projects included restoration/reference site pairs, and 8 projects had only post-restoration monitoring (Table 3). Site-scale AEM data included eight monitored indicators: WSE, water temperature, sediment accretion, channel cross section, vegetation, macroinvertebrates, fish capture, and fish passive integrated transponder (PIT) detection. Which indicators were monitored at a given project site depended on the restoration project objectives, available AEM resources, and other factors (BPA and Corps 2017a). Various data from 22 of these 35 sites were available and suitable for analysis for SM2 (Table 3). Not all data that have been collected were available for analysis because they are yet to be compiled, quality assured, and transferred to a central data repository. For macroinvertebrate data in particular, samples were collected from 12 sites, but had yet to be processed for 11 of these sites.

Table 3. Action effectiveness monitoring by project[(a)] by year since 2004. Bolded red "X" indicates construction and some monitoring occurred in that year. Bolded red "C" indicates construction but not monitoring occurred in that year. Highlight indicates data available (as of 9/29/17) for the analyses undertaken and reported herein.

`	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Batwater Station									X	X		**X**	X	X
Buckmire Slough											X	**X**	X	
Chinook River Estuary									X	X	**X**	X	X	X
Colewort Creek					X	X	X	X	**X**	X	X	X		
Crane Slough-Domeyer												X	**X**	X
Crims Island	**X**	**X**	X	X	X	X								
Dibblee Point									X	**X**	X	X	X	X
Elochoman Slough Thomas												**X**	X	X
Fee-Simon									X	X	**X**	X		
Fort Clatsop (South Slough)				**C**	X	X	X	X	X					
Fort Columbia								**X**						
Gnat Creek #1									**X**	X	X	X		
Gnat Creek #2										**C**	X	X		
Horsetail Creek										**X**	X	X	X	
JBH Mainland					**X**	**X**	X	X	X					
Kandoll Farm #2										**X**	X		X	
Karlson Island					X					X	**X**	X	X	X
Kerry Island												X	**X**	X
LA (Louisiana) Swamp									X	**X**	X	X		
LaCenter Wetlands										X	X	**X**	X	
Mill Road								**C**	X					
Mirror Lake Phase 1+2					**X**	X	**X**	X	X	X	X	X	X	X
Multnomah Channel Metro											**X**	X	X	
North Unit Ruby								X	X	**X**	X	X		
North Unit Widgeon/Deep/Millionaire										X	**X**	X		
North Unit Three Fingered Jack											X	**X**	X	
Otter Point									**X**	X	X	X		
Sandy River Dam Removal				X	X	X	X	X	X	**X**	X	X		
Steamboat Slough										X	**X**	X	X	X
Thousand Acres											**X**	X	X	
Vera Slough		X	**X**			X								
Wallacut River											X	X	**X**	X
Walluski River North, Elliot #1					**C**							X		X
Westport Slough USFWS #1												X	**X**	X
Willow Bar												X	**X**	X

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). Detailed site sampling reports are in Appendix A.

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 impacted by restoration actions. Two vegetation sampling areas provide an overview of overall site condition pre- and post-restoration. Photo points were established (Method ID: 820) near the vegetation sampling area. Sediment Accretion (Method ID 818) was measured to determine if constructed wetlands are self-sustaining. Water Temperature (Method ID 816) was measured to determine habitat suitability for juvenile salmonids. Water Surface Elevation (Method ID 814) was measured to determine opportunity for juvenile salmonid species to access the site and determine timing and level of wetland inundation.

We collected terrestrial macroinvertebrates to assess the capacity of a restoration site to provide prey resources for juvenile salmonids. Fall out traps were deployed once for a 48-hour period to sample insects that fall into the water from the aerial environment. Terrestrial macroinvertebrates were collected following methods outlined in "Terrestrial Invertebrates Standard Operating Procedures" (USGS and Nisqually Indian Tribe 2012). At Wallacut, Steamboat Slough, Dibblee Slough, and North Unit Sauvie Island Phase 2 Wetland restoration and reference sites terrestrial macroinvertebrates were collected.

Fish Monitoring

A PIT tag detection system was installed at the confluence of Horsetail and Oneonta Creeks to monitor fish passage through a culvert located under the I-84 highway. The system consists of a Biomark FishTRACKER 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 running under the freeway. The system is powered by an 840-watt solar panel array and supported by 24-volt, 800 amp-hour battery bank backup. The unit is connected to a fiber optic wireless modem that allows for daily downloads of tag data and system voltage monitoring updates.

Analysis

Water Temperature

To determine how monthly maximum 7-DMA pre- and post-restoration temperatures compare to outer reference tributary and main stem conditions we calculated the maximum 7-DMA temperature for each site and its reference to determine monthly average. An average of the 7-day average maximum daily water temperatures from the three Columbia main stem data collection stations S4 (Tongue Point, CMOP), S5 (Beaver Army Terminal, CMOP, EP), and S8 (Washougal, EP) were used for comparison. Previous research has shown that main stem temperatures do not vary substantially and using an average of these three stations provides an adequate representation of general main stem conditions for any given time period (Sager et al. 2014). Data quality assurance measures included removing times the data logger was not inundated.

Habitat Opportunity

We adapted a habitat opportunity metric developed by Bottom et al. 2011 to determined how overall salmonid habitat opportunity (days/month) changed pre- and post-restoration for each site. To determine how the restoration site's hydrologic reconnection actions changed the proportion of time (days/month) salmonids have access to the site (>0.5 m water depth) the water elevation required for fish access pre-and post-restoration were determined for each site. Pre-restoration this elevation was determined to be the top of the water control structure/levee which was removed/lowered due to restoration actions and post-restoration the elevation of the channel connection (or new levee elevation) near the point of reconnection (where the water control structure or levee was removed) was used. Using the post-restoration WSE data the number of days the WSE was at or above 0.5 meters in depth at these pre/post site access elevations were calculated. These data were then used to summarize the pre-and post-restoration change in salmonid access to the site. This analysis was conducted on mean daily WSE data and 7-day average maximum daily water temperatures. When the depth of the water was 0.5 meters or greater than the elevation of the water control structure pre-restoration or 0.5 meters or more than the channel elevation post-restoration and the temperature was ≤17.5 C access was considered optimal, when temperature was 17.5-22 C, access was considered marginal. There were no instances of ≥0.5 meters of depth and greater than 22 C in water temperature. When the depth of the water was <0.5 meters then there was no salmonid access.

Sediment Accretion

To estimate sediment accretion rates by year at each site, we used yearly measurements of the distance from the top-of-stake level to the ground surface level collected using a standard protocol (Roegner et al. 2009). (Note, the protocol does not include estimation of sampling error.) We calculated the sediment accretion rate from year to year by subtracting the prior year's distance measurement from the later year's measurement. We averaged these yearly values to estimate sediment accretion rate (cm/yr) for a given site elevation. For sites where practitioners measured land elevation (referenced to the Columbia River datum) at the sediment accretion sampling location, we aggregated the data across restoration sites and plotted land elevation versus sediment accretion rate to determine the relationship between these variables.

Channel Cross-Section

To estimate channel cross-sectional area we applied the methods of Diefenderfer et al. (2008). Changes were calculated by subtracting the prior years' estimates for area, width, and depth from a later years' estimates for the same survey transect. We tabulated cross-sectional areas by transect and sample survey for each site. Graphs of channel cross-sections are also presented.

Vegetation

To assess species richness (number of species) and percent cover for the herbaceous vegetation community at a given restoration site, we categorized plants species by native/non-native and by wetland status. Diefenderfer et al. (2013) provide a list of herbaceous plant species commonly found in the estuary that includes native plant and wetland status attributes. Wetland status is defined by information in the U.S. Department of Agriculture (USDA) plants database at http://plants.usda.gov/wetinfo.html#categories. We calculated species richness, species diversity (Equation 1), and relative cover for native and non-native plants out of the total assemblage for sampling episodes before and after restoration for seven restoration sites for which data were available.

Equation 1. Shannon Diversity Index

$$H' = -\sum_{j=1}^{s} p_i \ln p_i$$

where H' = Shannon Diversity Index
p_i = importance probability in column
i= matrix elements relativized by row totals (see Greig-Smith 1983, p.163; based on Shannon and Wiener 1949).

Nonmetric Multidimensional Scaling

Nonmetric multidimensional scaling (NMS, PC-ORDv6.20, McCune and Grace 2010) was used to examine the relationship between emergent vegetation communities and environmental characteristics. For NMS analyses, a random starting configuration was used with 250 runs performed with the real data. The number of dimensions assessed for the analysis was determined by a Monte Carlo randomization test (250 runs) to determine the number of significant axes with a low stress solution.

Site Similarity

A similarity index was constructed to examine the similarity between sites based on wetland emergent vegetation cover. The similarity index compared each vegetation sampling area in each emergent vegetation zone. The NMS represents a dissimilarity index between sites and years and was calculated using a Sorenson (Bray-Curtis) distance measure. The similarity index was calculated by subtracting 1.0 from the dissimilarity matrix.

Pre-restoration, post-restoration, and reference sites were examined to determine if differences in site condition existed related to emergent marsh vegetation zones. The term “site condition” is used to distinguish pre-restoration, post-restoration, and reference sites. Emergent marsh vegetation zones (vegetation zones) are defined by distinct vegetation species composition and cover groups as determined by salinity and inundation patterns (Borde et al. 2011). Segregating the river using vegetation zones is a more intuitive method to analyze vegetation at larger spatial scales than hydrogeomorphic reach. We included vegetation data collected through the Ecosystem Monitoring Program for applicable years and vegetation zones. The inclusion of long term status data establishes a baseline which describes natural variation and puts changes related to restoration activities into context.

PC-ORD version 6.20 was used to conduct non-parametric statistical analysis (McCune and Mefford 2011). Prior to analysis, vegetation data was summarized by calculating the average cover of identified species present in the survey area. Species with less than two occurrences in the dataset were removed. Deleting species that occur in less than 5% of the sample units reduces noise in the dataset without losing much information; furthermore, it often enhances the detection of relationships between community composition and environmental factors (McCune and Mefford 2002). The vegetation data was arcsine square root transformed to eliminate unequal variance and improve normality (Sokal and Rohlf 1995). Three weak outliers were detected after the data transformation; however, the outliers were retained in the analysis because the influence on the overall analysis was minimal. The vegetation matrix was constructed of 42 sample units and 130 vegetation species reported as average percent cover (Table 4). The environmental matrix consisted of 42 sample units and 10 environmental characteristics – average wetland elevation (Columbia River Datum meters), species richness, Shannon diversity, average percent cover detritus, average percent cover of drift wrack, average percent cover of bare ground, average percent cover of litter, average percent cover of standing dead, average percent cover of wood debris.

Table 4. Sites and years included in vegetation analysis

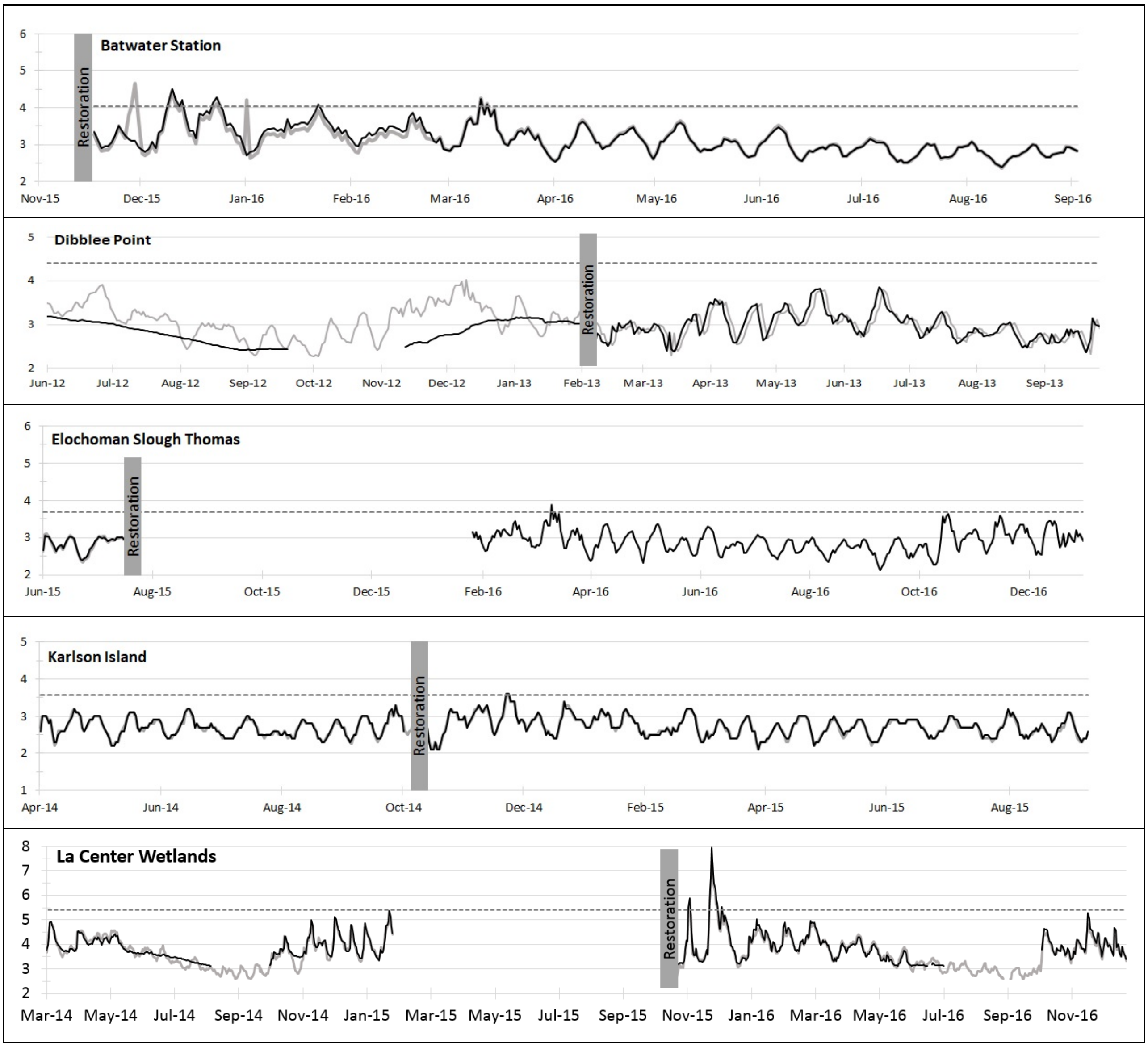
Site	Location	Pre-restoration	Post-restoration	Reference
Wallacut	Mouth	2014	2017	
	Upper	2014	2017	
	Illwaco			2014, 2017
Steamboat Slough	East	2013	2015, 2017	
	West	2013	2015, 2017	
	Welch			2013, 2015, 2017
Dibblee	Channel		2013, 2015, 2017	
	Pond		2013, 2015, 2017	
	Reference			2013, 2015, 2017
North Unit Phase 2	Millionaire North	2014	2015, 2017	
	Millionaire South	2014	2015, 2017	
	Deep Widgeon North	2014	2015, 2017	
	Deep Widgeon South	2014	2015, 2017	
	Cunningham Lake			2014, 2015, 2017
North Unit Flight's End	North	2017		
	South	2017		
	West	2017		
	Cunningham Lake			2017

Results

Water-Surface Elevation

Post-restoration WSE mirrored reference water elevations at sites and in a few cases achieved the 2-year flood elevation (Figure 2). The magnitude of the change in WSE depended on the degree of hydrologic disconnection to adjacent main stem river conditions. Batwater Slough, Dibblee Point, and Louisiana Swamp had poor connection to adjacent water bodies and restoration efforts resulted in a substantial change in WSE, which matched that in an adjacent water body and the main stem estuary.

These sites achieved complete hydrographic reconnection. At sites with partial connectivity, a change in WSE was less pronounced but still indicated improved hydrologic function relative to pre-restoration and resulting in similar hydrology to adjacent reference sites. WSE exceeding the 2-year flood elevation was comparable between restoration and reference sites (Table 5). Variability in climatic conditions between water years are the primary reason restoration sites did not exceed the 2-year flood elevation during the post-restoration data collection period. In cases in which hydrologic reconnection is not clear through the hydrograph, the habitat suitability/opportunity analysis which incorporates the removal of the hydrologic barrier through restoration is a better indicator of recovered/improved hydrologic connectivity (see habitat opportunity section).



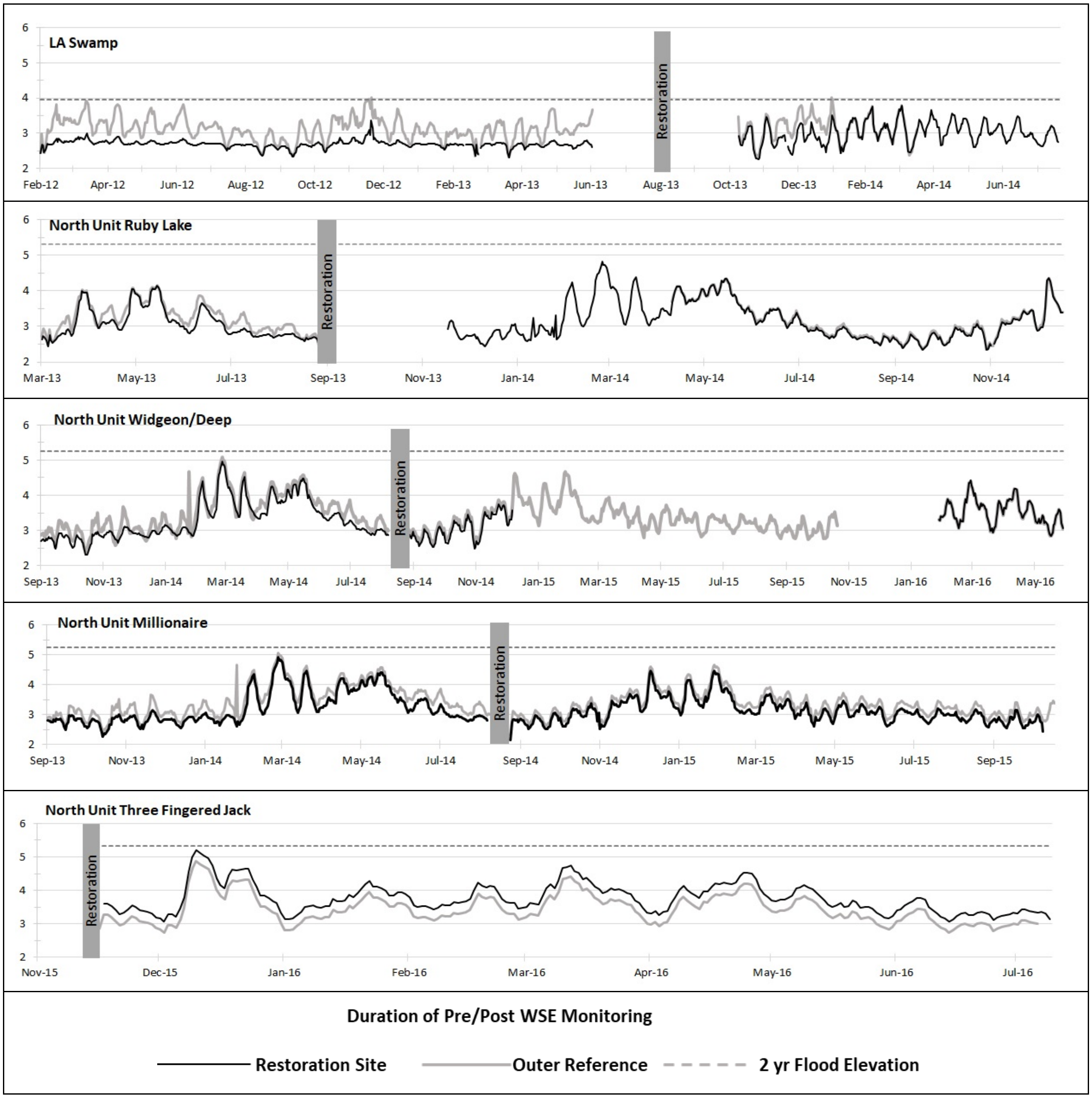


Figure 2. Water-surface elevation (m, NAVD88) pre/post-elevation with 2-year flood elevation. The "reference" is located in a water body adjacent to the restoration site.

Table 5. Number of days the maximum water-surface elevation exceeded the 2-year flood elevation for the project site. Mean and SE of WSE measurements (m, NAVD8) are also presented. The “reference” is located in a water body adjacent to the restoration site.

Batwater Station

Year		2015			2016								
Month		Octy	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Restored	n (days)	Restoration	14	31	31		31	30	31	30	31	31	2
Restored	Mean Max	Restoration	3.15	3.60	3.44		3.31	3.12	3.04	2.96	2.83	2.76	2.86
Restored	SE	Restoration	0.05	0.09	0.06		0.07	0.05	0.05	0.04	0.04	0.03	0.03
Restored	Days Exceeded 2 yr Flood Elevation	Restoration	0	8	1	0	2	0	0	0	0	0	0
Outside	n (days)	Restoration	14	31	31		31	30	31	30	31	31	2
Outside	Mean Max	Restoration	3.37	3.48	3.33		3.32	3.13	3.05	2.97	2.83	2.76	2.86
Outside	SE	Restoration	0.14	0.09	0.06		0.07	0.05	0.05	0.05	0.04	0.03	0.03
Outside	Days Exceeded 2 yr Flood Elevation	Restoration	1	5	1	0	2	0	0	0	0	0	0

Dibblee Point

Year		2012							2013									
Month		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	23	31	31	26		12	31	31	Restoration	31	30	31	30	31	31	30	3
Restored	Mean	3.12	2.92	2.61	2.43		2.57	2.89	3.11	Restoration	2.85	3.15	3.27	3.19	2.97	2.79	2.70	2.99
Restored	SE	0.01	0.02	0.02	0.00		0.01	0.03	0.01	Restoration	0.04	0.06	0.06	0.05	0.04	0.03	0.03	0.01
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	Restoration	0	0	0	0	0	0	0	0
Reference	n (days)	23	31	31	30	31	30	31	31	Restoration	31	30	31	30	31	31	30	3
Reference	Mean	3.43	3.30	2.90	2.64	2.70	3.14	3.56	3.10	Restoration	2.83	3.12	3.25	3.17	3.01	2.80	2.67	3.01
Reference	SE	0.03	0.05	0.04	0.04		0.06	0.04	0.05	Restoration	0.04	0.06	0.06	0.05	0.03	0.02	0.02	0.06
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	Restoration	0	0	0	0	0	0	0	0

Elochoman Slough Thomas

Year		2015		2016											
Month		Jun	Jul	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	30	Restoration	6	29	31	30	31	30	31	31	30	31	30	31
Restored	Mean	2.77	Restoration	3.03	3.03	3.09	2.88	2.86	2.84	2.77	2.73	2.62	2.92	3.11	3.00
Restored	SE	0.04	Restoration	0.05	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.04	0.07	0.05	0.05
Restored	Days Exceeded 2 yr Flood Elevation	0	Restoration	0	0	1	0	0	0	0	0	0	0	0	0
Reference	n (days)	30	Restoration												
Reference	Mean	2.75	Restoration												
Reference	SE	0.04	Restoration												
Reference	Days Exceeded 2 yr Flood Elevation	0	Restoration	0	0	0	0	0	0	0	0	0	0	0	0

Karlson Island

Year		2014									2015									
Month		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	2	31	30	31	31	30	Restoration	21	31	31	28	31	30	31	30	31	31	30	9
Restored	Mean	2.8	2.81	2.70	2.71	2.62	2.64	Restoration	2.66	3.03	2.84	2.87	2.68	2.59	2.64	2.66	2.74	2.71	2.67	2.56
Restored	SE	0.2	0.04	0.05	0.04	0.03	0.04	Restoration	0.09	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.07
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	Restoration	0	2	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	2	31	30	31	31	30	Restoration	30	31	31	28	31	30	31	30	31	31	30	9
Reference	Mean	2.85	2.82	2.69	2.68	2.60	2.63	Restoration	2.75	3.03	2.85	2.87	2.68	2.58	2.63	2.63	2.73	2.68	2.64	2.52
Reference	SE	0.15	0.04	0.05	0.04	0.03	0.04	Restoration	0.07	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.08
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	Restoration	0	2	0	0	0	0	0	0	0	0	0	0

La Center Wetlands

Year		2014										2015												2016											
Month		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	6	30	31	30	31	27		Restoration	30	31	31	13									26	31	31	29	31	30	31	28	12			19	30	31
Restored	Mean	4.44	4.03	4.18	3.74	3.53	3.24		Restoration	3.87	4.10	3.93	4.38									3.74	4.90	4.05	4.08	4.23	3.85	3.50	3.26	3.16			4.04	3.99	3.93
Restored	SE	0.21	0.06	0.02	0.03	0.01	0.02		Restoration	0.08	0.07	0.08	0.17									0.15	0.21	0.11	0.07	0.07	0.05	0.05	0.04	0.01			0.09	0.09	0.06
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	Restoration	0	0	0	0	0	0	0	0	0	0	0	0	2	9	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	6	30	31	30	31	31	30	Restoration	30	31	31	13									26	31	31	29	31	30	31	30	31	31	25	31	30	31
Reference	Mean	4.43	4.02	4.33	3.81	3.47	3.10	2.86	Restoration	3.68	4.04	3.89	4.35									3.61	4.75	3.95	3.99	4.19	3.91	3.57	3.31	3.10	2.97	2.79	3.55	3.91	3.84
Reference	SE	0.19	0.07	0.03	0.03	0.04	0.03	0.03	Restoration	0.10	0.07	0.07	0.14									0.14	0.19	0.09	0.06	0.07	0.06	0.05	0.05	0.03	0.03	0.03	0.10	0.07	0.05
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	Restoration	0	0	0	0	0	0	0	0	0	0	0	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0

LA Swamp

	Year	2012											2013												2014							
	Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Restored	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	29	30	31	30	1		Restoration		23	30	31	28	31	30	31	30	31	18
Restored	Mean	2.55	2.73	2.79	2.74	2.73	2.72	2.66	2.59	2.60	2.69	2.83	2.69	2.66	2.64	2.65	2.68	2.67	2.61				2.75	2.85	2.95	3.02	3.21	3.11	3.19	3.04	2.98	2.90
Restored	SE	0.12	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.01	0.01	0.02	0.02	0.01	0.01					0.07	0.05	0.05	0.06	0.05	0.07	0.04	0.04	0.04	0.05
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	30	30	31	30	1				24	31	31	28	31	15				
Reference	Mean	2.71	3.24	3.35	3.25	3.29	3.22	3.00	2.77	2.87	3.17	3.48	3.07	2.97	2.93	3.04	3.11	3.14	3.67				2.88	3.22	3.44	3.03	3.21	2.93				
Reference	SE	0.27	0.05	0.05	0.05	0.04	0.05	0.03	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.03					0.07	0.05	0.05	0.06	0.05	0.11				
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0		0	0	0	1	0	0	0	0	0	0	0

North Unit Ruby Lake

	Year	2013										2014											
	Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	17	30	31	30	31	31	Restoration			31	31	28	31	30	31	30	31	31	30	31	29	31
Restored	Mean	2.69	3.28	3.60	3.19	2.94	2.73				2.74	2.83	3.25	3.95	3.55	3.97	3.44	3.06	2.75	2.59	2.68	2.86	3.44
Restored	SE	0.03	0.07	0.08	0.05	0.03	0.01				0.03	0.03	0.09	0.10	0.07	0.04	0.04	0.03	0.02	0.02	0.03	0.05	0.07
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	17	30	31	30	31	31								7	31	30	31	31	30	31	30	31
Reference	Mean	2.85	3.46	3.71	3.41	3.17	2.90								3.98	3.97	3.46	3.10	2.80	2.63	2.72	2.89	3.46
Reference	SE	0.05	0.06	0.06	0.05	0.04	0.02								0.06	0.04	0.04	0.03	0.02	0.02	0.04	0.05	0.07
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

North Unit Widgeon/Deep

	Year	2013				2014												2016					
	Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	19		20	31	30	31	10
Restored	Mean	2.72	2.68	2.85	2.93	2.99	3.41	4.09	3.71	4.08	3.55	3.17		2.79	2.91	3.12	3.49		3.49	3.72	3.66	3.36	3.36
Restored	SE	0.02	0.03	0.02	0.02	0.02	0.09	0.09	0.06	0.04	0.04	0.03		0.03	0.04	0.06	0.04		0.05	0.07	0.06	0.05	0.06
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		26	31	30	31		20	31	30	31	10
Reference	Mean	2.90	2.91	3.06	3.09	3.17	3.61	4.24	3.86	4.23	3.78	3.43		2.91	3.03	3.24	3.80		3.49	3.71	3.64	3.34	3.34
Reference	SE	0.04	0.04	0.04	0.04	0.04	0.10	0.09	0.07	0.04	0.03	0.04		0.03	0.04	0.06	0.06		0.05	0.07	0.06	0.05	0.06
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0

North Unit Millionaire

	Year	2013				2014												2015									
	Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	31	31	28	31	30	31	30	31	31	30	20
Restored	Max Mean WSE	2.77	2.70	2.81	2.83	2.86	3.27	4.03	3.62	4.06	3.48	3.08		2.74	2.86	3.09	3.63	3.52	3.77	3.25	3.11	3.07	3.01	2.99	2.96	2.81	2.74
Restored	SE	0.03	0.03	0.02	0.03	0.02	0.10	0.10	0.07	0.04	0.05	0.03		0.03	0.04	0.05	0.06	0.06	0.08	0.04	0.05	0.03	0.04	0.03	0.02	0.03	0.04
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		26	31	30	31	31	28	31	30	31	30	31	31	30	29
Reference	Mean	2.90	2.91	3.06	3.08	3.17	3.61	4.24	3.86	4.23	3.78	3.43		2.91	3.03	3.24	3.80	3.70	3.99	3.48	3.34	3.31	3.24	3.22	3.19	3.03	3.02
Reference	SE	0.04	0.04	0.04	0.04	0.04	0.10	0.09	0.07	0.04	0.03	0.04		0.03	0.04	0.06	0.06	0.06	0.07	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.04
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0

North Unit Three Fingered Jack

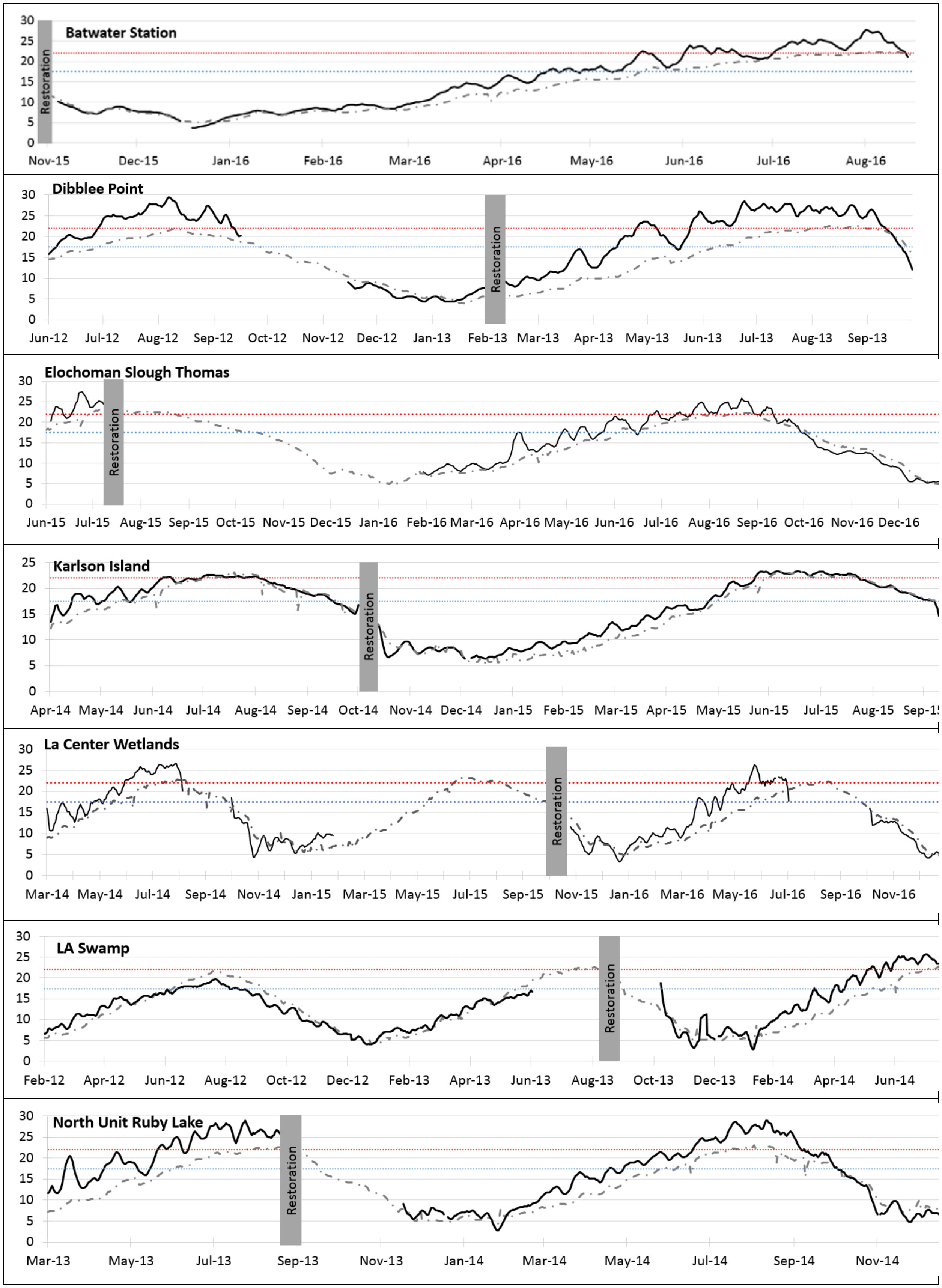
	Year	2015			2016										
	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Restored	n (days)	Restoration	14	31	31	28	31	30	31	30	9			19	15
Restored	Mean		3.43	4.15	3.72	3.72	4.03	3.97	3.65	3.36	3.34			3.51	3.40
Restored	SE		0.03	0.12	0.06	0.05	0.07	0.07	0.05	0.04	0.03			0.05	0.04
Restored	Days Exceeded 2 yr Flood Elevation		0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)		16	31	31	28	31	30	31	30	6			20	15
Reference	Mean		3.08	3.82	3.39	3.39	3.71	3.65	3.32	3.04	3.05			3.15	3.07
Reference	SE		0.03	0.12	0.06	0.05	0.07	0.07	0.05	0.04	0.02			0.05	0.04
Reference	Days Exceeded 2 yr Flood Elevation		0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Percent time post-restoration water-surface elevation exceeded the 2-year flood elevation for a given season.

Water Year	Site	Two Year Flood Elevation	Jan, Feb, Mar	Apr, May, Jun,	Jul, Aug, Sept	Oct, Nov, Dec
2013	Dibblee Point	4.4	0	0	0	0
	La Swamp	3.97	No Data			0
2014	Karlson	3.58	0	0	0	4%
	LA Swamp	3.97	0	0	0	0
	North Unit Millionaire	5.26	No Data			0
	North Unit Ruby Lake	5.31	0	0	0	0
	North Unit Widgeon/Deep	5.26	No Data			0
2015	Karlson	3.58	0	0	0	No Data
	La Center	5.24	0	No Data		19%
	North Unit Three Fingered Jack	5.34	No Data			0
	North Unit Millionaire	5.26	0		0	0
2016	Batwater	4.04	6%	0	0	0
	La Center	5.24	0	0	No Data	0
	Elochoman	3.69	0	2%	0	0
	North Unit Three Fingered Jack	5.34	0	0	0	0
	North Unit Widgeon/Deep	5.26	0	0	No Data	

Water Temperature

Variability in climatic conditions between water years are an important driver of differences in water temperature before and after restoration occurred among all of the restoration sites. Generally, water temperatures among the restored wetlands matched the main stem conditions (Figure 3). Restoration site water temperatures typically become cooler than the main stem conditions in the early fall and conversely became slighter warmer than the main stem in the early summer (Figure 3). This pattern of seasonal differences between restoration sites and the main stem is simply reflecting the seasonal influence climate has on these smaller water bodies compared to the main stem conditions. The maximum mean monthly temperatures at most restoration sites stayed below 22°C during March through June; during July and August temperatures regularly exceeded 22°C, similar to the trend seen in the main stem temperature conditions during these time periods (Table 8). At restoration sites, diurnal changes in temperature were greater than in the main stem estuary, although they followed the same general weekly trend as in the main stem. Overall, the adjacent main stem estuary had a higher proportion of days at < 17.5°C than the nearby restoration sites and a lower proportion of days > 22°C (Table 8).


Batwater Station
Restoration
0 5 10 15 20 25 30
Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16
Dibblee Point
Restoration
0 5 10 15 20 25 30
Jun-12 Jul-12 Aug-12 Sep-12 Oct-12 Nov-12 Dec-12 Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13
Elochoman Slough Thomas
Restoration
0 5 10 15 20 25 30
Jun-15 Jul-15 Aug-15 Sep-15 Oct-15 Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16 Sep-16 Oct-16 Nov-16 Dec-16
Karlson Island
Restoration
0 5 10 15 20 25
Apr-14 May-14 Jun-14 Jul-14 Aug-14 Sep-14 Oct-14 Nov-14 Dec-14 Jan-15 Feb-15 Mar-15 Apr-15 May-15 Jun-15 Jul-15 Aug-15
La Center Wetlands
Restoration
0 5 10 15 20 25 30
Mar-14 May-14 Jul-14 Sep-14 Nov-14 Jan-15 Mar-15 May-15 Jul-15 Sep-15 Nov-15 Jan-16 Mar-16 May-16 Jul-16 Sep-16 Nov-16
LA Swamp
Restoration
0 5 10 15 20 25 30
Feb-12 Apr-12 Jun-12 Aug-12 Oct-12 Dec-12 Feb-13 Apr-13 Jun-13 Aug-13 Oct-13 Dec-13 Feb-14 Apr-14 Jun-14
North Unit Ruby Lake
Restoration
0 5 10 15 20 25 30
Mar-13 May-13 Jul-13 Sep-13 Nov-13 Jan-14 Mar-14 May-14 Jul-14 Sep-14 Nov-14

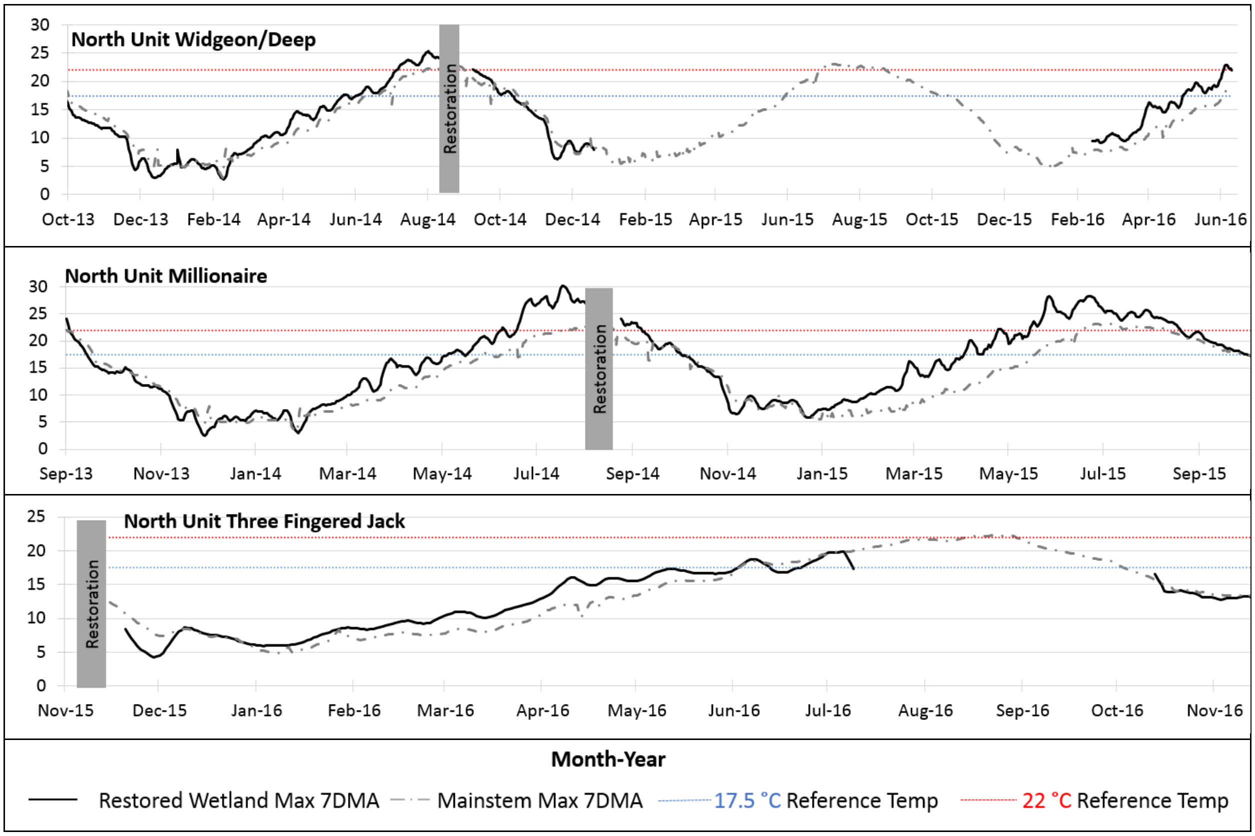


Figure 3. Pre- and post-restoration water temperatures (°C) for restoration sites and main stem estuary.

Table 7. Monthly maximum mean water temperature at restoration, reference, and main stem locations. Temperatures greater than 17.5°C are in yellow and temperatures greater than 22°C are in red.

Batwater Station												
Year		2015			2016							
Month		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Restored	n (days)	Restoration	11	31	28		31	30	31	30	31	31
Restored	Mean		8.7	7.6	6.1		10.0	14.9	18.1	21.7	22.7	24.8
Restored	SE		0.3	0.2	0.3		0.3	0.2	0.1	0.3	0.3	0.3
Main Stem	n (days)		14	31	31	29	31	30	31	30	31	31
Main Stem	Mean		9.6	7.4	6.0	7.48	8.7	12.2	15.2	18.3	20.6	21.9
Main Stem	SE		0.4	0.1	0.2	0.06	0.1	0.2	0.1	0.1	0.1	0.1

Dibblee Point																	
Year		2012							2013								
Month		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Restored	n (days)	23	31	31	23		9	31	31	Restoration	31	30	31	30	31	31	30
Restored	Mean	18.9	24.0	26.6	24.2		8.0	6.6	5.0		11.9	16.4	20.6	24.1	26.9	26.4	22.3
Restored	SE	0.3	0.3	0.3	0.5		0.2	0.2	0.1		0.4	0.5	0.4	0.2	0.2	0.1	0.6
Reference	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30
Reference	Mean	18.9	22.9	25.2	22.0	15.8	11.0	7.2	5.0		10.1	13.8	17.2	21	25.0	24.4	22.0
Reference	SE	0.4	0.2	0.3	0.3	0.4	0.3	0.2	0.1		0.3	0.3	0.2	0.2	0.1	0.1	0.6
Main Stem	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30
Main Stem	Mean	15.8	18.7	21	19.5	15.6	11.5	7.8	4.9		7.4	10.5	14.2	17	20.7	22.0	21
Main Stem	SE	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.1		0.2	0.1	0.1	0.2	0.1	0.1	0.3

Elochoman Slough Thomas

Year		2015							2016											
Month		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	27	13	Restoration						29	31	30	31	30	31	31	30	31	30	28
	Mean	23.7	24.2							8.6	10.6	14.7	17.8	20	22.2	23.7	20.8	13.8	11.1	6.0
	SE	0.4	0.2							0.1	0.5	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.2
Reference	n (days)	30	13																	
	Mean	22.9	24.6																	
	SE	0.3	0.3																	
Main Stem	n (days)	30	31		30	31	30	31	31	29	31	30	31	30	31	31	30	31	30	31
	Mean	20	22.8		19.6	17	11.8	7.4	6.0	7.5	8.7	12.2	15.2	18	20.6	21.9	19.8	15.4	12.4	6.6
	SE	0.2	0.1		0.2	0.2	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3

Karlson Island

Year		2014									2015									
Month		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	2	31	30	31	31	30	Restoration	21	31	28	28	31	30	31	30	31	31	30	9
	Mean	14.0	17.3	19.1	21.8	22.3	20.3		8.7	8.0	7.2	8.7	10.9	13.6	16.7	21.3	23.0	22.3	19.5	17.1
	SE	0.5	0.2	0.2	0.1	0.0	0.2		0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.0	0.1	0.2	0.4
Reference	n (days)	2	31	30	31	31	30		30	31	31	28	31	30	31	30	31	31	30	9
	Mean	17.1	18.1	20.8	23.9	23.7	20.6		10.8	8.3	6.8	8.4	10.3	13.2	16.5	21	23.0	22.3	19.5	18.2
	SE	0.0	0.2	0.2	0.2	0.2	0.2		0.7	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.0	0.1	0.2	0.1
Main Stem	n (days)	2	31	30	31	30	28		30	31	31	28	31	30	31	30	31	31	30	9
	Mean	12.6	14.7	17.5	20.7	22.5	19.7		11.0	7.9	6.1	6.8	8.6	11.6	15.5	20	22.8	22.2	19.6	17.8
	SE	0.4	0.2	0.1	0.2	0.0	0.2		0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1

La Center Wetlands

Year		2014										2015				2016											
Month		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	6	30	31	30	31	27		Restoration	30	31	31	13	23	31	31	29	31	30	31	28	12			19	30	31
	Mean	12.4	14.7	16.7	20.9	24.8	25.4			8.8	7.8	7.7	9.5	8.3	7.2	6.7	9.6	11.6	17	20.8	23.2	22.1			12.9	11.1	5.6
	SE	0.9	0.3	0.2	0.3	0.1	0.3			0.5	0.2	0.2	0.1	0.5	0.3	0.4	0.2	0.4	0.3	0.2	0.3	0.5			0.2	0.3	0.2
Reference	n (days)	6	30	31	30	31	31	30		30	31	31	10	26	31	31	29	31	30	31	30	31	31	25	31	30	31
	Mean	9.9	10.8	14.0	17.5	22.4	23.6	19.4		8.1	7.8	7.4	8.8	8.2	7.4	6.5	8.3	9.1	12.9	16.5	20	21.6	22.7	18	12.2	10.3	6.1
	SE	0.6	0.1	0.3	0.2	0.3	0.1	0.2		0.4	0.2	0.2	0.1	0.4	0.2	0.3	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.3	0.3	0.2	0.2
Main Stem	n (days)	6	30	31	30	31	30	28		30	31	31	28	30	31	31	29	31	30	31	30	31	31	30	31	30	31
	Mean	9.1	11.0	14.7	17.5	20.7	22.5	19.7		11.0	8.0	6.1	6.8	11.8	7.4	6.0	7.5	8.7	12.2	15.2	18	20.6	21.9	20	15.4	12.4	6.6
	SE	0.0	0.2	0.2	0.1	0.2	0.0	0.2		0.4	0.1	0.1	0.1	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3

LA Swamp

Year		2012											2013												2014							
Month		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	A
Restored	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	30	30	31	30			Restoration		24	31	28	28	31	30	31	30	31	
	Mean	6.6	8.5	11.7	14.4	15.9	17.5	18.8	16.9	13.2	10.2	7.5	5.0	7.3	8.4	11.6	14.2	15.7					9.7	6.5	6.9	6.8	11.9	15.3	19	22	24.6	2
	SE	0.0	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.2	0.2	0.1	0.1					0.7	0.5	0.1	0.4	0.2	0.3	0.2	0.2	0.1	
Reference	n (days)	2	31	30	31	30	31	31	30	31	30	28	31	28	31	30	31	30					24	31	31	28	31	16				
	Mean	8.1	10.6	13.8	17.7	19.5	21.6	23.7	21.6	16.0	10.4	7.5	5.9	8.8	10.3	13.4	17.5	19.3					10.5	5.3	6.6	7.6	12.4	15.6				
	SE	0.2	0.4	0.3	0.3	0.2	0.1	0.2	0.3	0.6	0.4	0.2	0.2	0.2	0.3	0.3	0.2	0.2					0.5	0.2	0.1	0.4	0.5	0.6				
Main Stem	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	31	30	31	30	31	31		31	30	31	31	27	31	30	31	30	31	
	Mean	5.6	6.6	9.6	13.1	15.5	18.7	21	19.5	15.6	11.5	7.8	4.9	5.7	7.4	10.5	14.2	17.3	20.7	22		14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	18	21	
	SE	0.0	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1		0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2	

North Unit Ruby Lake

Year		2013										2014											
Month		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	17	30	31	30	31	31	Restoration			31	29	28	31	30	31	30	31	31	30	31	29	31
	Mean	14.5	15.8	18.5	22.9	26.5	26.3				7.0	6.6	6.1	11.0	15.0	18.1	20.5	24.4	27.5	23.9	18	9.9	6.5
	SE	0.8	0.4	0.3	0.3	0.2	0.2				0.1	0.1	0.4	0.3	0.2	0.2	0.1	0.2	0.2	0.4	0.4	0.5	0.2
Reference	n (days)	15	30	31	30	31	31								5	31	30	31	31	30	31	30	31
	Mean	15.4	15.7	18.4	22.9	26.5	26.3								16.0	18.9	21.8	27.2	26.0	22.2	17	9.8	8.7
	SE	0.8	0.4	0.3	0.3	0.2	0.2								0.8	0.2	0.2	0.2	0.2	0.3	0.3	0.5	0.1
Main Stem	n (days)	17	30	31	30	31	31		31	30	31	31	27	31	30	31	30	31	24	28	31	30	31
	Mean	8.1	10.5	14.2	17.3	20.7	22		14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7	22.4	19.7	17	11.0	8.0
	SE	0.2	0.1	0.1	0.2	0.1	0.1		0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.4	0.1

North Unit Widgeon/Deep

Year		2013				2014												2016					
Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	23	31	30	19		17	31	30	31	10
Restored	Mean	19.2	13.0	8.9	4.6	5.4	5.5	9.9	13.5	16.3	18.6	23.2		20	16.4	9.6	8.3		9.7	11.2	15.7	18.9	22.2
Restored	SE	0.5	0.2	0.5	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.3	0.2	0.5	0.1		0.1	0.3	0.1	0.1	0.2
Reference	n (days)	18	31	30	28	31	28	31	30	31	30	31		23	31	30	31		20	31	30	31	10
Reference	Mean	19.4	13.4	9.2	4.5	5.5	5.8	10.2	14.0	17.1	19.5	23.6		22	17.2	10.1	8.4		10.0	12.0	15.4	19.2	22.8
Reference	SE	0.5	0.2	0.5	0.3	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.4	0.3	0.5	0.1		0.1	0.3	0.2	0.2	0.6
Main Stem	n (days)	18	31	30	31	31	27	31	30	31	30	31		28	31	30	31	31	29	31	30	31	10
Main Stem	Mean	20.2	14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7		20	17.3	11.0	8.0	6.0	7.5	8.7	12.2	15.2	18
Main Stem	SE	0.3	0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2		0.2	0.3	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.2

North Unit Millionaire

Year		2013				2014												2015									
Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	31	31	28	31	30	31	30	31	31	30	17
Restored	Mean	19.4	14.1	9.4	5.0	6.2	6.2	10.5	14.8	17.1	20.7	27.2		22	17.3	9.9	8.4	7.6	10.2	14.2	17	21.2	25.8	25.9	24.2	20	18
Restored	SE	0.56	0.17	0.45	0.24	0.11	0.34	0.28	0.26	0.14	0.18	0.29		0.3	0.3	0.49	0.11	0.19	0.18	0.31	0.3	0.21	0.27	0.3	0.16	0.2	0.1
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		23	31	30	31	31	28	31	30	31	30	31	31	30	29
Reference	Mean	18.9	13.4	9.2	4.6	5.5	5.8	10.2	14.0	17.1	19.5	23.6		21	17	10.1	8.4	7.4	9.8	12.6	15.2	19.3	24.6	25.9	24.2	21	17
Reference	SE	0.4	0.2	0.5	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.3	0.3	0.5	0.1	0.2	0.1	0.3	0.2	0.2	0.4	0.2	0.1	0.2	0.2
Main Stem	n (days)	18	31	30	31	31	27	31	30	31	30	31		28	31	30	31	31	28	31	30	31	30	31	31	30	29
Main Stem	Mean	20.2	14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7		20	17.3	11.0	8.0	6.1	6.8	8.6	11.6	15.5	20	22.8	22.2	20	17
Main Stem	SE	0.3	0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2		0.2	0.3	0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1

North Unit Three Fingered Jack

Year		2015		2016										
Month		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Restored	n (days)	Restoration	31	31	28	31	30	31	30	9			19	15
Restored	Mean		7.1	7.0	9.1	11.1	15.2	16.7	17.9	19.2			14.0	13.0
Restored	SE		0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.3			0.2	0.1
Reference	n (days)		31	31	28	31	30	31	30	6			20	12
Reference	Mean		6.7	6.2	9.5	12.0	17.7	21	23.7	22			14.2	13.8
Reference	SE		0.2	0.4	0.2	0.4	0.2	0.2	0.4	0.7			0.3	0.1
Main Stem	n (days)		31	31	28	31	30	31	30	31	31	30	31	15
Main Stem	Mean		7.4	6.0	7.5	8.7	12.2	15.2	18.3	20.6	21.9	19.8	15.4	13.4
Main Stem	SE		0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1

Table 8. Percent time post-restoration water temperature was <17.5°C, 17.5–22°C, and >22°C for spring and summer months. Columbia River temperature level is from Table 1.5.

Water Year	Site		Spring - Apr, May, Jun, <17.5°C	Spring 17.5 - 22°C	Spring >22	Summer - Jul, Aug, Sept <17.5°C	Summer 17.5 - 22°C	Summer >22
2013	Dibblee Slough	Restored	33	33	33			100
		Reference	66		33			100
	Main stem		100				100	
2014	LA Swamp	Restored	33	33	33			100
		Reference	No Data			No Data		
	North Unit Ruby	Restored	33	66				100
		Reference	33	66				100
	Main stem		66	33			66	33
2015	Karlason	Restored	66	33			33	66
		Reference	66	33			33	66
	North Unit Millionaire	Restored	33	33	33		33	66
		Reference	33	33	33		33	66
	Main stem		66	33			33	66
2016	Batwater	Restored	33	66			33	66
		Reference	66	33			66	33
	Elochoman	Restored	33	66			33	66
		Reference	No Data			No Data		
	La Center	Restored	33	33	33			66
		Reference	66	33			66	33
	North Unit Three Fingered Jack	Restored	66	33		No Data		
		Reference		66	33	No Data		
	North Unit Widgeon Deep	Restored	33	33	33			33
		Reference	33	33	33			33
	Main stem		66	33			100	

Habitat Opportunity

Post-restoration, juvenile salmon access to suitable habitat within restoration sites increased compared to pre-restoration conditions (Table 9). Post-restoration site conditions with a depth 0.5 m or greater and a temperature threshold less than 17.5°C increased by 85% on average for all projects combined in April (Table 9). In May and June for the same water depth and temperature criteria, post-restoration average increases in habitat opportunity were 30% and 4% respectively. Restoration site habitat opportunity for the same depth parameters but a temperature threshold between 17.5°C and 22°C increased 12% in April, 44% in May, and 29% June on average (Table 11). The month of June primarily had a temperature threshold greater than 22°C and also had the most periods of no access (i.e. barrier or low water levels), however, the post-restoration periods of no access were lower than pre-restoration condition (Table 11).

Table 9. Percent time with 0.5 m water depth and water temperature used to establish site opportunity.

Batwater Opportunity (% Access)

Year	2015			2016							
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Good <17.5 Pre	Restoration	0	0	0		97%	90%	13%	0	0	0
Fair 17.5-22 Pre		0	0	0		0	0	81%	37%	16%	3%
Poor >22 Pre		0	0	0		0	0	0	47%	48%	61%
No Access		100%	100%	100%		3%	10%	6%	17%	35%	35%

Dibblee Point Opportunity (% Access)

Years	2012							2013										
Months	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0		0	0	0	Restoration	84%	67%	10%	0	0	0	7%	100%
Fair 17.5-22 Pre	0	0	0	0		0	0	0		0	33%	52%	0	0	0	27%	0
Poor >22 Pre	0	0	0	0		0	0	0		0	0	39%	100%	97%	87%	53%	0
No Access	100%	100%	100%	100%		100%	100%	100%		16%	0%	0%	0%	3%	13%	13%	0%

Elochoman Slough Thomas Opportunity (% Access)

Year	2015			2016											
Month	Jun	Jul	Aug	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	0	0	Restoration	100%	100%	97%	93%	52%	7%	0	0	3%	100%	100%	100%
Fair 17.5-22 Pre	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Poor >22 Pre	0	0		0	0	0	0	0	10%	45%	97%	27%	0	0	0
No Access	100%	100%		0%	0%	3%	7%	48%	83%	55%	3%	70%	0%	0%	0%

Karlson Island Opportunity (% Access)

Year	2014								2015									
Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0	0	Restoration	100%	100%	100%	100%	100%	100%	81%	0	0	0	0	33%
Fair 17.5-22 Pre	0	0	0	0	0		0	0	0	0	0	0	19%	70%	0	29%	100%	67%
Poor >22 Pre	0	0	0	0	0		0	0	0	0	0	0	0	30%	100%	71%	0	0
No Access	100%	100%	100%	100%	100%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

LA Swamp Opportunity (% Access)

Years	2012											2013												2014							
Moths	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Good <17.5 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		Restoration		79%	97%	100%	100%	100%	100%	19%	0	0	0
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				4%	0	0	0	0	0	0	0	0	0
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	67%	100%	95%
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%				17%	3%	0%	0%	0%	0%	81%	33%	0%	5%

La Center Wetlands Opportunity (% Access)

Year	2014										2015												2016											
Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	50%	13%	0	0	0	0		Restoration	63%	87%	74%	92%									39%	84%	61%	100%	94%	50%	0	0	0			89%	80%	81%
Fair 17.5-22 Pre	0	0	0	0	0	0			0	0	0	0									0	0	0	0	0	33%	42%	0	0			0	0	0
Poor >22 Pre	0	0	0	0	0	0			0	0	0	0									0	0	0	0	0	0	0	11%	0			0	0	0
No Access	50%	87%	100%	100%	100%	100%			37%	13%	26%	8%									61%	16%	39%	0%	6%	17%	58%	89%	100%			11%	20%	19%

North Unit Millionaire Opportunity (% Access)

Years	2013				2014												2015									
Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0	0	0	10%	0	0	0	0	Restoration	0	48%	90%	100%	100%	100%	100%	50%	0	0	0	0	0	24%
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0		46%	42%	0	0	0	0	0	50%	74%	0	0	0	100%	76%
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0		50%	0	0	0	0	0	0	0	26%	97%	100%	100%	0	0
No Access	100%	100%	100%	100%	100%	100%	90%	100%	100%	100%	100%		4%	10%	10%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%

North Unit Ruby Lake Opportunity (% Access)

Year	2013										2014											
Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	0	0	0	0	0	0	Restoration			84%	100%	100%	100%	100%	29%	0	0	0	0	0	83%	100%
Fair 17.5-22 Pre	0	0	0	0	0	0				0	0	0	0	0	71%	100%	6%	0	23%	45%	0	0
Poor >22 Pre	0	0	0	0	0	0				0	0	0	0	0	0	0	94%	100%	50%	29%	0	0
No Access	100%	100%	100%	100%	100%	100%				16%	0%	0%	0%	0%	0%	0%	0%	0%	27%	26%	17%	0%

North Unit Three Fingered Jack Opportunity (% Access)												
Years	2015		2016									
Months	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Good <17.5 Pre	0	0	0	0	0	0	0	0	0		Restoration	100%	100%
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0			0	0
Poor >22 Pre	0	0	0	0	0	0	0	0	0			0	0
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%			0%	0%

North Unit Widgeon Deep Opportunity (% Access)																						
Year	2013				2014												2016					
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Good <17.5 Pre	0	0	0	0	0	0	0	0	0	0	0	Restoration	0	65%	100%	100%		100%	100%	100%	0	0
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0		96%	35%	0	0		0	0	0	100%	20%
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0	0	0	0	0
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%		4%	0%	0%	0%		0%	0%	0%	0%	80%

Table 10. Site habitat opportunity post-restoration for April through June. By definition, a water depth of 0.5 m or more is needed to provide adequate salmonid access.

Water Year	Site	Condition	Opportunity Type	Apr	May	June
2013	Dibblee Point	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	67%	10%	0
			Fair, 17.5-22	33%	53%	0
			Poor, >22	0	37%	100%
2014	LA Swamp	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	81%	33%
			Good, <17.5	100%	19%	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	67%
	North Unit Ruby	Pre	No Access	97%	74%	100%
			Good, <17.5	3%	0	0
			Fair, 17.5-22	0	26%	0
			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	100%	29%	0
			Fair, 17.5-22	0	71%	100%
			Poor, >22	0	0	0
2015	Karlson	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0

			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	100%	81%	0
			Fair, 17.5-22	0	19%	70%
			Poor, >22	0	0	30%
	North Unit Millionaire	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	3%
			Good, <17.5	50%	0	0
			Fair, 17.5-22	50%	74%	0
			Poor, >22	0	26%	97%
2016	Batwater	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	10%	6%	17%
			Good, <17.5	90%	13%	0
			Fair, 17.5-22	0	81%	37%
			Poor, >22	0	0	47%
	Elochoman	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	7%	48%	83%
			Good, <17.5	93%	52%	7%
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	10%
	La Center	Pre	No Access	100%	100%	93%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	17%	58%	83%
			Good, <17.5	50%	0	0
			Fair, 17.5-22	33%	42%	0
			Poor, >22	0	0	10%
	North Unit Three Fingered Jack	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0

			Poor, >22	0	0	0
		Post	No Access	0	0	7%
			Good, <17.5	100%	100%	33%
			Fair, 17.5-22	0	0	60%
			Poor, >22	0	0	0
	North Unit Widgeon Deep	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	80%
			Good, <17.5	100%	0	0
			Fair, 17.5-22	0	100%	20%
			Poor, >22	0	0	0

Table 11. Average habitat opportunity for all sites

Pre-restoration			
	Apr	May	June
No Access	100%	97%	100%
Good, <17.5	0%	0%	0%
Fair, 17.5-22	0%	3%	0%
Poor, >22	0%	0%	0%
Post-restoration			
	Apr	May	June
No Access	3%	19%	31%
Good, <17.5	85%	30%	4%
Fair, 17.5-22	12%	44%	29%
Poor, >22	0%	6%	36%

Sediment Accretion

Sediment accretion or loss varied within and among the restoration sites (Table 12). For example, sites at Kandoll Farm with similar high elevations showed both loss and gain. Slightly more than half of the restoration sites had a positive annual average rate, however variability in these data make generalizations within and between sites difficult to determine. While this study observed no trends with sediment accretion and elevation within or among sites other researchers have identified strong correlations between marsh topography and hydrology (e.g., Craft et al. 1993, Callaway et al. 1997, Kidd Unpublished Data) (Figure 4). Future monitoring should consider the observed high data variability associated with using sediment accretion benches for monitoring within this system. Installing a greater number of sediment benches located across a restoration site's elevation and hydrologic gradient may provide more robust results for analysis and comparison, additionally, other more accurate methods such as Sedimentation-Erosion Tables (SET) and feldspar marker horizons should also be considered for comparison (Roelof and Day 1993, Cahoon et al. 2000).

Table 12. Sediment accretion annual rate and restoration site average.

Site	Years Post Restoration	Reach	Site Average Annual Rate	Standard Error
Batwater Station	1.9	C	2.58	1.87
Elochoman Slough Thomas	2.4	B	4.10	3.25
Kandoll Farm	2.7	B	-1.19	1.19
Karlson Island	1.1	B	-3.68	6.05
La Center Wetlands	1.9	E	0.84	1.22
LA Swamp	2.7	C	4.01	-
North Unit Millionaire	1.5	F	-0.42	1.65
North Unit Ruby Lake	1.0	F	3.97	1.32
North Unit Widgeon/Deep	1.5	F	1.85	2.56
Wallacut Slough	1.7	A	-0.54	2.15

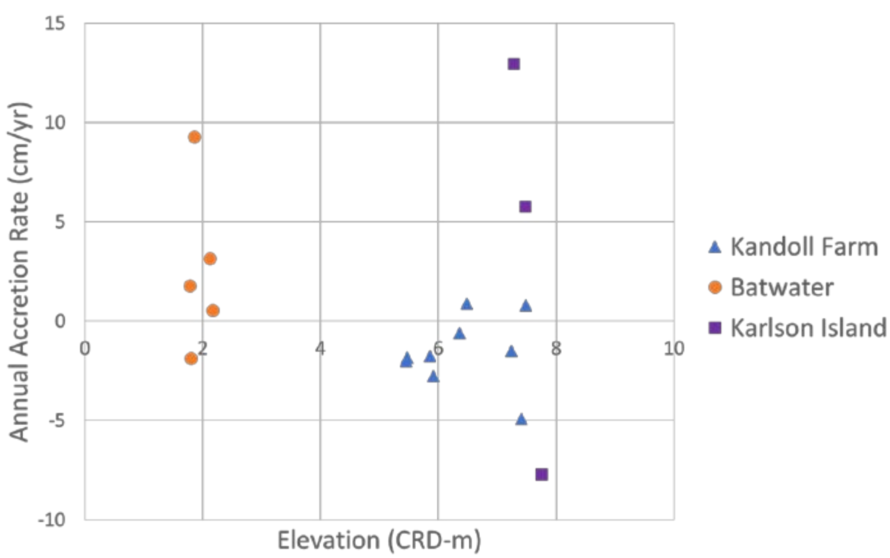


Figure 4. Annual accretion rate by elevation for three restoration sites.

Channel Cross Section

Channel cross-section data from the AEM data collection effort included three sites located in the Lower Estuary zone: Kandoll #2, Mill Road, and Wallacut. Kandoll #2 and Mill Road involved new channel construction, while Wallacut was a reconnection to an existing channel. Other cross-section data for CEERP projects are available in the literature (Crims and Vera in Diefenderfer et al. In Prep; Sandy River delta in Johnson et al. 2011). For the three AEM sites, the relationship between area and years elapsed since restoration was equivocal (Figure 5). The number of years post-restoration does not appear to be an indicator of change in channel cross-sectional area. The percent change in channel cross-sectional area was negatively related to channel order (Figure 6). In general, channels in closer proximity to the main stem water body will increase in channel volume while channels further in the wetland showed a reduction in channel area. Overall, more time post-restoration and additional sediment data is required to clearly understand the impact of restoration on channel cross sectional area and channel development.

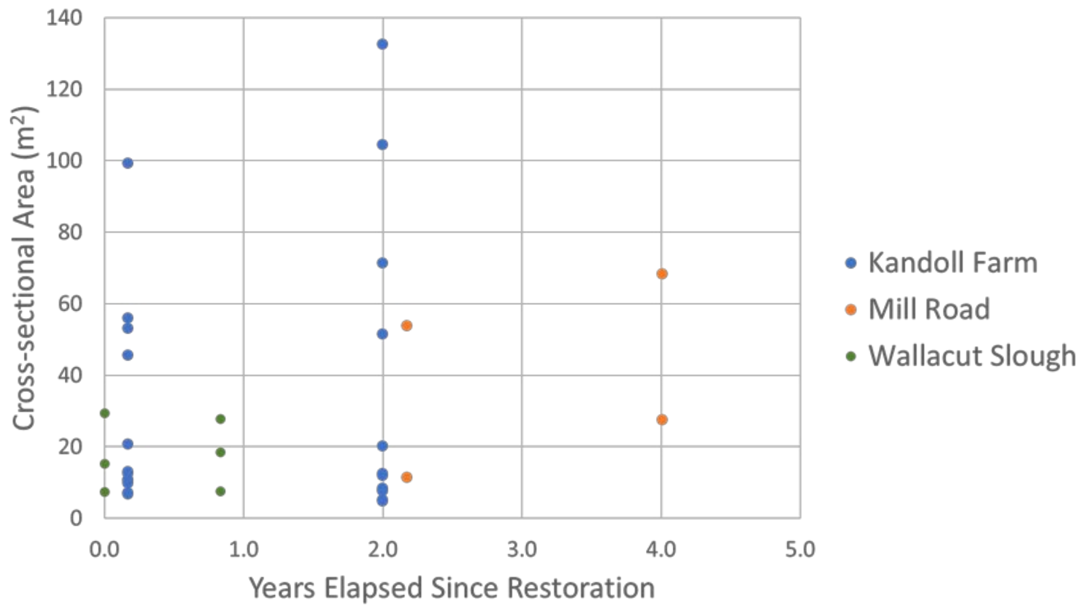


Figure 5**.** Cross-sectional area after restoration.

Figure 6. Change in channel cross-section area with channel order.

Vegetation 2017

A NMS ordination with a three-dimensional solution of plots in species space was used (Final stress= 12.77, final stability ≤.000001, number of iterations= 67). The three-axis solution explained 83% of the variation in the data. The solution was rotated so average marsh elevation was parallel with axis one. Species richness, species diversity, large woody debris, and standing dead were parallel with axis three (Figure 3). Axis one shows vegetation has a weak negative correlation with average marsh elevation (r =-.479). Axis three shows a negative strong correlation with species richness (r =-.72), a strong negative correlation with species diversity (r =-.77), weak negative correlation with Large Woody Debris (r=-.47), and moderate positive correlation with standing dead vegetation (r=.54) (Figure 7).

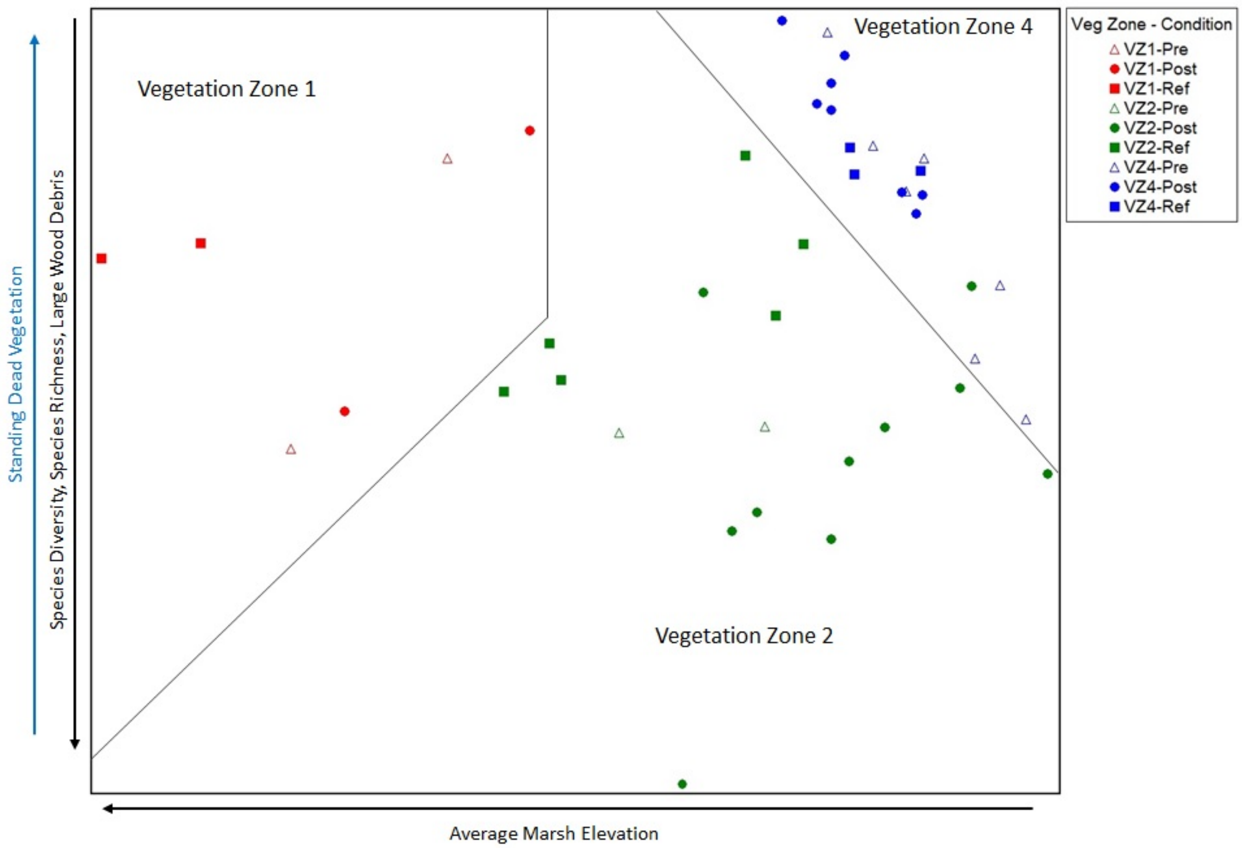


Figure 7. NMS ordination of sample units in species space. Axis 1 is correlated with average marsh elevation. Axis 3 is correlated with species richness, species diversity, large woody debris, and standing dead. Different vegetation zones are demarcated.

Wallacut Slough

The Wallacut restoration site has two vegetation monitoring areas which were sampled pre-restoration and one year post-restoration. Vegetation monitoring at the levy breach (WAM) and upper portion (WAU) of the wetland was established to capture changes related to tidal reconnection.

Vegetation Similarity

Wallacut and associated reference site were sampled (n=6) once pre-restoration (2014) and one year post-restoration (2017). Pre-restoration Wallacut had a 46% similarity between the two vegetation sampling areas and had less than a 19% similarity with the reference site at Illwaco Slough (IL, Table 13). Year one post-restoration Wallacut had a 60% similarity between the two vegetation sampling areas. In year one post restoration, Wallacut had less than 10% similarity to the reference site (Table 13). Year one post-restoration at mouth sited had a 57% similarity to pre-restoration condition. At upper wetland site, from pre-restoration to year one post-restoration, the vegetation similarity was 46. At the reference site, when 2015 and 2017 were compared the vegetation similarity was 60%.

Table 13. Similarity index for restoration and reference sites in vegetation zone one. Yellow highlights represent 60-69% similarity.

	IL17	WAM14	WAU14	WAM17	WAU17
IL14	0.60	0.19	0.17	0.22	0.19
IL17		0.15	0.16	0.10	0.05
WAM14			0.52	0.57	0.38
WAU14				0.34	0.46
WAM17					0.60

IL = Illwaco Slough Reference
WAM = Wallacut Mouth
WAU = Wallacut Upper Wetland

Vegetation Composition

At Wallacut in 2017 species richness increased slightly at the mouth site and decreased in the upper wetland compared to pre-restoration and species diversity decreased since pre-restoration monitoring (Table 14). Invasive reed canarygrass (*Phalaris arundinacea*) cover did not change from pre-restoration remaining at 47%, while creeping bent grass (*Agrostis stolonifera L.*) cover increased by 15% (Figure 8). Native American sloughgrass (*Beckmannia syzigachne*) which was not present pre-restoration increased 9% post-restoration (Figure 8). At the upper wetland monitoring area, non-native soft rush (*Juncus effuses*) disappeared and was replaced by native slough sedge (*Carex obnupta*) and Baltic rush (*Juncus balticus*). Lyngby sedge (*Carex lyngbyei*) was the dominant vegetation species with an average cover of 41%, but nonnative creeping bentgrass (*Agrostis stolonifera L.*) increased by 20% at the reference site (Figure 8).

Table 14. Species richness and species diversity at Wallacut

Condition	Area	Avg. Marsh Elevation (CRD, m)	Overall Species Richness	Overall Species Diversity
Pre-restoration	WAM14	2.6	37	2.04
	WAU14	2.5	37	2.13
Post-restoration	WAM17	2.6	38	1.88
	WAU17	2.6	34	1.88
Reference	IL14	2.1	19	1.94
	IL17	2.0	17	1.96

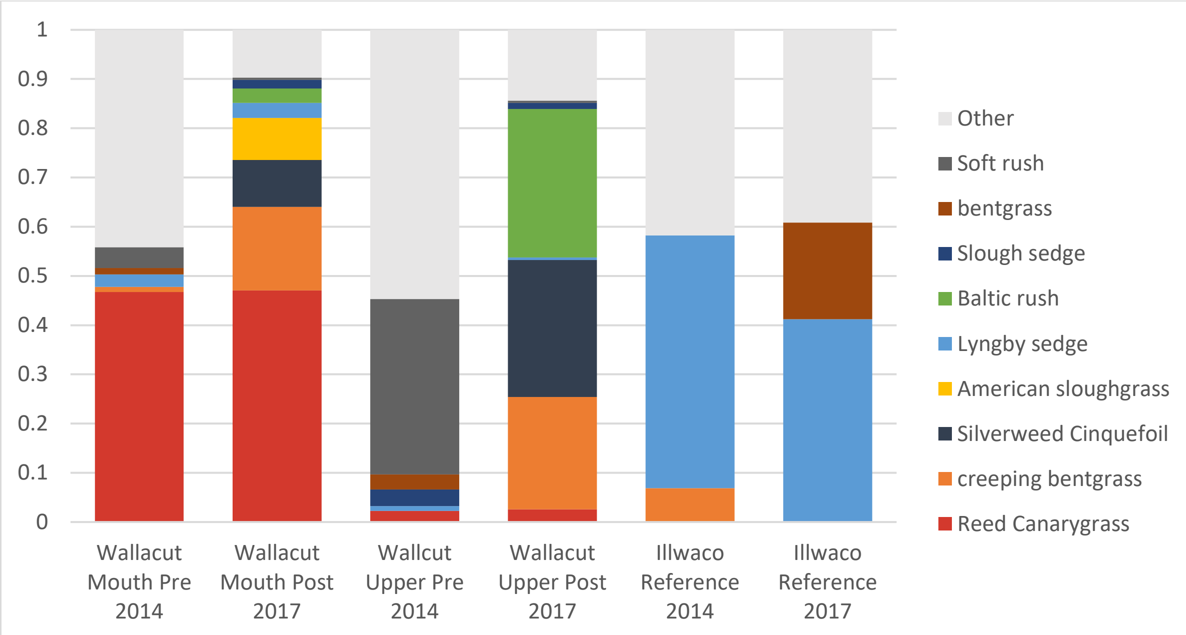


Figure 8. Relative trend and vegetation cover for Wallacut and Illwaco Reference site

Steamboat Slough

Steamboat Slough site has two vegetation monitoring areas which were sampled pre-restoration, one year post-restoration, and three years post-restoration. Vegetation monitoring at Steamboat Slough West (SBW) was established to capture changes directly related to the lowering of the marsh elevation and unrestricted connection to the Columbia River. Vegetation monitoring at Steamboat Slough East (SBE) was established to track indirect changes to established wetland within the restoration site following tidal reconnection.

Vegetation Similarity

Steamboat slough and associated reference site were sampled (n=9) once pre-restoration (2013) and twice post-restoration (2015, 2017). Pre-restoration Steamboat Slough had a vegetation similarity of 44% between the east and west sampling areas. The east site had 19% similarity to the reference site while south site had a 13% vegetation similarity. Year one post-restoration within site vegetation similarity decreased to 52% and 54% at three years post-restoration. Pre-restoration Steamboat east had a vegetation similarity of 28% to the same area year three post-restoration. The Steamboat west site pre-restoration had a vegetation similarity of 17% to year one post-restoration and 13% year three post-restoration. When compared to the reference site, the north and south sampling areas differ dramatically. Pre-restoration Steamboat west had a 13% vegetation similarity to the reference site. Year one post-restoration the vegetation similarity decreased to 10% but increased to 28% year three post-restoration. At the Steamboat east pre-restoration, the vegetation similarity to the reference site was 19%. Post-restoration the vegetation similarity did not change substantially remaining at 18% year one post-restoration but increasing to 29% post restoration year three. Over the same period of time the vegetation similarity between years at the reference site ranged from 73% to 77% (Table 15).

Table 15. Similarity index for restoration and reference sites in vegetation zone one. Yellow highlights represent 60-69% similarity and green represent greater than 70% similarity.

	SBW13	SBE15	SBW15	SBE17	SBW17	WI13	WI15	WI17
SBE13	0.44	0.46	0.35	0.28	0.22	0.19	0.23	0.19
SBW13		0.14	0.17	0.17	0.13	0.13	0.12	0.09
SBE15			0.52	0.33	0.20	0.13	0.18	0.18
SBW15				0.19	0.28	0.10	0.10	0.09
SBE17					0.54	0.17	0.27	0.29
SBW17						0.25	0.32	0.28
WI13							0.77	0.73
WI15								0.77

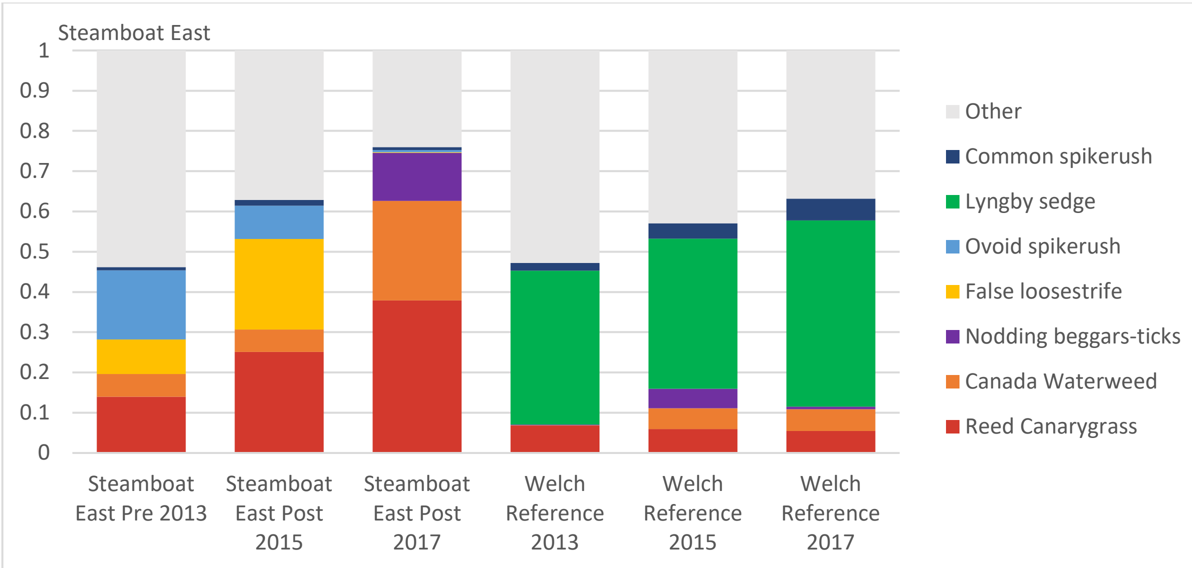
SBW = Steamboat Slough West
SBE = Steamboat Slough East
WI = Welch Island reference site

Vegetation Composition

At Steamboat east species richness and species diversity decreased from pre-restoration to post-restoration year one but increased post-restoration year three (Table 16). In 2017 non-native reed canarygrass and native Canada waterweed (*Elodea canadensis*) comprised the largest proportion of vegetation at 38% and 25% respectively and represents an increase from pre-restoration (Figure XXX). The Steamboat west site increased in both species richness and species diversity from pre-restoration condition. Invasive field fescue (*Festuca arvernensis*) was the dominant species pre-restoration. Year one post-restoration, due to the lowering of the marsh elevation, the vegetation community began to shift towards a native emergent wetland (Figure XXXX). Year three post-restoration the native plant community continued to be dominated by native wetland plant community with sawbeak sedge (*Carex stipata*), northern water plantain (*Alisma triviale*), and common spikerush (*Eleocharis palustris*) (Figure 9). At the reference site, Lyngby sedge was dominant with cover ranging between 37% to 46% (Figure 9).

Table 16. Species richness and species diversity at Steamboat Slough

Condition	Area	Avg. Marsh Elevation (CRD m)	Overall Species Richness	Overall Species Diversity
Pre-restoration	SBE13	0.7	41	2.74
	SBW13	1.2	13	1.66
Post-restoration 1	SBE15	0.7	27	2.27
	SBW15	1.0	35	2.42
Post-restoration 3	SBE17	0.8	33	2.03
	SBW17	1.0	48	2.84
Reference	WI13	1.6	50	2.65
	WI15	1.6	52	2.68
	WI17	1.6	46	2.35



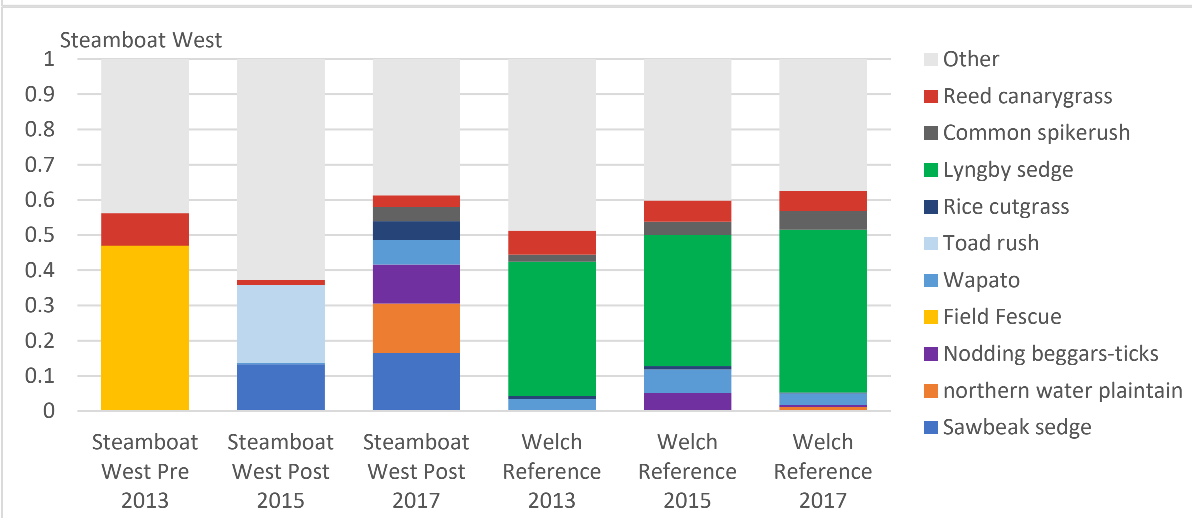


Figure 9. Relative trend vegetation cover and composition for Steamboat Slough and Welch Island Reference site

Dibblee Slough

The Dibblee Slough restoration site has two vegetation sampling areas - a channel site and pond site. The vegetation sampling areas were sampled one year, three years, and five years post-restoration. The channel site was established to capture changes in vegetation related to the widening and lowering of the slough channel. The pond site was established to capture indirect changes to vegetation related to removal of an undersized culvert.

Vegetation Similarity

The Dibblee Slough and reference site were sampled (n=9) one year, three years, and five years post-restoration. Year one post-restoration the vegetation similarity between the two monitoring areas was 40%. Compared to the reference site, the channel site had a 37% similarity and the pond site had a 38% similarity one year post-restoration (Table 17). Five years post-restoration, the pond monitoring site had a 50% vegetation similarity to the reference site, while the channel only had a 37% similarity to the reference site. The vegetation similarity between years at the reference site ranged from 54% to 62% (Table 17).

Table 17. Similarity index for restoration and reference sites for La Center Wetlands. Yellow highlights represent 60-69% similarity.

	DIBP13	DIBR13	DIBCH15	DIBP15	DIBR15	DIBCH17	DIBP17	DIBR17
DIBCH13	0.40	0.37	0.50	0.33	0.30	0.36	0.30	0.26
DIBP13		0.38	0.38	0.52	0.35	0.20	0.37	0.26
DIBR13			0.39	0.44	0.63	0.19	0.36	0.54
DIBCH15				0.48	0.35	0.43	0.27	0.24
DIBP15					0.38	0.21	0.42	0.30
DIBR15						0.16	0.39	0.62
DIBCH17							0.35	0.29
DIBP17								0.50

DIBP = Dibblee Pond
DIBCH = Dibblee Channel
DIBR = Dibblee Reference

Vegetation Composition

Dibblee channel species richness decreased and species diversity increased from post-restoration year one to post-restoration year five (Table 18). Year one post-restoration algae was the most dominant species in the channel monitoring area. Five years post-restoration, native trees like black cottonwood (*Populus balsamifera*) and red alder (*Alnus rubra*) increased in dominance along with non-native Himalayan blackberry (*Rubus armeniacus*) and retop (*Agrostis gigantea*). Non-native reed canarygrass had an average cover of 13% three years post-restoration but was not present five years post-restoration (Figure 10). Dibblee pond species richness and species diversity decreased from post-restoration year one to post-restoration year five (Table 18). At year five post-restoration, native Douglas spiraea increased to 20% of the absolute and native wapato to 28%. Non-native reed canarygrass from year one post-restoration and year five post-restoration remained constant near 10% of the absolute cover. The reference site followed a similar trend as Dibblee pond with a decrease in species richness and a decrese species diversity. However, the amount of reed canarygrass was consistently higher across the sampling period ranging from 15% to 39% of the absolute cover (Figure 10).

Table 18. Average marsh elevation, species richness, and species diversity at Dibblee Slough

Condition	Area	Avg. Marsh Elevation (CRD m)	Overall Species Richness	Overall Species Diversity
Post-restoration 1	DIBCH13	1.9	63	2.35
	DIBP13	1.7	28	2.38
Post-restoration 3	DIBCH15	1.9	53	3.05
	DIBP15	1.5	42	2.88
Post-restoration 5	DIBCH17	1.9	47	2.67
	DIBP17	1.6	23	2.11
Reference	DIBR13	1.5	46	2.50
	DIBR15	1.3	34	2.34
	DIBR17	1.3	30	2.07

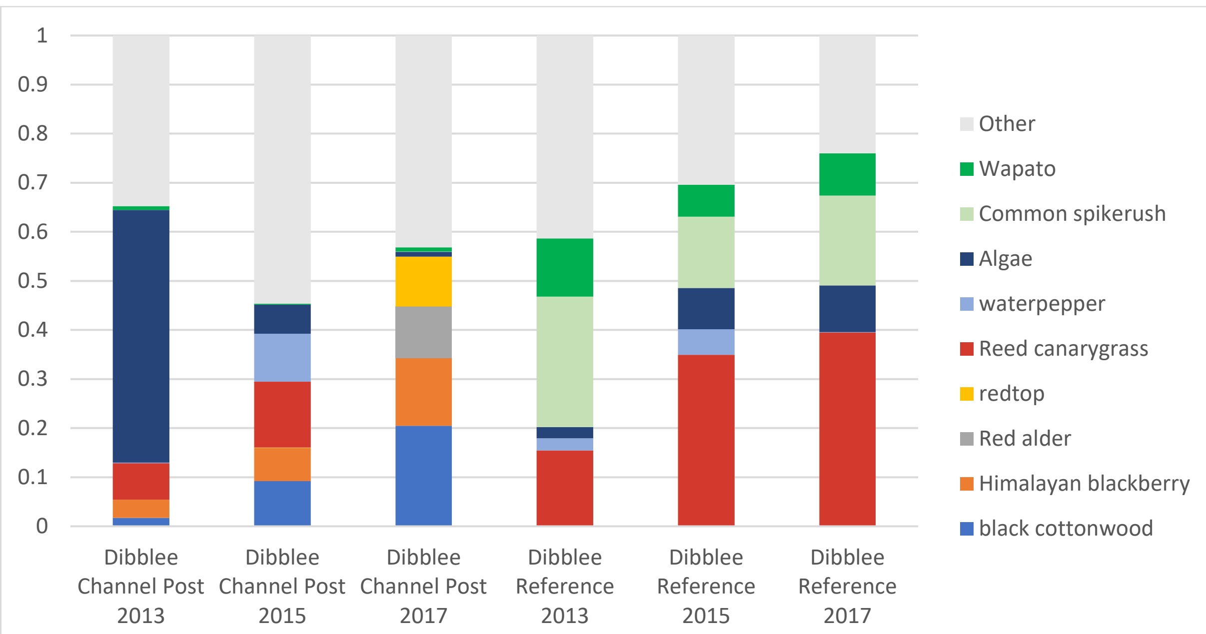


Figure 10. Relative trend vegetation cover and composition for Dibblee Slough and reference site

Sauvie Island North Unit Phase 2 (Millionaire/Deep Widgeon)

The Sauvie Island North Unit Phase 2 restoration consists of two vegetation sampling areas, Millionaire and Deep Widgeon, bisected by Cunningham Slough. The two sites were divided into four sampling areas.

Vegetation Similarity Millionaire

The Millionaire sampling areas are in an area with direct restoration action where marsh lowering occurred (Millionaire North, MILN) and an area where the removal of the water control structure would change the hydrology of an existing wetland (Millionaire South, MILS). Pre-restoration Millionaire North and South had a vegetation similarity of 54%. Post-restoration year one the vegetation similarity between the areas did not change, but three years post restoration the two sites were more similar at 67% (Table 19). When compared to the reference site, pre-restoration both monitoring sites were like the reference site. One year post-restoration only Millionaire South was found to have a high similarity to the reference area. Three years post-restoration neither monitoring are was found to be similarity greater than 54% to the reference area. The reference site had vegetation similarity to itself that ranged from 59% to 80%.

Table 19. Similarity index for restoration and reference sites in vegetation zone one. Yellow highlights represent 60-69% similarity and green represent greater than 70% similarity.

	CL15	CL17	MILN14	MILS14	MILN15	MILS15	MILN17	MILS17
CL14	0.59	0.63	0.63	0.68	0.56	0.50	0.40	0.53
CL15		0.80	0.40	0.60	0.49	0.73	0.45	0.54
CL17			0.44	0.57	0.43	0.60	0.40	0.49
MILN14				0.54	0.54	0.47	0.34	0.48
MILS14					0.48	0.64	0.40	0.64
MILN15						0.53	0.40	0.52
MILS15							0.39	0.54
MILN17								0.67

DWN = Deep Widgeon North
DWS = Deep Widgeon South
MILN = Millionaire North
MILS = Millionaire South
FEN = Flight's End North
FES = Flight's End South
FEW = Flight's End West
CL = Cunningham Lake

Vegetation Composition Millionaire

At both Millionaire North and South sampling areas species richness was lower or the same as pre-restoration condition. Species diversity decreased at both sampling sites since pre-restoration (Table 20). Reed canarygrass increased to 90% of the observed cover for the North area and 70% of the observed cover for the South area three years post-restoration. The same trend was not observed at the reference site where reed canarygrass cover was similar to previous sampling years. At the south sampling area native wapato and rice cutgrass (*Leersia oryzoides*) had a similar cover to values observed one year post-restoration (Figure 11). At the reference site, wapato and common spikerush followed a similar trend in vegetation composition over the same sampling period (Figure 11).

Table 20. Species richness and species diversity at Sandy River Delta and reference

Condition	Area	Avg. Marsh Elevation (CRD m)	Overall Species Richness	Overall Species Diversity
Pre-restoration	MILN14	1.6	10	1.544
	MILS14	1.5	20	2.054
Post-restoration 1	MILN15	1.6	35	1.984
	MILS15	1.6	29	1.897
Post-restoration 3	MILN17	1.2	10	0.503
	MILS17	1.1	15	1.166
Reference	CL14	1.2	16	1.967
	CL15	1.5	24	1.696
	CL17	1.5	20	1.887

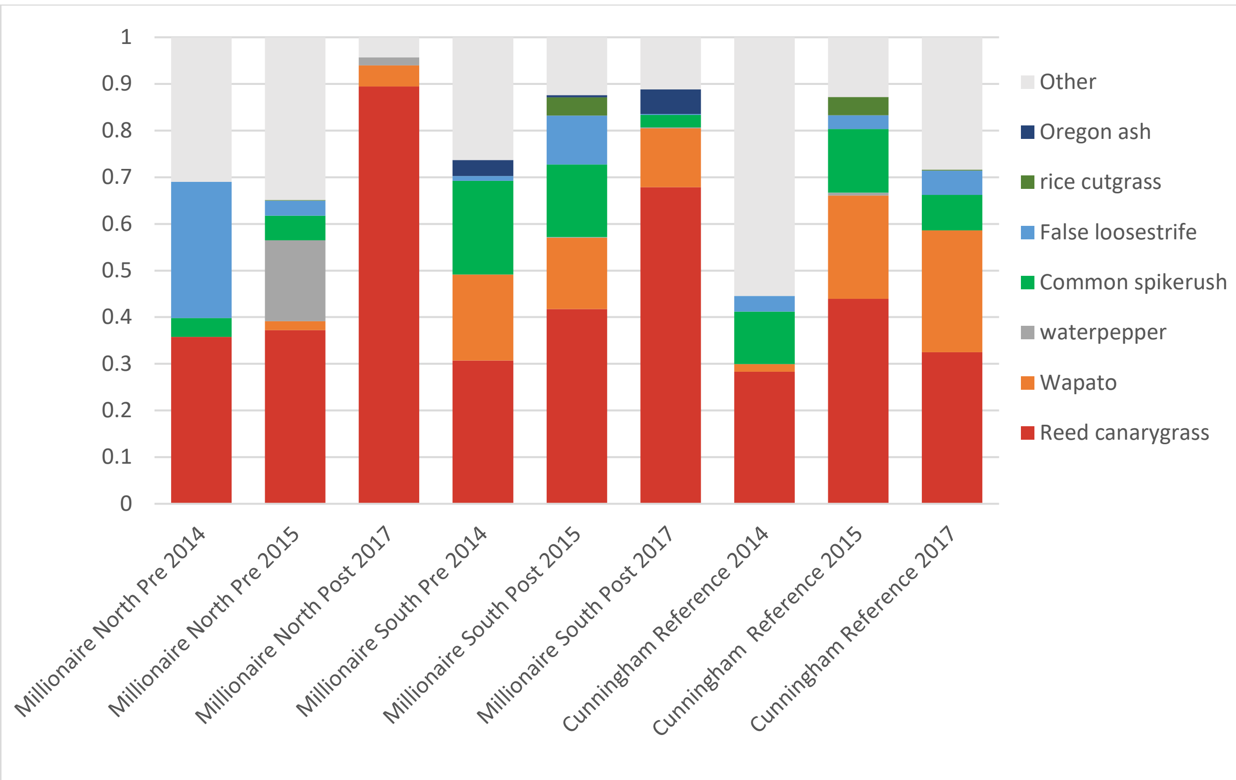


Figure 11. Relative trend vegetation cover and composition for Millionaire and reference site

Vegetation Similarity Deep Widgeon

Sampling at Deep Widgeon occurred in an area with direct restoration action of marsh lowering (Deep Widgeon North, DWN) and an area where the removal of the water control structure changed the hydrology of an existing wetland (Deep Widgeon South, DWS). Pre-restoration Deep Widgeon North and South had a vegetation similarity of 60%. Post-restoration year one the vegetation similarity between the areas decreased. Three years post restoration the two sites increased in vegetation similarity to 53% (Table 22). When compared to the reference site, pre-restoration both monitoring sites were dissimilar to the reference site. One year post-restoration only Deep Widgeon South a slight increase in similarity to the reference area. Three years post-restoration neither monitoring area was found to be similarity greater than 55% to the reference area. The reference site had vegetation similarity to itself that ranged from 59% to 80%.

Table 21. Similarity index for restoration and reference sites in vegetation zone one. Yellow highlights represent 60-69% similarity and green represent greater than 70% similarity.

	CL15	CL17	DWN14	DWS14	DWN15	DWS15	DWN17	DWS17
CL14	0.59	0.63	0.44	0.57	0.45	0.42	0.46	0.44
CL15		0.80	0.31	0.52	0.24	0.53	0.39	0.58
CL17			0.29	0.47	0.24	0.46	0.38	0.55
DWN14				0.60	0.43	0.63	0.65	0.64
DWS14					0.39	0.63	0.64	0.68
DWN15						0.29	0.46	0.33
DWS15							0.46	0.77
DWN17								0.53

DWN = Deep Widgeon North
DWS = Deep Widgeon South
CL = Cunningham Lake

Vegetation Composition Deep Widgeon

At the Deep Widgeon North sampling area, species richness and species diversity were higher three years post restoration. Pre-restoration non-native reed canarygrass and alage were the dominant vegetation species at the site but decreased in cover one year post-restoration. Native slender hairgrass (*Deschampsia cespitosa*) and canada waterweed were prominent with a decrease in non-native species. Three years post-restoration reedcanary grass cover and alage cover increased while slender hairgrass was not observed. Deep Widgeon South species richness and species diversity decreased for pre-restoration to year three post-restoration. Pre-restoration Deep Widgeon South was dominated by reed canarygrass, wapato, and algae. At one year post-restoration, reed canarygrass covered increased to 83% of cover of the site, but decreased to 67% of the total cover three years post-restoration. Wapato cover remained at 9% from year one to year three post restoration (Figure 12).

Table 22. Average marsh elevation, species richness, and species diversity at Deep Wigeon

Condition	Area	Avg. Marsh Elevation (CRD m)	Overall Species Richness	Overall Species Diversity
Pre-restoration	DWN14	1.96	6	0.53
	DWS14	1.65	12	1.35
Post-restoration 1	DWN15	1.86	28	2.05
	DWS15	1.66	10	0.66
Post-restoration 3	DWN17	1.49	17	1.34
	DWS17	1.28	6	0.80
Reference	CL14	1.24	16	1.97
	CL15	1.47	24	1.70
	CL17	1.49	20	1.89

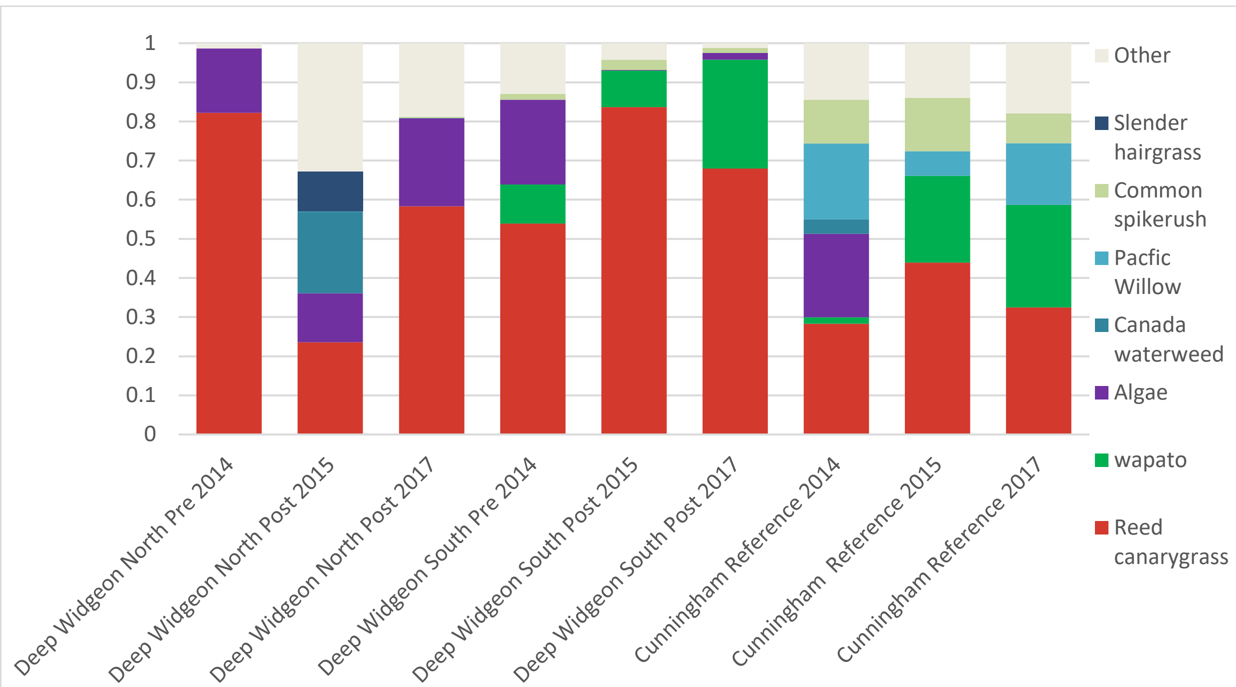


Figure 12. Relative trend vegetation cover and composition for Deep Widgeon and reference site

Sauvie Island North Flight's End

Vegetation Similarity

Sampling at Flight's End occurred in three areas. Flight's End North and West were selected to track the impact of tidal reconnection and lowering of the marsh elevation to promote native wet prairie grass communities. The Flight's End South sampling area was chosen to quantify to track changes related to tidal reconnection on the existing wetlands post-restoration. Flight's End North and West had the highest wetland similarity at 65%. Flight's End South had a similarity to the North and West site that ranged between 51 to 55%. The pre-restoration monitoring areas at Flight's End had less than 43% similarity when compared to the reference wetland (Table 23).

Table 23. Similarity index for restoration and reference sites in vegetation zone one. Yellow highlights represent 60-69% similarity and green represent greater than 70% similarity.

	FEN17	FES17	FEW17
CL17	0.32	0.33	0.43
FEN17		0.55	0.65
FES17			0.51

FEN = Flight's End North
FES = Flight's End South
FEW = Flight's End West
CL = Cunningham Lake

Vegetation Composition

At Flight's End pre-restoration in the North and South sampling area, species richness and species diversity were higher than the reference site. Flight's End West had similar species richness and higher species diversity than the reference site. The North sampling area was dominated by native water smartweek (*Polygonum amphibium*), reed (*Junucs* sp.), and non-native barnyardgrass (*Echinochloa crus-galli*). The South sampling area was dominated by native nutsedge (*Ludwigia palustris*) and non-native Canada bluegrass (*Poa compressa*). The West sampling area was dominated by native wapato, but non-native reed canarygrass present (Figure 13).

Table 24. Average marsh elevation, species richness, and species diversity at Flight's End

Condition	Area	Avg. Marsh Elevation (CRD m)	Overall Species Richness	Overall Species Diversity
Pre-restoration	FEN17	2.04	29	2.53
	FES17	1.46	31	2.314
	FEW17	2.13	20	2.11
Reference	CL17	1.49	20	1.887

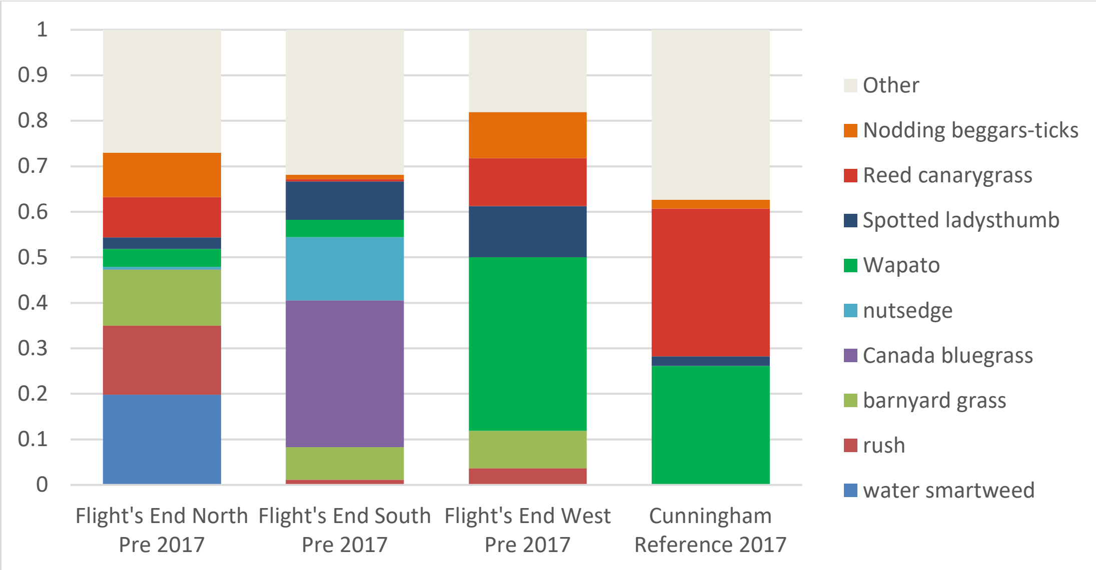


Figure 13. Relative trend vegetation cover and composition for Flight's End and reference site

Vegetation Synthesis 2012-2017

For the sites included in the vegetation synthesis analysis, relative native cover post-restoration was within 25% of reference conditions for Dibblee Slough, North Unit Ruby Lake, Steamboat Slough, and Sandy River Dam (Figure 14 & 15, Table 25), however relative non-native cover did appear to be increasing at the Sandy River Dam site between years 1 and 3 post restoration (Table 26). Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire did not show a trend towards increasing native cover similar to reference conditions (Figure 14 & 15, Table 25) and these sites also showed an increase in non-native cover between years 1 and 3 post-restoration (Table 28). At reference sites for all years, relative native species cover was between 63 and 94% (Table 25) and non-native relative cover ranged between 4 and 39 % among the sites (Table 26).

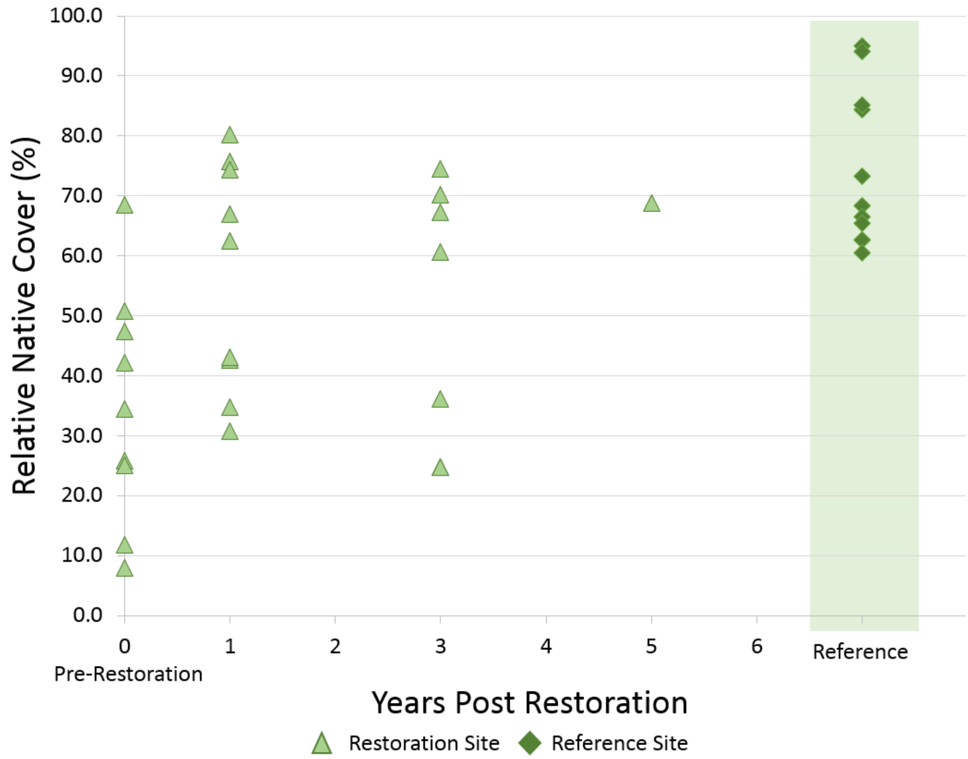


Figure 14. Relative native cover for all sites pre-restoration, post-restoration, and reference.

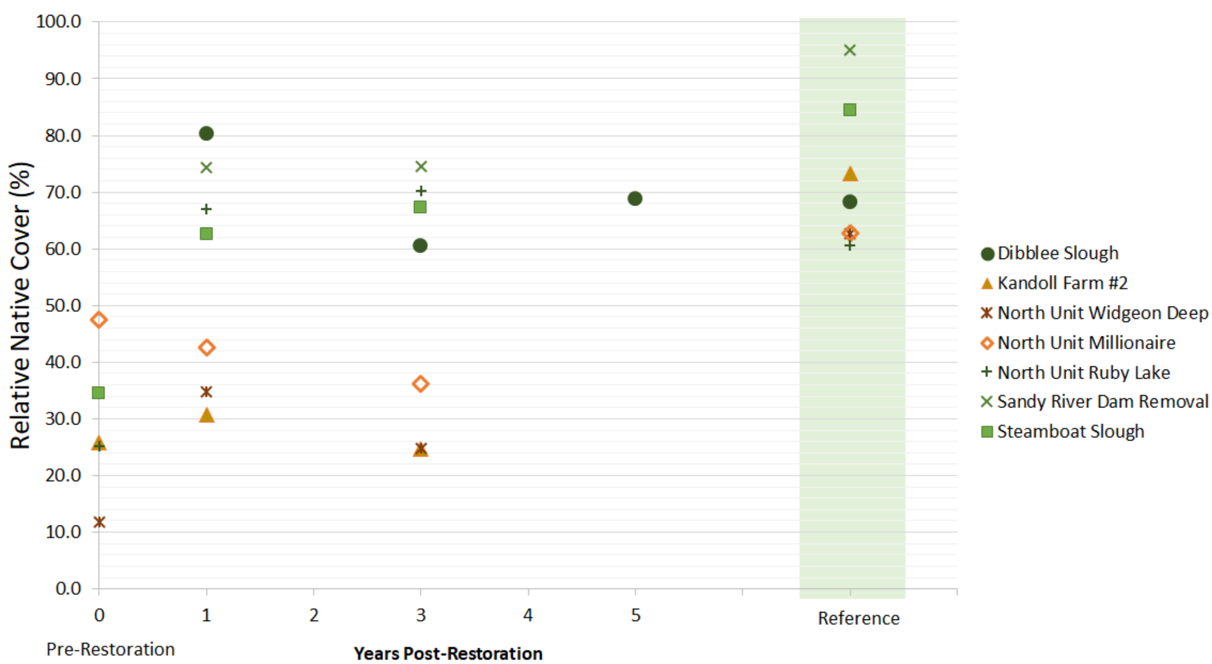


Figure 15. Relative native cover for pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table 25. Relative native cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress towards reference conditions: green = similar to reference within ±25%, orange = not similar to reference ± 25%.

Native Relative Cover	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	80.3	4	56	60.6	4.5	66	68.8	3.7	101	68.3	3.3
Kandoll Farm #2	72	25.8	3.1	72	30.7	4	60	24.7	4				61	73.3	3
La Center Wetlands	71	68.5	4	71	75.7	4.2							71	65.4	4.6
North Unit Flights End	60	50.7	3.9										69	66.5	3.5
North Unit Millionaire	72	47.5	5	72	42.6	4.4	72	36.2	4.9				174	62.7	2.6
North Unit Ruby Lake	79	25.1	4.1	55	67	5.2	59	70.3	4.3				139	60.5	3.2
North Unit Widgeon/Deep	72	11.9	3.2	72	34.7	4.3	70	24.8	4.3				174	62.7	2.6
Sandy River Dam Removal				56	74.4	4	61	74.4	3.9				49	95	1.2
Steamboat Slough	72	34.4	4.8	63	62.6	3.8	68	67.3	4.2				186	84.4	1.6
Wallacut River	72	42.2	3	72	43	3.5							83	85.1	2.1
Wallooskee River	68	8	2.6										36	94.1	2.3

Table 26. Non-native relative cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress towards reference conditions: green = similar to reference within ±25%, light orange = < ± 25% difference but not trending towards reference, orange = > ± 25% difference and not trending towards reference.

Non-native Relative Cover (%)	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	15.7	3.6	56	37.3	4.4	66	12	2.8	101	27.1	3.4
Kandoll Farm #2	72	74.1	3.1	72	69.1	4	60	75.3	4				61	25.3	3
LaCenter Wetlands	71	28.5	3.9	71	24.3	4.2							71	32.5	4.6
North Unit Flights End	60	41.2	3.7										69	32.5	3.4
North Unit Millionaire	72	52.5	5	72	55.6	4.6	72	61.4	5				174	36.9	2.6
North Unit Ruby Lake	79	74.8	4.2	55	32.7	5.2	59	24.1	3.9				139	38.9	3.2
North Unit Widgeon Deep	72	87.7	3.1	72	63.5	4.4	70	65.8	4.6				174	36.9	2.6
Sandy River Dam Removal				56	12.5	2.7	61	23.7	3.7				49	4.2	1.2
Steamboat Slough	72	63.7	5	63	37.4	3.8	68	30.5	4.3				186	14	1.6
Wallacut River	72	54.9	3.2	72	56.8	3.5							83	5.5	1.4
Wallooskee River	68	82.6	2.9										36	5.9	2.3

Generally, native species richness increased following restoration (Figure 16 and 17). Conversely, non-native species richness decreased as the number of years post-restoration increased (Table 27 and 28). Native species richness post-restoration was within ±1 species richness of reference conditions for Dibblee Slough, North Unit Ruby Lake, and Sandy River Dam (Figure 16 and 17, Table 27). Steamboat slough did not reach the ±1 native species richness threshold by year three post restoration but did show a strong trend of increasing native species richness between pre-restoration and three-year post-restoration conditions (Figure 17, Table 27). Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire did not show a strong trend towards increasing native species richness (Figure 17, Table 27), however, these sites did show a trend of decreasing non-native species richness between years one and three post-restoration (Table 28). The Sandy River Dam site was the only restoration site which showed an increase in non-native species richness post-restoration (Table 28). Across all reference sites for all years, mean native species richness ranged between 2.7 and 8.4 (Table 27) and non-native species richness ranged between 0.9 and 2.2.

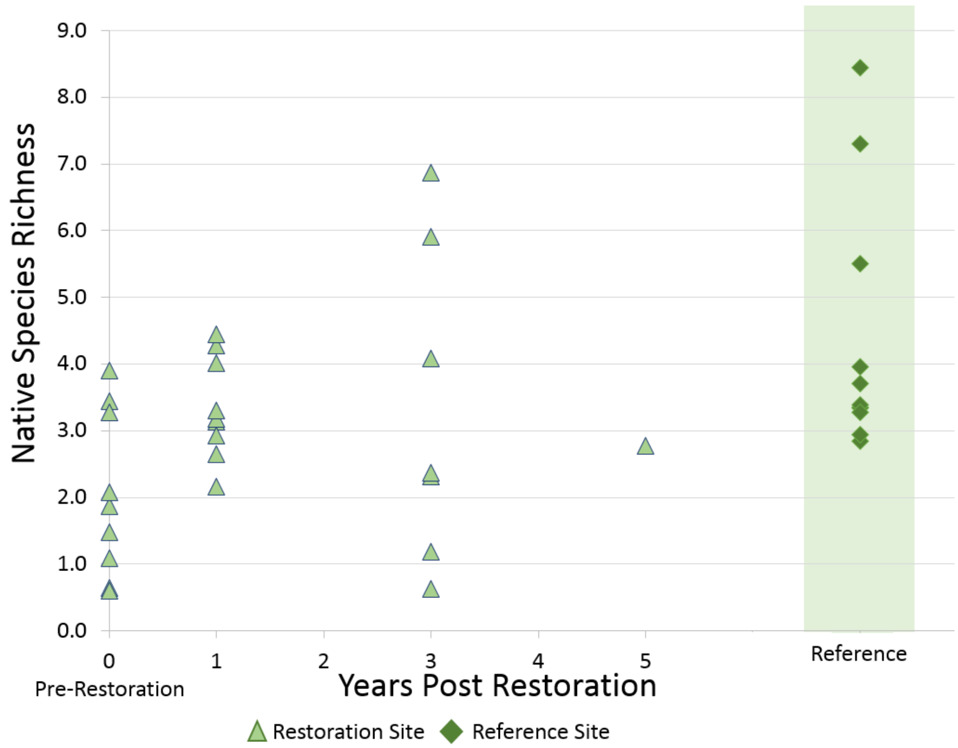


Figure 16. Native species richness for all pre-restoration, post-restoration, and reference sites.

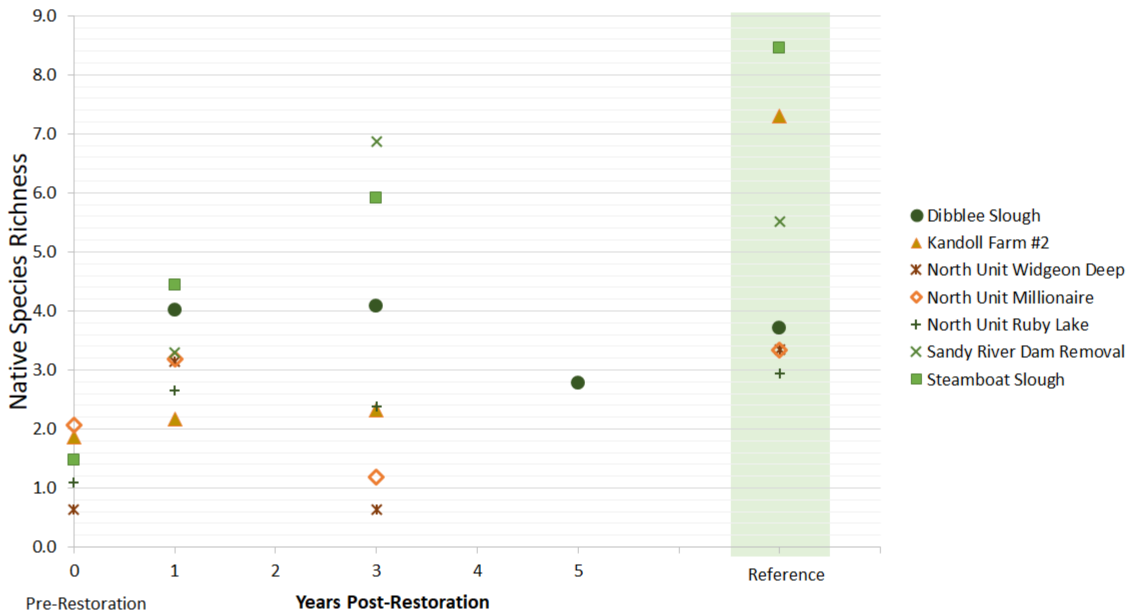


Figure 17. Native species richness for pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table 27. Native species richness for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress towards reference conditions: green = similar to reference within ±1, light green = > ±1difference but trending towards reference, yellow = > ±1difference and not trending towards reference.

				Years Post-Restoration											
Native Species Richness	Pre-Restoration			1			3			5			Reference		
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	4	0.3	56	4.1	0.3	66	2.8	0.2	101	3.7	0.2
Kandoll Farm #2	72	1.9	0.1	72	2.2	0.2	60	2.3	0.3				61	7.3	0.4
LaCenter Wetlands	71	3.4	0.2	71	4.3	0.3							71	2.8	0.2
North Unit Flights End	60	3.9	0.3										69	4	0.2
North Unit Millionaire	72	2.1	0.2	72	3.2	0.3	72	1.2	0.2				174	3.3	0.1
North Unit Ruby Lake	79	1.1	0.1	55	2.7	0.3	59	2.4	0.2				139	2.9	0.2
North Unit Widgeon Deep	72	0.6	0.1	72	3.1	0.4	70	0.6	0.1				174	3.3	0.1
Sandy River Dam Removal				56	3.3	0.3	61	6.9	0.5				49	5.5	0.4
Steamboat Slough	72	1.5	0.2	63	4.4	0.3	68	5.9	0.4				186	8.4	0.2
Wallacut River	72	3.3	0.2	72	2.9	0.2							83	3.4	0.3
Wallooskee River	68	0.6	0.2										36	3.3	0.3

Table 28. Non-native species richness for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress towards reference conditions: green = similar to reference within ±1, yellow = > ±1 difference and not trending towards reference.

Non-native Species Richness	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	0.8	0.1	56	2.4	0.2	66	0.8	0.1	101	1.2	0.1
Kandoll Farm #2	72	2.5	0.2	72	2.3	0.2	60	2	0.2				61	2.2	0.1
LaCenter Wetlands	71	1.9	0.1	71	0.8	0.1							71	0.7	0.1
North Unit Flights End	60	3.1	0.2										69	1.1	0.1
North Unit Millionaire	72	1.2	0.1	72	1.7	0.1	72	0.9	0.1				174	1	0
North Unit Ruby Lake	79	1.1	0.1	55	1	0.1	59	0.7	0.1				139	1	0.1
North Unit Widgeon Deep	72	1	0	72	2.6	0.2	70	0.9	0				174	1	0
Sandy River Dam Removal				56	1.1	0.2	61	2	0.2				49	0.9	0.1
Steamboat Slough	72	3.2	0.3	63	2	0.1	68	2	0.2				186	1.7	0.1
Wallacut River	72	2.3	0.1	72	2.1	0.1							83	0.4	0.1
Wallooskee River	68	3.7	0.2										36	0.7	0.2

Reed canarygrass (RCG) relative cover followed a similar trend to the overall non-native relative cover for most sites (Figure 18, Table 26 and Table 29), reaching within ± 25% of reference conditions at Dibble Slough, North Unit Ruby Lake, Sandy River Dam, and Steamboat Slough three to five years post-restoration. While Sandy River Dam and Steamboat Slough achieved RCG levels within the reference range they exhibit a trend towards an increase in mean RCG cover between years one and three post-restoration (Figure 19, Table 29). Kandoll Farm #2, North Unit Widgeon Deep, and North Unit Millionaire did not achieve levels of RCG cover within the reference range and all site show an increase in mean RCG between years one and three post-restoration (Figure 19, Table 29). Pre-restoration relative RCG cover ranged between 11 and 87%.

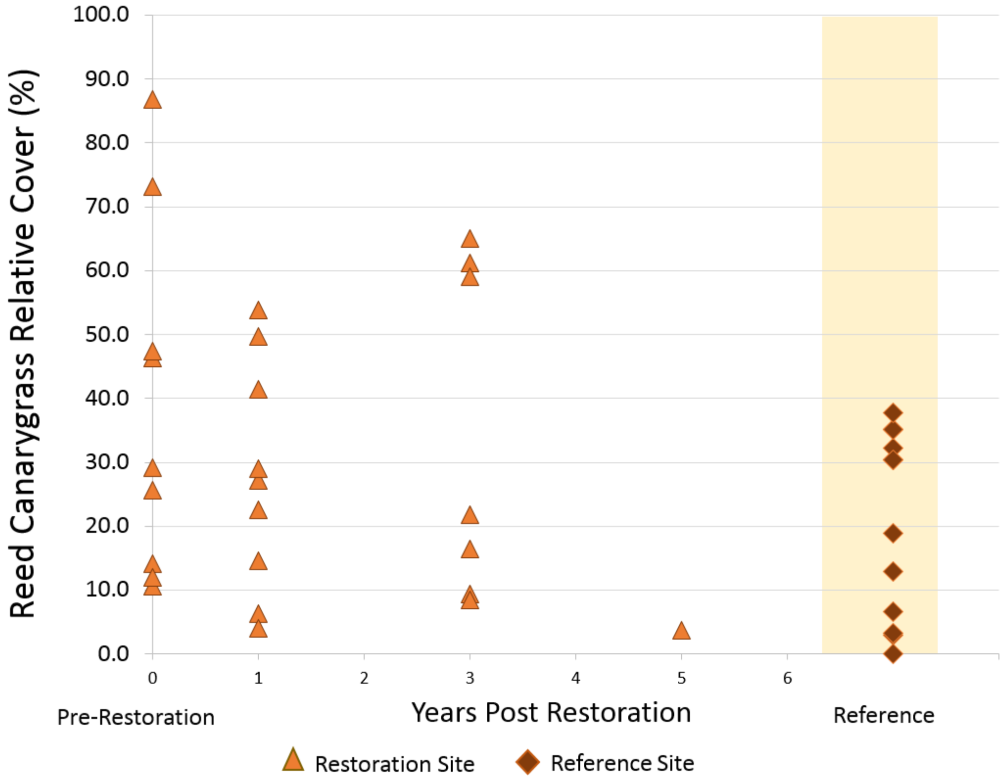


Figure 18. Reed canarygrass cover at pre-restoration, post-restoration, and reference sites

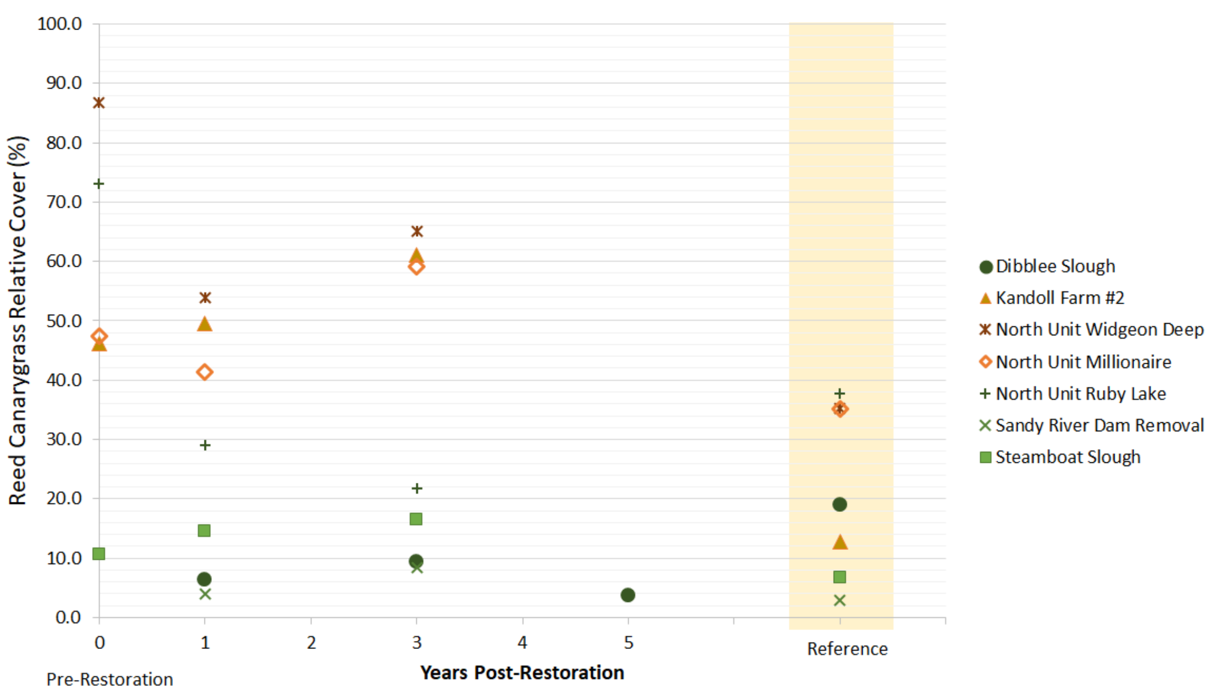


Figure 19. Reed canarygrass relative cover at pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table 29. Reed canarygrass relative cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress towards reference conditions: green = similar to reference within ±25%, yellow = < ± 25% difference but not trending towards reference, orange = > ± 25% difference and not trending towards reference.

Reed Canarygrass Relative Cover (%)	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	6.3	2.5	56	9.3	2.6	66	3.7	2	101	19	3.1
Kandoll Farm #2	72	46.3	4.8	72	49.6	4.8	60	61.2	5.1				89	12.9	2.3
LaCenter Wetlands	71	14.2	3.5	71	22.6	4.2							71	32.3	4.6
North Unit Widgeon Deep	72	86.8	3.3	72	53.9	5.3	70	65.1	4.6				174	35.2	2.6
North Unit Flights End	60	12	2.7										69	30.3	3.5
North Unit Millionaire	72	47.5	5.1	72	41.4	4.7	72	59.1	5.1				174	35.2	2.6
North Unit Ruby Lake	79	73.1	4.4	55	29	5.3	59	21.8	3.9				139	37.7	3.3
Sandy River Dam Removal				56	4	1.3	61	8.5	2.6				49	2.9	1.1
Steamboat Slough	72	10.6	3.2	63	14.6	3.1	68	16.5	4.1				186	6.7	1.5
Wallacut River	72	25.7	4.1	72	27.2	4.7							83	0	0
Wallooskee River	68	29.2	4.1										36	3.2	1.5

There were significant relationships between various vegetation metrics. Relative percent cover of native plants was significantly ($p < 0.000$) positively correlated to the species richness of native plants (Figure 20). Similarly, relative percent cover of *non-native* plants was significantly ($p < 0.000$) negatively correlated to the species richness of native plants (Figure 21).

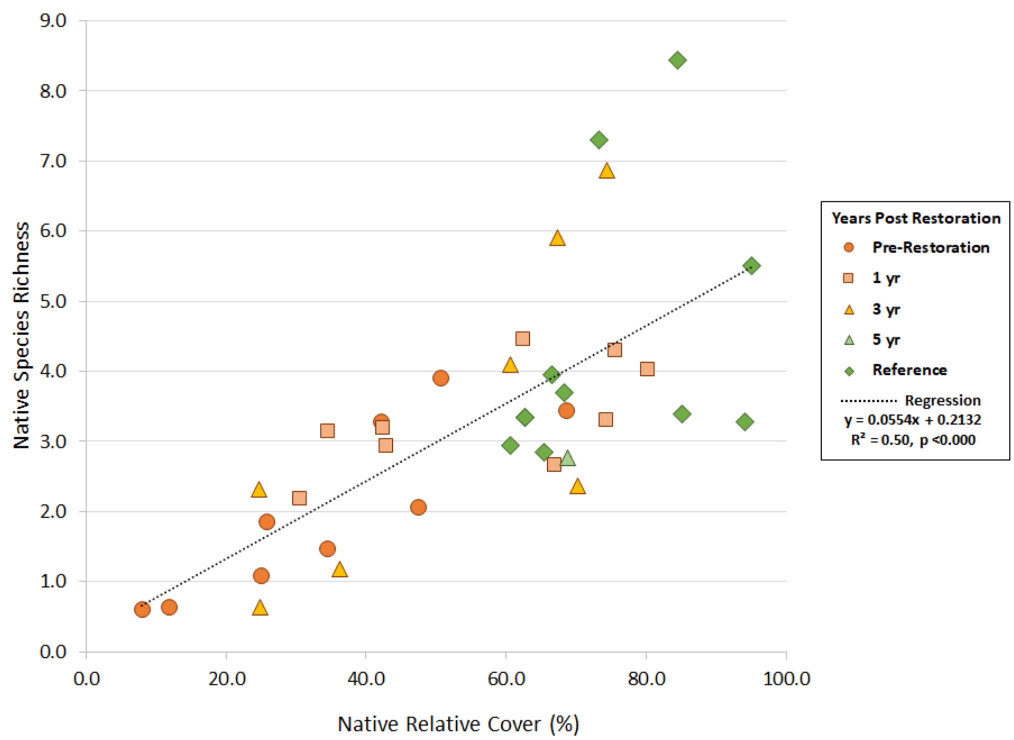


Figure 20. Restoration and reference sites mean native species richness vs. native relative cover.

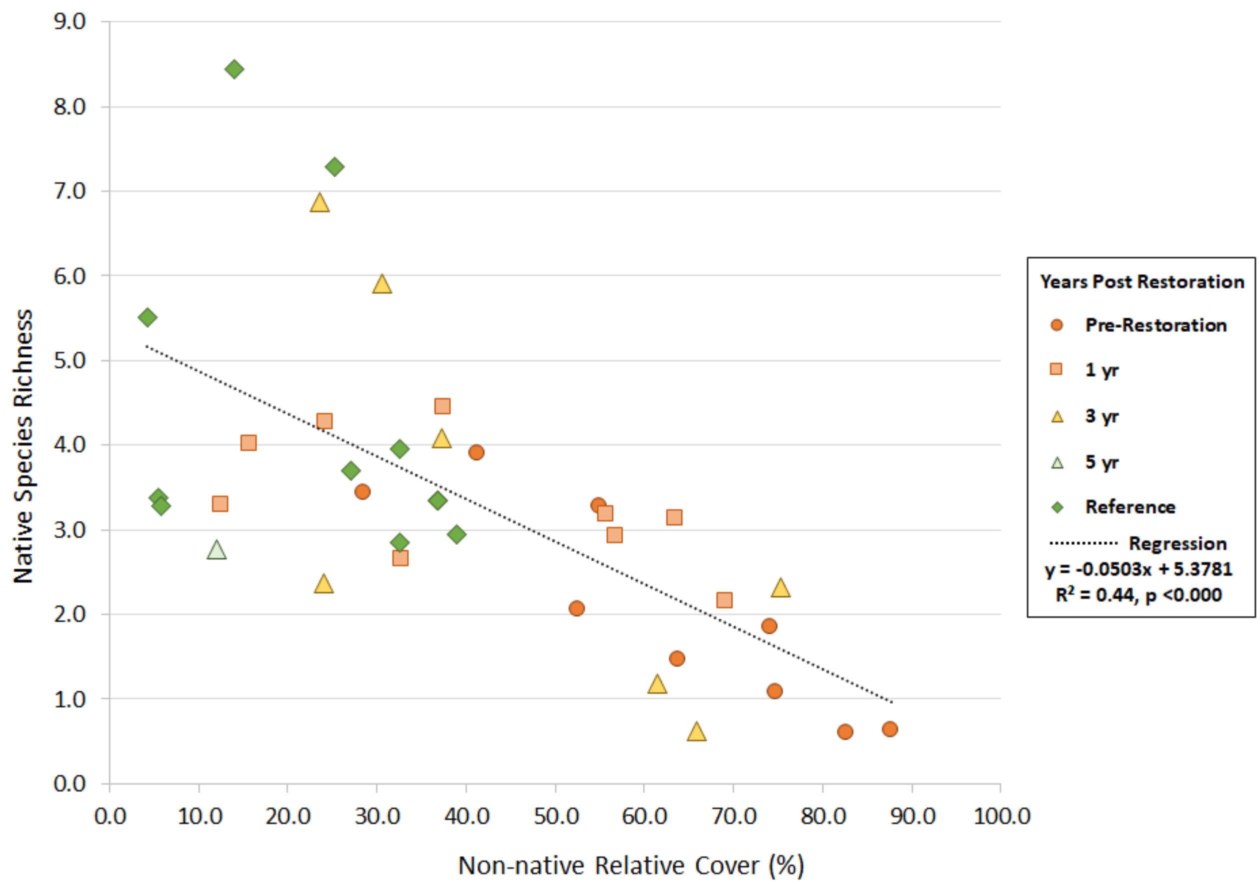


Figure 21. Restoration and reference sites mean native species richness vs. non-native relative cover.

Relative percent cover of non-native plants was significantly positively correlated to non-native species richness (P < 0.02) (Figure 22). Relative percent cover of native plants was negatively related to species richness on non-native plants (p < 0.002) (Figure 23).

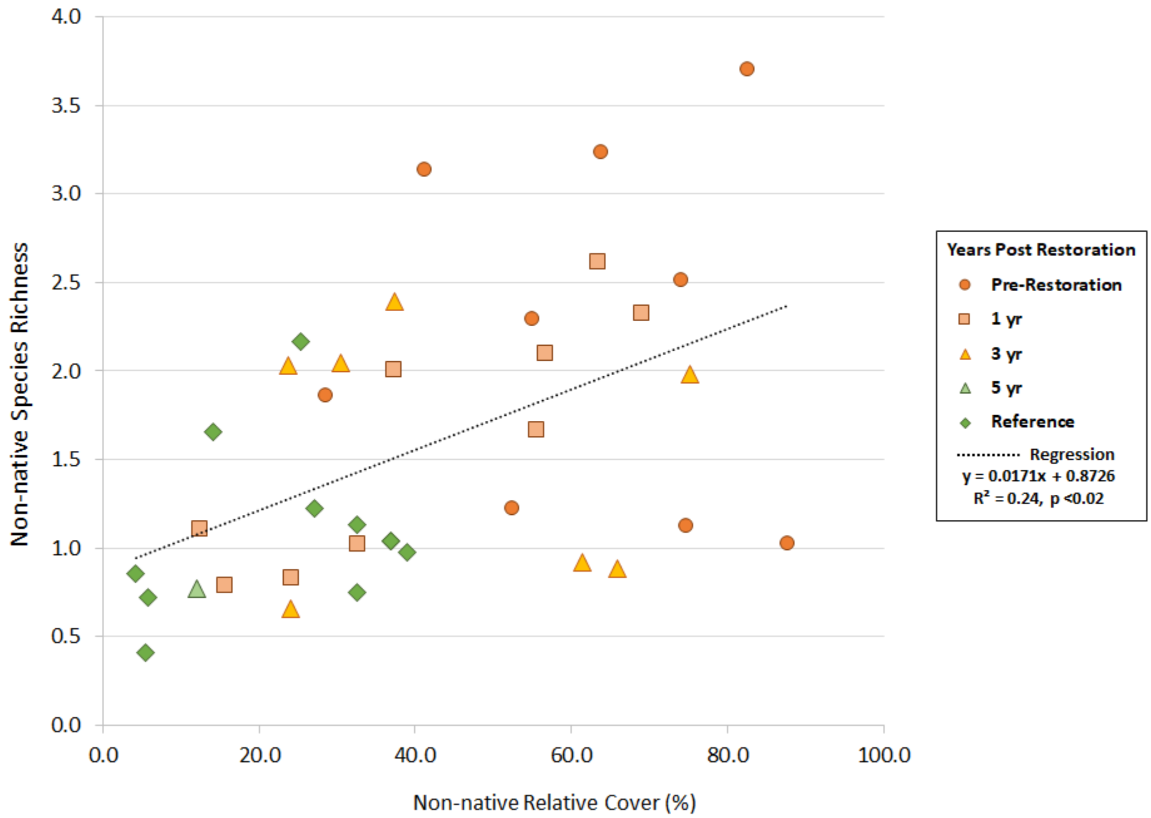


Figure 22. Restoration and reference sites mean non-native species richness vs. non-native relative cover.

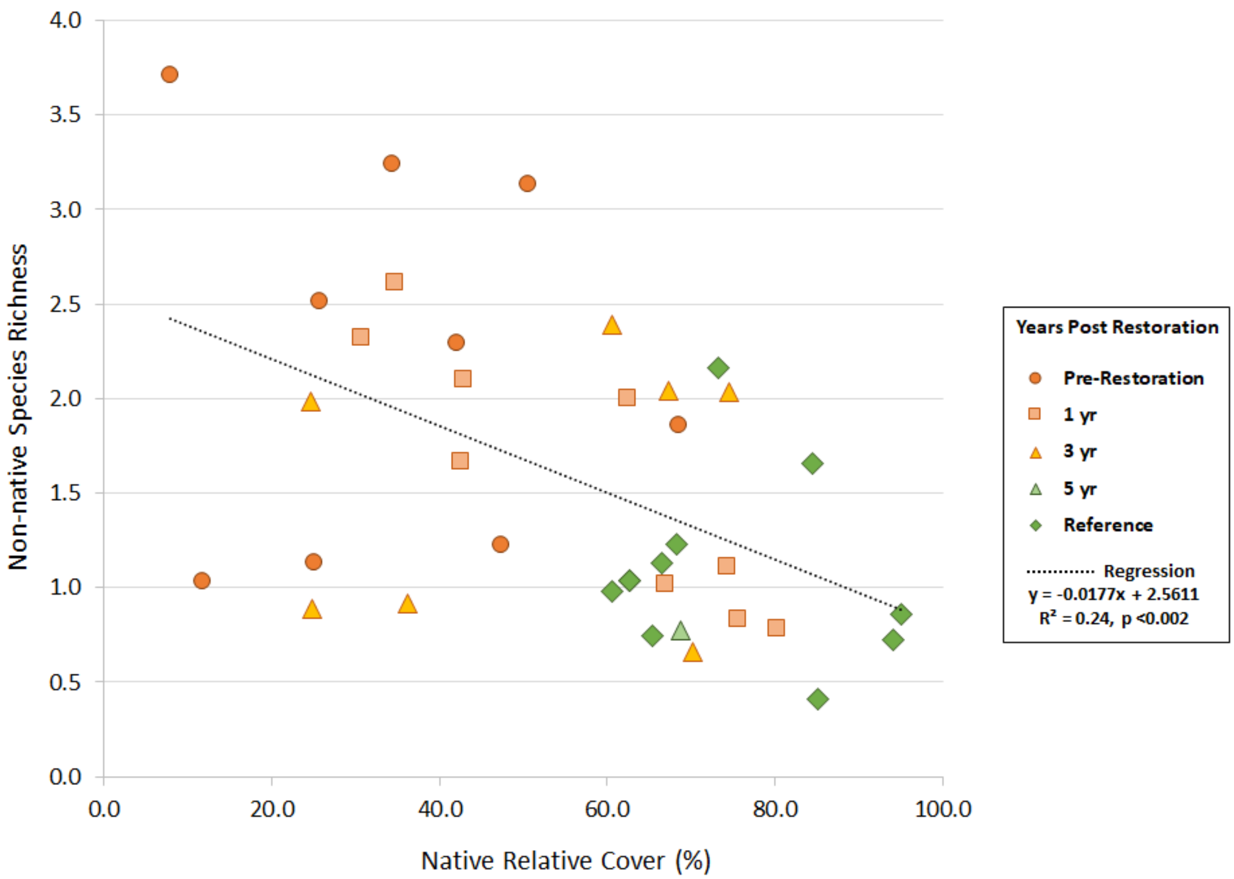


Figure 23. Restoration and reference sites mean non-native species richness vs. native relative cover.

Fish Detection and Passage

The Horsetail Creek PIT detection array was operational from February 25–November 30, 2017. Although not all 10 antennas were operating, we had coverage of two antennas on the downstream side and three antennas on the upstream side of the culvert.

Twenty-nine individual fish were detected from May 7–November 26. Thirty-eight percent of fish detected were juvenile fall Chinook. The second most prevalent category was juvenile steelhead at 24%. Juvenile spring Chinook and adult Coho salmon represented 14 and 7 % of detections, respectively. One northern pikeminnow and four unknown (no tag data in the regional database; www.ptagis.org) fish were also detected. Residence times provided are a measure of elapsed time from first to last overall detection. We have not yet analyzed the data to determine whether a fish passed through the culvert and how much time was spent on the upstream side in the restoration area. Most fall Chinook originated from hatcheries in the Bonneville Pool, however, one was Snake River stock. The majority of steelhead and spring Chinook were also from Snake River populations (Table 30).

Table 30. Number and residence time (max and median) of fish detected at Horsetail Creek PIT array in 2017. Residence time is a measure of elapsed time from first to last overall detection, not a measure of

time spent upstream of the array. Numbers in parentheses represent the number of known wild origin fish in the total.

		Residence time	
	N	Max	Median
Fall Chinook	11 (1)	2.5 h	33 m
Spring Chinook	4 (1)	1 h	12 m
Steelhead	7 (4)	24.5 d	47 m
Coho (adult)	2	20.5 h	11 h
Northern Pikeminnow	1	21 d	
Unknown	4	38 m	14 m

Discussion

Water-Surface Elevation

Water surface elevation is a proxy for hydrology for a site. WSE together of with marsh elevations are the strongest predictors of fish access and vegetation communities likely to develop at a site. The 2-year flood elevation is a good measure of project wetted area and should be monitored to ensure if that design criteria is achieved; however, it is not necessarily the best indicator for measuring the impact of restoration actions to out migrating juvenile salmonids potentially using a site. Of all the restoration sites that achieve the 2-flood elevation, most did so between October and March. Only one site achieved the 2-year flood elevation between April and June. Pairing post-restoration WSE data with main stem data as a reference, show all sites achieving a similar hydrology. This indicates an important physical process was established which is a critical step to achieving a reference ecological state.

Water Temperature

Water temperature is an important environmental factor that can impact if a site is suitable for juvenile salmonids. It is important to monitor temperatures to ensure restoration sites can be inhabited by juvenile salmonids when water levels are high enough to access the channel and floodplain. However, water temperature is strongly influenced by climatic conditions and a hydrologically connected tidal wetland will be strongly influenced by the main stem Columbia River temperatures. Unless a site has a sizable cold water input, achieving a cooler water temperature post-restoration is not feasible objective.

Habitat Opportunity

A restored hydrology is an immediate impact of all tidal reconnection projects. Additionally, water temperatures that support juvenile salmonids during critical life stages is a key restoration project objective. Pairing WSE and water temperature together to creates a more meaningful a measure of habitat opportunity than looked at separately. Furthermore, pre- and post-restoration conditions to compared to measure increase in habitat opportunity and resolves issues related to the variability water years. In all instances restoration sites showed increases in habitat opportunity during periods of time when upstream out migrating juvenile salmonids could be potentially be at restoration sites.

Sediment Accretion

A positive sediment accretion rate is expected due to subsidence of most previously dike restoration sites. Annual sediment accretion rates are small and a longer monitoring period is needed to determine a trend at sites. In the future, more sediment accretion stakes should be installed at sites across the elevation their gradient to better quantify where sediment loss and gain is occurring. Sediment accretion monitoring is important to track to know the resilience of restored wetlands given shifting climate conditions.

Channel Cross Sections

Channel cross sections can provide important information regarding the amount of hydraulic exchange a site can have with the adjacent main stem waterbody. There does not appear to be a trend in the change to channel cross section volume related to the number of years post-restoration. A general trend in change in channel volume and channel order did emerge. Smaller channels higher in the wetland tend to accumulate sediment while channels lower in the wetland tend to lose sediment across time. A longer dataset is needed to determine if this trend continues or a sediment equilibrium is achieved. Although higher order channels are losing cross section area, it is not known if the upper ends of these channels are growing. Tracking channel growth would complement channel cross section data.

Vegetation

Plant communities showed clear trends towards native relative cover reference conditions at Dibblee Slough, North Unit Ruby Lake, Steamboat Slough, and Sandy River Dam, while trends towards reference conditions were not observed at Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire. Reed canarygrass levels, however, showed trends of increasing over the one to three-year post-restoration monitoring period for all sites except Dibblee Slough and Steamboat Slough, which showed trends od decreasing RCG cover. Further monitoring is required to identify if these trends continue and require sites to undergo adaptive management to control non-native plant community abundance. Future monitoring and evaluation should focus on comparing restored and reference wetland hydrologic zones to help identify areas requiring adaptive management.

In 2017 distinct vegetation zones were evident based on the collected vegetation data. The presence of distinct emergent marsh vegetation zones provides a method to examine how restoration sites and reference sites at a larger ecosystem scale compare given inherent inter-annual variability. Vegetation was moderately negatively correlated to average marsh elevation, species richness, species diversity, and bare ground. Increasing marsh elevation was associated with decreasing bare ground. Species richness was lowest at pre-restoration sites and highest at year three post-restoration sites, but species diversity decreased from year one post-restoration. This likely a result of the vegetation community approaching a new stable ecological state where a few vegetation species are dominant and other species are present depending on inter-annual variability of the site hydrology.

Juvenile Salmonids

The PIT array at Horsetail Creek continued to detect upstream salmonid species. Hatchery Spring, Fall, and Summer Chinook visited the site between April and June. Hatchery Coho, steelhead, summer sockeye was also detected at the site. All detections at the site showed the fish occupied the area for less than one day. Northern Pike Minnow were detected at the site in May.

Conclusion

The establishment of functional wetland processes and habitat that support juvenile salmonids is the goal of restoration efforts. Action effectiveness monitoring is tracking the ecological impact of restoration work and providing valuable information to adaptively manage restoration sites. Furthermore, AEM shows the rate at which physical processes and habitats recover after restoration activities varies. For example, physical processes like water surface elevation, water temperature, and habitat opportunity change immediately after the wetland is reconnected and have shown a positive trend when compared to pre-restoration or reference conditions over a short period of time. Although physical processes change quickly, other aspects of the wetland recover more slowly. Changes in vegetation community, sediment accretion, and channel formation occur over a longer time scale which makes it difficult to assess trends over the short term. It will be necessary to monitor these attributes over a longer period to determine the predominant trend. Limited fish monitoring shows juvenile salmonids are present in restoration sites after tidal reconnection, but 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. 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.

Adaptive Management & Lessons Learned

At the site-scale, based on AEM data from 23 projects, restoration actions seem to be having the desired physical and biological effects beginning the reestablishment of natural physical processes which in turn creates habitat conditions that directly and indirectly support salmonids. The extent of the water surface elevation (WSE) response depends on the level of reconnection, river level, and numerous climatic and environmental variables. It is clear WSE responds immediately to hydrologic reconnection and is the necessary first step to establishing ecological processes. Water temperatures at the restoration sites included in this analysis generally were warmer than nearby main stem waters but were also generally suitable during the spring and early summer juvenile outmigration periods. It is expected that restoration sites would have higher temperatures than the main stem because of their shallower water depths. When WSE and water temperature are examined together, it is possible to determine habitat opportunity for salmonids. Following restoration, all sites had water levels and water temperature conducive to support juvenile salmonids during the outmigration period. Combining these two metrics shows that project sites are available to salmonids and provide suitable habitats immediately following restoration.

Other metrics collected post-restoration are beginning to show how restoration of physical processes will have a long-term impact on restoration site function. Sediment accretion rates were usually positive, indicating a rejuvenation of sedimentation processes at the restoration sites, many of which had subsided. Created channels were undergoing a period of adjustment with channel area increasing or decreasing based on proximity to adjacent water bodies. Vegetation percent cover and species richness of native plants increased over time relative to non-native plants and were trending towards conditions observed at reference sites. Clear relationships between native species and native relative cover shows the potential for the recovery of vegetation communities post-restoration.

The PIT array at Horsetail Creek continues to be challenging to operate but provides valuable fish presence and stock data. Since the installation of PIT array, we have recorded out migrating upriver species visiting the site for periods ranging from a few hours to couple of days. However, due to natural and human factors, keeping the PIT array functional year round is difficult. We continue to maintain and repair the array and attempt to manage the system in a manner to continuously provide pertinent fish data.

In most cases, AEM findings show restoration sites are achieving increases in connectivity and salmonid opportunity, however platn community recovery is more variable across sites. . Given the inherent inter-annual climatic variability, it can be difficult to predict restoration outcomes on a year to year basis. Re-establishment of natural physical processes to sites can be accomplished in a relative short period of time, but to understand how the site will respond ecologically will need take place over a longer period. Ultimately, continued monitoring will elucidate and improve our understanding of the connections between physical processes, habitat responses, and the resulting benefits to juvenile salmon.

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